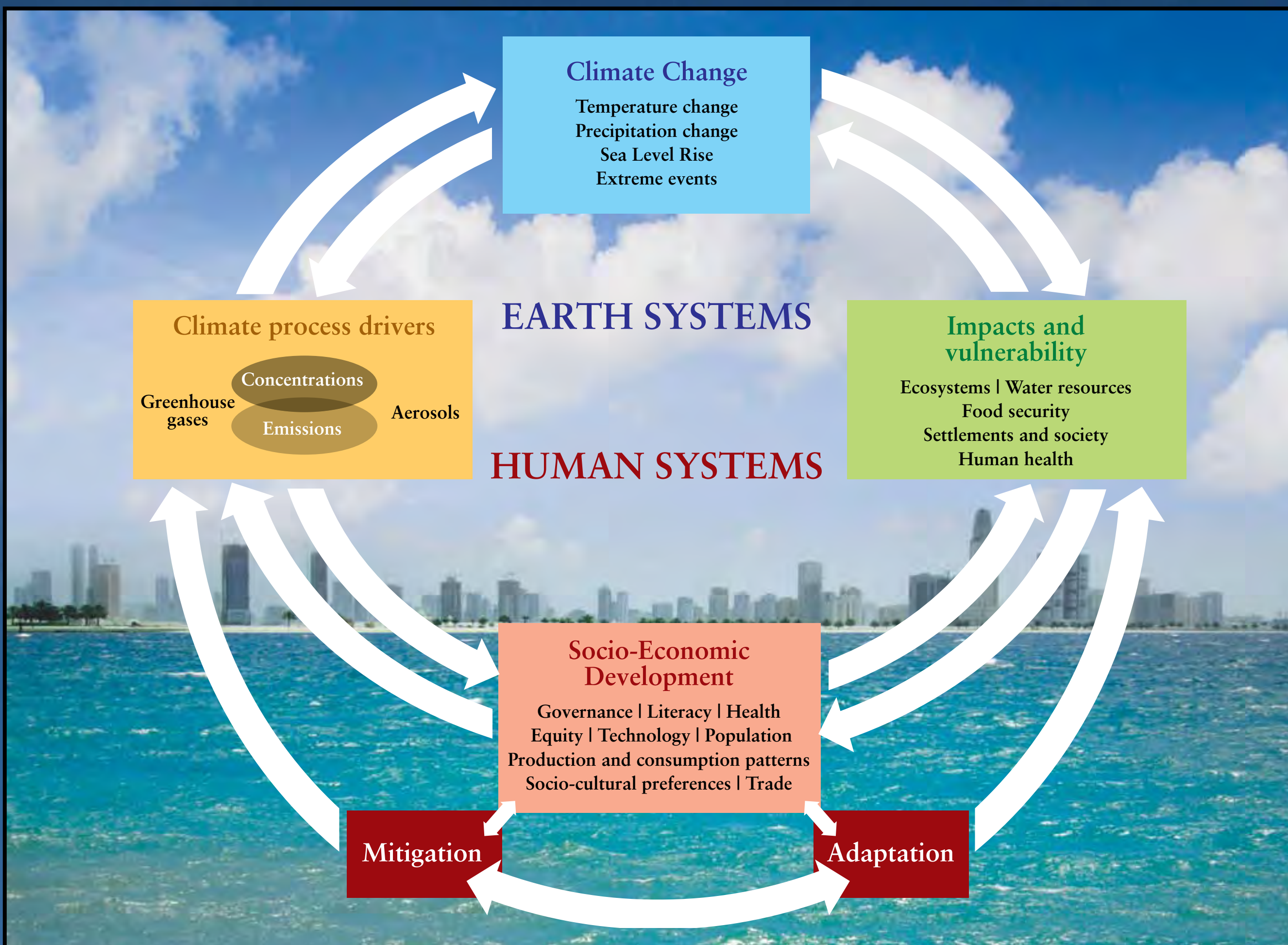
TOWARDS NEW SCENARIOS FOR ANALYSIS OF EMISSIONS, CLIMATE CHANGE, IMPACTS, AND RESPONSE STRATEGIES

TOWARDS NEW SCENARIOS FOR ANALYSIS OF EMISSIONS, CLIMATE CHANGE, IMPACTS, AND RESPONSE STRATEGIES

IPCC EXPERT MEETING REPORT

19–21 September, 2007

Noordwijkerhout, The Netherlands



WMO

Intergovernmental Panel on Climate Change

UNEP

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

WMO UNEP

TOWARDS NEW SCENARIOS FOR ANALYSIS OF EMISSIONS, CLIMATE CHANGE, IMPACTS, AND RESPONSE STRATEGIES

IPCC EXPERT MEETING REPORT

19–21 September, 2007
Noordwijkerhout, The Netherlands

Supporting material prepared for consideration by the Intergovernmental Panel on Climate Change. This material has not been subjected to formal IPCC review processes. This expert meeting was agreed in advance as part of the IPCC work plan, but this does not imply working group or panel endorsement or approval of this report or any recommendations or conclusions contained herein.

The report has been subjected to an expert peer review process and revised accordingly. A collation of the comments received is available on the IPCC website (http://www.ipcc.ch/ipccreports/supporting-material.htm).

IPCC Secretariat, c/o WMO, 7bis, Avenue de la Paix, C.P. N° 2300, 1211 Geneva 2, SWITZERLAND
Phone: +41 22 730 8208/8254/8284 Fax: +41 22 730 8025/8013
E-mail: IPCC-Sec@wmo.int Website: http://www.ipcc.ch

Recommended citation: Richard Moss, Mustafa Babiker, Sander Brinkman, Eduardo Calvo, Tim Carter, Jae Edmonds, Ismail Elgizouli, Seita Emori, Lin Erda, Kathy Hibbard, Roger Jones, Mikiko Kainuma, Jessica Kelleher, Jean Francois Lamarque, Martin Manning, Ben Matthews, Jerry Meehl, Leo Meyer, John Mitchell, Nebojsa Nakicenovic, Brian O'Neill, Ramon Pichs, Keywan Riahi, Steven Rose, Paul Runci, Ron Stouffer, Detlef van Vuuren, John Weyant, Tom Wilbanks, Jean Pascal van Ypersele, and Monika Zurek, 2008. *Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies*. Intergovernmental Panel on Climate Change, Geneva, 132 pp.

ISBN: 978-92-9169-125-8

Cover photo: photomontage by Alexandre Keshavjee, WMO

TOWARDS NEW SCENARIOS FOR ANALYSIS OF EMISSIONS, CLIMATE CHANGE, IMPACTS, AND RESPONSE STRATEGIES

IPCC EXPERT MEETING REPORT

Lead Authors:

Richard Moss, Mustafa Babiker, Sander Brinkman, Eduardo Calvo, Tim Carter, Jae Edmonds, Ismail Elgizouli, Seita Emori, Lin Erda, Kathy Hibbard, Roger Jones, Mikiko Kainuma, Jessica Kelleher, Jean Francois Lamarque, Martin Manning, Ben Matthews, Jerry Meehl, Leo Meyer, John Mitchell, Nebojsa Nakicenovic, Brian O'Neill, Ramon Pichs, Keywan Riahi, Steven Rose, Paul Runci, Ron Stouffer, Detlef van Vuuren, John Weyant, Tom Wilbanks, Jean Pascal van Ypersele, Monika Zurek.

Contributing Authors:

Fatih Birol, Peter Bosch, Olivier Boucher, Johannes Feddema, Amit Garg, Amadou Gaye, Maria Ibarraran, Emilio La Rovere, Bert Metz, Shuzo Nishioka, Hugh Pitcher, Drew Shindell, P.R. Shukla, Anond Snidvongs, Peter Thorton, Virginia Vilariño.

Steering Committee:

Richard Moss and Ismail Elgizouli (Co-Chairs); Mustafa Babiker, Olivier Boucher, Eduardo Calvo, Tim Carter, Jae Edmonds, Seita Emori, Amit Garg, Martin Manning, Jose Marengo, Jerry Meehl, Bert Metz, Leo Meyer, John Mitchell, Nebojsa Nakicenovic, Shuzo Nishioka, Martin Parry, Paul Runci, Ronald Stouffer, Jean Pascal van Ypersele, Monica Zurek.

Preface

This report summarizes the findings and recommendations from the Expert Meeting on New Scenarios in Noordwijkerhout, The Netherlands, 19-21 September 2007. This report is the culmination of the combined efforts of the New Scenarios Steering Committee, an author team composed primarily of members of the research community, and numerous other meeting participants and external reviewers who provided extensive comments during the expert review process.

The expert meeting included presentations focused on needs for scenarios as seen from a policymaking perspective, a review of past IPCC scenarios, overviews of evolving plans in the research community, needs and opportunities for scenarios on two different time scales ("near term"—to 2035, and "longterm"—to 2100, extended to 2300 for some applications), and a review of options for the benchmark scenarios, referred to in the report as "Representative Concentration Pathways" (RCPs). Additional presentations addressed institutional issues and options for increasing participation by developing and transition-economy countries. The remainder of the meeting was organized around a series of breakout groups and plenary sessions that provided an opportunity for the research communities to further coordinate their plans, to refine the proposal for the RCPs, and to consider additional cross-cutting issues.

To ensure representation of all major stakeholder groups in the discussion, the Steering Committee selected over 130 participants for the expert meeting from among a much larger number of applicants. These participants represented diverse perspectives from the climate science, impacts, and integrated assessment research communities, scenario user groups, and multilateral and international organizations. More than 30 percent of the meeting participants came from developing countries and countries with an economy in transition.

As requested, through the expert meeting we identified a set of RCPs from the published literature. These pathways provide common starting points from which climate and integrated assessment modelers can begin to work in parallel toward the generation of new integrated scenarios of climate change for a possible AR5. The expert meeting conditionally recommended that the lowest radiative forcing pathway available in the literature from this class of models – IMAGE 2.6 – be used as one of the RCPs because of the strong interest of participating representatives of the policy community. But because this radiative forcing pathway has not been replicated by other models in this class of IAMs, the Steering Committee requested that the Integrated Assessment Modeling Consortium (IAMC) form an evaluation panel to ensure that the scenario is scientifically suitable for use as an RCP. An evaluation process was agreed to by the IAMC and Steering Committee and is described in the report and a series of letters provided in an Appendix. While evaluation panel members may not necessarily agree on all aspects of the robustness of the IMAGE 2.6 scenario, they are asked to provide a single recommendation to the IAMC as the convening body on whether or not it should be considered robust. The IAMC will then transmit the finding to the Steering Committee for expected confirmation of the recommendation.

The steering committee adhered to the catalytic role defined by the IPCC. The report thus describes the current state of planning by the scientific community for preparation of new scenarios. Aspects of the process are still being planned, and thus the report describes a "work in progress". It is important to note that many of the planned activities encouraging communication and integration across the climate modeling, impacts, adaptation, and integrated assessment communities will require a great deal of effort by the research communities and additional support from governments and funding agencies.

Two additional points made at the time of the meeting should be mentioned:

First, the scientific community had anticipated that, in line with past practice, a decision on the time line and phases of a potential AR5 report would be made by the Panel in 2008. This stems from the fact that, in the absence of a date certain for the completion of AR5, all the major Working Group I modeling groups would have continued active development of their models until the AR5 time line is announced. The details of these developments can affect what types of inputs are needed, particularly with regard to the coupling of atmospheric chemistry and the carbon cycle. Thus increasing this model development period raises the potential for substantive changes that would require detailed reconsideration of the scenario-based inputs to be provided by Working Group III. Collectively, these timing considerations necessitate a period of at least 5 to 6 years for the completion of AR5 following its initial announcement.

This recommendation was taken up by the Panel at its 28th Session, when the timing of AR5 was decided along with the two following decisions:

(1) The Panel invites the scientific community developing new scenarios for analysis of emissions, climate change, impacts, and response strategies to move forward actively and with strength, for timely delivery of the scenario results as indicated in timeline presented in the report “Further work on scenarios” presented at the 28th Session of IPCC (Fig.II.1 p.19).

(2) The Panel requests the Bureau to assist timely transfer of the scenarios products outlined in the report “Further work on scenarios” into development of the Fifth Assessment report (AR5), in particular in relation to impacts, adaptation and vulnerability.

Second, the expert meeting and subsequent process of drafting the report has engendered extensive interactions across the research communities and with various user groups. Given their previous roles in the climate modeling and integrated assessment modeling communities, the World Climate Research Programme and the IAMC are poised to play key roles in the proposed plan. However, as yet there is no institutional arrangement to assist the necessary cross-disciplinary communication required—particularly on such a tight timeline. Thus, despite the current willingness and engagement of key individuals, success will be a major challenge and is by no means assured. Given the existing role of the TGICA in facilitating cross-disciplinary communication, the Panel may wish to invite the TGICA to regularly monitor and report to the Panel on progress in the planned activities.

Ismail Elgizouli | Richard H. Moss

Co-Chairs, New Scenarios Steering Committee

Rajendra K. Pachauri

Chairman IPCC

Acknowledgments

We would like to offer our gratitude to those who have made this work possible. We wish to thank the Government of the Netherlands, which provided administrative and logistical support to the Steering Committee and served as a gracious host for the Noordwijkerhout meeting. The Working Group III TSU provided tireless assistance in organizing teleconferences, communications, and the expert meeting itself. Finally, we would like to offer our deepest thanks to the members of the New Scenarios Steering Committee and the report's author team. These individuals showed tremendous dedication without them preparation of the meeting and this report would not have been possible.

Ismail Elgizouli Richard H. Moss

Co-Chairs, New Scenarios Steering Committee

Table of Contents

Technical Summary

I. Background

Scenarios of potential future anthropogenic climate change, underlying driving forces, and response options have always been an important component of the work of the Intergovernmental Panel on Climate Change (IPCC). In the past, the IPCC coordinated the process of developing scenarios for its assessments. During its 25th session (Mauritius, 26–28 April 2006), the IPCC decided that rather than directly coordinating and approving new scenarios itself, the process of scenario development should now be coordinated by the research community. The IPCC would seek to "catalyze" the timely production by others of new scenarios for a possible Fifth Assessment Report (AR5) by convening an expert meeting to consider the scientific community's plans for developing new scenarios, and to identify a set of "benchmark emissions scenarios" (now referred to in this report as "Representative Concentration Pathways—RCPs" —for reasons discussed in Section I.2). The RCPs will be used to initiate climate model simulations for developing climate scenarios for use in a broad range of climate-change related research and assessment and were requested to be "compatible with the full range of stabilization, mitigation and baseline emissions scenarios available in the current scientific literature."[1]

The expert meeting was held on 19–21 September 2007 in Noordwijkerhout, The Netherlands. The meeting brought together over 130 participants, including users of scenarios and representatives of the principal research communities involved in scenario development and application. The representatives of the scenario user community included officials from national governments, including many participating in the United Nations Framework Convention on Climate Change (UNFCCC), international organizations, multilateral lending institutions, and nongovernmental organizations (NGOs). The principal research communities represented at the expert meeting were the integrated assessment modeling (IAM) community; the impacts, adaptation, and vulnerability (IAV) community; and the climate modeling (CM) community. Because of this broad participation, the meeting provided an opportunity for the segments of the research community involved in scenario development and application to discuss their respective requirements and coordinate the planning process.

This summary provides an overview of a new parallel process for scenario development and the RCPs discussed and refined at the expert meeting. It briefly reviews recommendations for institutional developments and increased participation of experts and users from developing countries and countries with an economy in transition that would further strengthen the process. Further details are provided in the full report of the expert meeting.

[1] See Box I.1 in the full report of the expert meeting for additional information about the IPCC's decision on further work on emissions scenarios taken at its 26th Session, Bangkok, Thailand, 30 April–4 May 2007.

I.1 Scenario characteristics and needs from an end-user perspective

During earlier IPCC meetings on scenarios[2] and the planning process for this expert meeting, a variety of user groups participated and provided input about their needs for scenarios of socio-economic, climate, and other environmental conditions. These users could be classified into two broad groups: "end users," policy- and decisionmakers who use scenario outputs and insights in various decision processes; and "intermediate users," researchers who use scenarios from another segment of the research community as inputs into their work.

Based on the interests and needs of end users, the new scenario process will develop global scenarios for two time periods:

- "near-term" scenarios that cover the period to about 2035; and
- "long-term" scenarios that cover the period to 2100 and, in a more stylized way, the period to 2300.

The distinction between near- and long-term scenarios is important because the nature of policy- and decisionmaking, the climate system responses, and capabilities of model projections all change with time scale.

Major motivations for the near-term scenarios are understanding the effect of emissions on air quality, providing information on trends and extreme events, and providing high-resolution output for the IAV community. Near-term adaptation and mitigation analyses can be matched to conventional planning time scales, can explore opportunities and constraints given institutional and technological inertia, and can play an important role in integrating climate change considerations into other areas of management and policy. Key issues on this time scale include identifying immediate risks; developing corresponding adaptive capacity; reducing vulnerability; making efficient investments to cope with climate change; and implementing investments in low-emission technologies, energy conservation, and sink preservation and/or enhancement. This is a new activity for the CM community and as such, is a research issue in progress. Initialization of climate models is a more significant issue for the near term than the longer term. It is anticipated that use of initial conditions that are consistent with the current phase of natural variability of climate system may reduce the spread in ensembles of simulations over the next one or two decades. Thus, the effort to provide high-resolution (0.5°–1°) scenarios for the near-term time scale must still be considered experimental.

The longer term policy focus shifts towards evaluating climate targets to avoid risks from climate change impacts, improving the understanding of risks of major geophysical and biogeochemical change and feedback effects, and adopting strategies for adaptation, mitigation, and development that are robust over the long term to remaining uncertainties. Scenarios of different rates and magnitudes of climate change provide a basis for assessing the risk of crossing identifiable thresholds in both physical change and impacts on biological and human systems.

---

[2] New scenarios for the IPCC process were discussed during several sessions of the Panel and in workshops in Washington, DC, USA (January 2005), Laxenburg, Austria (July 2005), and Seville, Spain (March 2006). For further information on these previous meetings and associated recommendations and decisions, see: http://www.ipcc.ch/pdf/supporting-material/expert-meeting-2005-01.pdf (Washington), http://www.mnp.nl/ipcc/pages_media/meeting_report_workshop_new_emission_scenarios.pdf (Laxenburg), and http://www.ipcc.ch/meetings/session25/doc11.pdf (Seville).

At the expert meeting, representatives of the policy community expressed a strong interest in very low radiative forcing profiles (e.g., radiative forcing that peaks at 3 W/m^2 before 2100 and then declines). It is evident that the policy discussion is moving towards increasingly stringent emissions reductions targets, and that policymakers will need information on the implications of these targets for climate change, unavoidable impacts of even low trajectories, and economic and technological pathways for achieving these targets. How best to reflect this interest in the choice of RCPs, which must be drawn from the existing literature that is only beginning to address this issue, was a major topic of discussion at the meeting.

Another clear interest of scenario users is development of regional- or national-scale socio-economic scenarios that are consistent with global scenarios but that also reflect unique local conditions. This topic seems especially important as increasing attention is focused on regional and national implementation of adaptation and mitigation options, and on how these two response classes can be effectively integrated in climate risk management. The expert meeting addressed this issue in several breakout groups, and preliminary recommendations are included in the full meeting report.

I.2 A parallel process for scenario development

Past scenario development has been conducted in a mainly sequential form, with socioeconomic and emissions scenarios developed first and climate change projections based on those scenarios carried out next. In contrast with the previous linear process, this parallel approach should provide better integration, consistency, and consideration of feedbacks, and more time to assess impacts and responses. The research community developed this process in a series of meetings and workshops.[3] As with all multi-year research plans, this plan is subject to review and revision throughout the process.

The parallel process is initiated with the identification of the RCPs, which will enable the CM community to proceed with new climate change projections at the same time that new work is carried out in the IAM and IAV communities (see Figure 1b). While the RCPs will enable CM scenario development that explores and characterizes future climate change, they do not constrain future work by the IAM community, which, in its portion of the parallel process, will simultaneously develop a range of completely new socioeconomic and emissions scenarios. IAM teams will have complete freedom to develop new scenarios across the full range of possibilities. IAM teams will also explore alternative technological, socioeconomic, and policy futures including both reference (without explicit climate policy intervention) and climate policy scenarios. This approach seems both promising and important given the interest of decisionmakers in exploring how to attain different stabilization levels.

[3] These meetings include a "summer institute" held under the auspices of the Aspen Global Change Institute in July 2006; a joint meeting of the World Climate Research Program's Working Group on Coupled Models (WGCM) and the International Geosphere-Biosphere Programme's Analysis, Integration and Modeling of the Earth System core project in September 2006; an additional summer workshop that was held under the auspices of the Energy Modeling Forum in Snowmass, Colorado in July 2007; and a meeting of the WGCM in Hamburg, Germany from 3–5 September 2007.

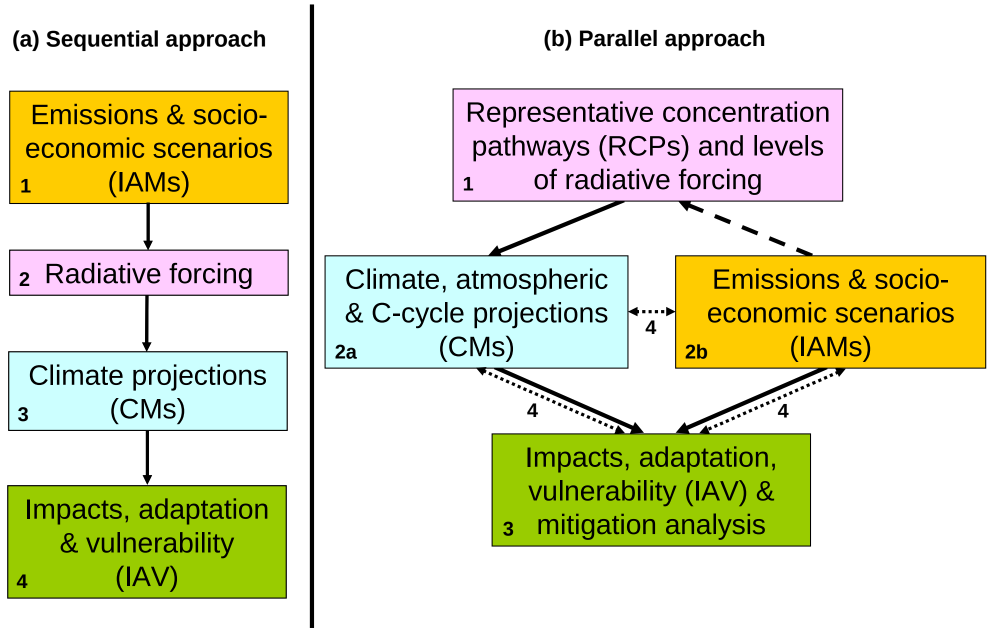


Figure 1. Approaches to the development of global scenarios: (a) previous *sequential* approach; (b) proposed *parallel* approach. Numbers indicate analytical steps (2a and 2b proceed concurrently). Arrows indicate transfers of information (solid), selection of RCPs (dashed), and integration of information and feedbacks (dotted).

The parallel process is an advance from the prior sequential approach for a number of reasons. The approach will allow better use of the expensive and time-consuming simulations carried out by the CM community, as these no longer need to be rerun each time the emissions scenarios are changed. A parallel approach using RCPs partially decouples climate science from the issues of socioeconomic projections because a given concentration trajectory can result from different socioeconomic projections and IAM model outcomes. In the past, when the socioeconomic scenarios were modified, the model simulations had to be run again, even though the changes seldom resulted in meaningful (i.e., detectable) alterations to the modeled future climates. In the future, updated CMs can be run using the same RCPs, allowing modelers to isolate the effects of changes in the CMs themselves. New forcing scenarios can be used to scale the existing CM simulations using simpler models that have been calibrated to give comparable results to the full three-dimensional climate models. There would be no need to rerun models for each new scenario. The saving in computing time could be used to generate larger ensembles at higher resolution, hopefully leading to refined simulations of regional change and extreme events, and a more robust representation of uncertainties and/or probabilities. Of course, the use of pattern scaling always yields an approximation to the output that would have been produced by a state-of-the-art climate model had it been run, and the resulting approximation is better for some variables than for others. The savings in cost and time for climate model set up and runs is therefore purchased at the price of approximation.

I.3 Explanation of RCP terminology, and the role of RCPs in the "parallel process"

The name "representative concentration pathways" was chosen to emphasize the rationale behind their use. RCPs are referred to as *pathways* in order to emphasize that their primary purpose is to provide time-dependent projections of atmospheric greenhouse gas (GHG) concentrations. In addition, the term pathway is meant to emphasize that it is not only a specific long-term concentration or radiative forcing outcome, such as a stabilization level, that is of interest, but also the trajectory that is taken over time to reach that outcome. They are *representative* in that they are one of several different scenarios that have similar radiative forcing and emissions characteristics. The term "benchmark," used in the IPCC decision, was considered less desirable as it implies that a particular scenario has a special status relative to others in the literature, rather than simply being representative of them. This is a key point because as is explained more completely in Section II of this summary and the full report, the identification and use of the RCPs in climate modeling is only the first step in a new parallel process of scenario development being coordinated by the research community. Consistent with the IPCC's decision to play a catalytic role in the development of new scenarios, the RCPs are simply intended to expedite the preparation of integrated scenarios by enabling modeling the response of the climate system to human activities to proceed in parallel to development of emissions and other scenarios for use in IAV and mitigation assessments.

I.4 Expected products

To meet the needs of the range of intermediate and end users, the research community is planning to develop five principal products in the lead-up to the publication of a possible AR5:

1. *Representative concentration pathways (RCPs).* Four RCPs will be produced from IAM scenarios available in the published literature: one high pathway for which radiative forcing reaches >8.5 W/m^2 by 2100 and continues to rise for some amount of time; two intermediate "stabilization pathways" in which radiative forcing is stabilized at approximately 6 W/m^2 and 4.5 W/m^2 after 2100; and one pathway where radiative forcing peaks at approximately 3 W/m^2 before 2100 and then declines. These scenarios include time paths for emissions and concentrations of the full suite of GHGs and aerosols and chemically active gases, as well as land use/land cover (see Table A1.1 in the full report). The anticipated completion date is September 2008.

2. *RCP-based climate model ensembles and pattern scaling*. Ensembles of gridded, time-dependent projections of climate change produced by multiple climate models including atmosphere–ocean general circulation models (AOGCMs), Earth system models (ESMs), Earth system models of intermediate complexity, and regional climate models will be prepared for the four long-term RCPs, and high-resolution, near-term projections to 2035 for the 4.5 W/m^2 stabilization RCP only. The long-term scenarios are expected to be run at approximately 2° resolution, while the near-term scenarios may have higher (0.5° to 1°) resolution. These projections can be scaled upward or downward according to the ratio of simulated global mean temperature for the RCP and the temperature change defined in simple CMs forced with different scenarios. The anticipated completion date is fall 2010.

3. *New IAM scenarios*. New scenarios will be developed by the IAM research community in consultation with the IAV community exploring a wide range of dimensions associated with anthropogenic climate forcing. These scenarios are anticipated to be combined with pattern-scaled outputs of the ensemble climate projections (Product 5). Anticipated outputs include alternative socioeconomic driving forces, alternative technology development regimes, alternative realizations of Earth system science research, alternative stabilization scenarios including traditional "not exceeding" scenarios, "overshoot" scenarios, and representations of regionally heterogeneous mitigation policies and measures, as well as local and regional socioeconomic trends and policies. These are anticipated to be available in the third quarter of 2010.

4. *Global narrative storylines*. These are detailed descriptions associated with the four RCPs produced in the preparatory phase and such pathways developed as part of Product 3 by the IAM and IAV communities. These global and large-region storylines should be able to inform IAV and other researchers. New narrative storylines will also be developed as new reference scenarios emerge within Product 3, potentially extending narrative storyline development into the integration phase. Narrative storyline development will be a joint undertaking employing researchers from both the IAM and IAV communities. This product is anticipated to be available in the third quarter of 2010.

5. *Integrated scenarios*. RCP-based climate model ensembles and pattern scaling (Product 2) will be associated with combinations of new IAM scenario pathways (Product 3) to create combinations of ensembles. These scenarios will be available for use in new IAV assessments. In addition, IAM research will begin to incorporate IAV results, models, and feedbacks to produce comprehensively synthesized reference, climate change, and IAM results. These are anticipated to be available in the spring of 2012.

The anticipated time line for the production of these five products is depicted in Figure 2.

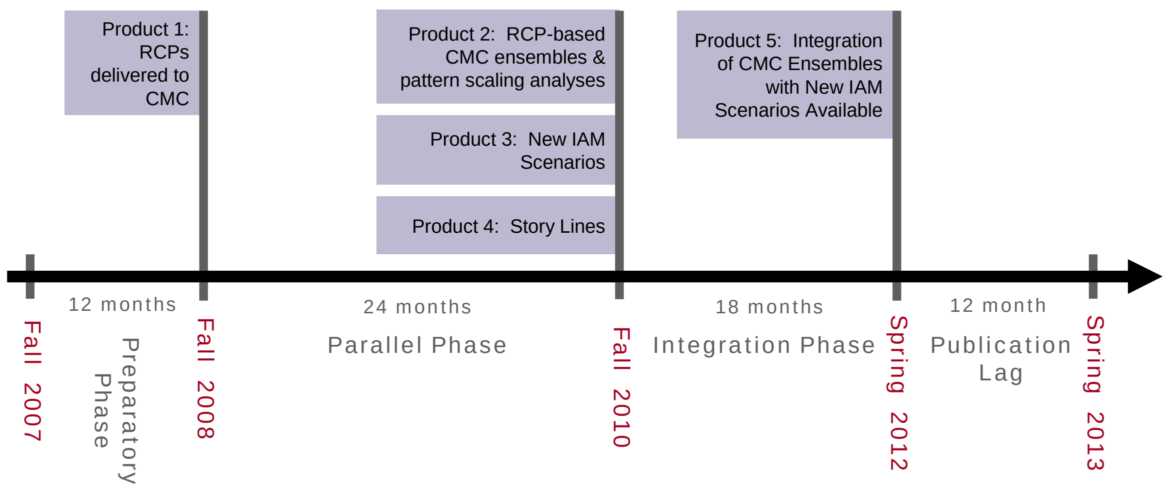


Figure 2. Timeline of key scenario development products (CMC = climate modeling community).

II. Process for Scenario Development

These products will be produced through a new scenario development process that comprises three phases: a preparatory phase and two main phases of scenario development: a parallel phase for modeling and developing new scenarios; and an integration, dissemination, and application phase.

II.1 Preparatory phase

The principal product of the preparatory phase will be four RCPs, produced by IAMs to satisfy the data requirements of the CM community and respond to the IPCC's request for "benchmark" scenarios from the research community. The RCPs are not to be the focus of all subsequent research. They are a device that provides a consistent analytical thread through the research communities and facilitates exploration and characterization of uncertainty—in climate, socioeconomics, emissions, vulnerability, and impacts.

The IAM and CM communities will work together to insure that RCPs reflect the needs of the CM community. Development of the RCPs entails a number of challenges that are the focus of current research across the IAM community. The set of data provided with each RCP will need to be spatially downscaled for short-lived species, gaseous and aerosol emissions, and land use/land cover. Another important challenge is to extend the RCPs from 2100, the typical end point for published results from IAMs, to the year 2300. Given the large socioeconomic uncertainties over such a time scale, a variety of stylized approaches for producing emissions and concentrations data for CMs is under discussion. The planned methods resulting from those discussions will be available for comment. Another important early step in the process will be the development of data reporting standards by the IAM community in conjunction with the CM and IAV communities. The IAM community will produce the required data for CM groups. A careful review and cross-check of the data by participating IAM and CM groups will be included as part of the process. All data associated with the RCPs will be made publicly available to those interested in using them. To help coordinate this work across the IAM teams and between them and other communities involved in global change research, an Integrated Assessment Modeling Consortium (IAMC) has been formed.[4]

II.2 Parallel modeling phase

As illustrated in Figure 1, the parallel phase was developed to expedite the scenario development process. It telescopes work that has traditionally occurred sequentially over a longer period of time. There are advantages and disadvantages to both the traditional sequential approach and the new parallel approach, as discussed in the full report.

The parallel modeling phase will be comprised of extensive, independent work across the research communities that is designed to provide a rich and consistent characterization of the many facets of climate change. In the parallel phase, three activities proceed concurrently. First, CMs employ the RCPs and associated emissions to develop scenarios of changes in the atmosphere, climate, and related conditions (e.g., ocean acidity or sea level rise) over the two time horizons of interest: near term (to 2035) and long term (to 2300). This activity will conclude with pattern scaling analyses designed to characterize a fuller climate space. Second, the IAM research community begins to develop a new suite of scenarios that revisit reference, stabilization, technology, and policy options to create a "library" of new scenarios. Third, the IAM and IAV research communities work to develop "global and regional narrative storylines," downscaling methodologies, and regional/sectoral impact models that can be used by IAV researchers in conjunction with the new scenarios, including the RCPs.

II.3 Integration phase and publication lag

In the integration phase, new ensemble climate scenarios developed during the parallel phase (Product 2) will be integrated with the parallel phase IAM emissions and socioeconomic scenarios (Products 3 and 4) as an input to new IAV studies. To ensure appropriate pairing of CM outputs with

[4] The IAMC was established in November 2006. So far, 37 groups have joined the consortium. See Section IV of the report for further information.

new socioeconomic scenarios, interpolation and pattern scaling of climate model results will also be undertaken. Results will be compiled in a proposed IAV research archive that will facilitate intercomparison and synthesis of results. In the integration phase, IAM researchers will begin the process of integrating IAV research tools directly into IAMs. The goal is to produce internally consistent representations of human activities conducted within the context of changing climate, oceans, and ecosystems. Similarly, climate modelers will also incorporate insights from IAM and IAV research into a new generation of ESMs, to provide a more realistic representation of the effects of human drivers on the physical and biogeochemical systems being modeled. Such integration (by both IAMs and ESMs incorporating results from IAV studies) may also enable new investigation of feedback processes.

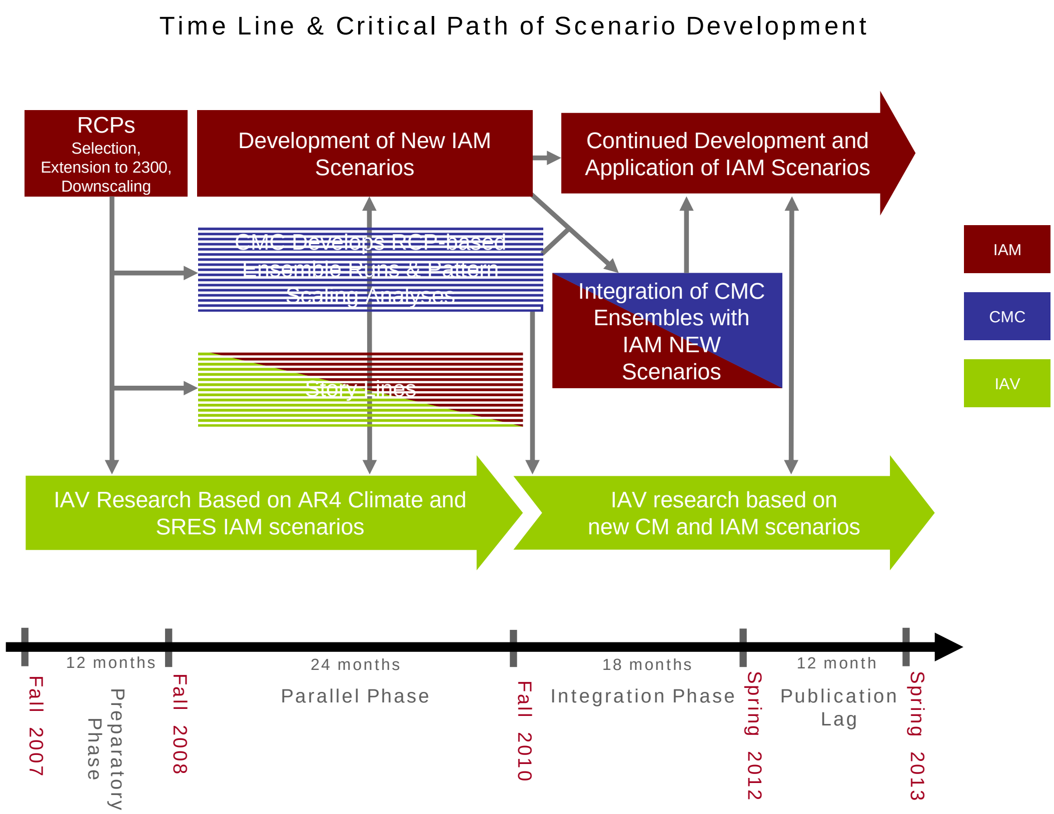


Figure 3: Some of the major scenario-related activities across the IAV, IAM, and CM research communities and relationships among them. The boundaries between these phases are not precisely defined, although near-term deadlines, such as the fall 2008 deadline for availability of RCPs, can be taken as relatively more precise.

There is a time lag between the completion of research and its documentation and publication. Thus, while publication will proceed throughout the years leading up to a potential AR5, some time needs to be budgeted at the end of the process to accommodate those research products that emerge at the latest date. That time lag is about one year. The lag is presently unavoidable and should be incorporated in planning.

The interactions among research communities during the three phases of scenario development are depicted in Figure 3.

III. "Representative Concentration Pathways"

The early identification of a set of "Representative Concentration Pathways" (RCPs) will facilitate coordination of new integrated socioeconomic, emissions, and climate scenarios. The main rationale for beginning with RCPs is to expedite the development of a broad literature of new and integrated scenarios by allowing the modeling of climate system responses to human activities to proceed in parallel to emissions scenario development (see Figure 2).

The IPCC requested that the RCPs should be "compatible with the full range of stabilization, mitigation and baseline emission scenarios available in the current scientific literature," and that they should include information on a range of factors beyond concentrations and emissions of long-lived GHGs, including emissions of other radiatively active gases and aerosols (and their precursors), land use, and socioeconomic conditions (see Appendix 1 of the full report for a detailed description of the data requirements). This information should be sufficient to meet user needs, in particular the data needs for climate modeling. In order to take into account the effects of emissions of all GHGs and aerosols, the RCPs have been selected based primarily on their emissions, associated concentration outcomes, and net radiative forcing. Each of the selected RCPs will come from a different IAM and include the concentration pathway and corresponding emissions and land use pathways.

III.1 Uses and limits

The core uses of RCPs and the CM outcomes associated with them are:

- *Input to CMs*. As discussed in Section II, RCPs are mainly intended to facilitate the development of integrated scenarios by jump-starting the CM process through the provision of data on emissions, concentrations, and land use/land cover needed by CMs. Results from these CM simulations will then be used to recalibrate the climate system components of IAMs, to inform IAV studies, and to incorporate feedbacks from climate impacts back into the socioeconomic drivers during later phases of the scenario development process.
- *To facilitate pattern scaling of climate model outcomes*. Climate change projections based on RCPs will cover a wide range of outcomes. These outcomes, together with control runs with no anthropogenic radiative forcing, will be used to investigate the extent to which they can be scaled to provide climate change outcomes for intermediate forcing levels without re-running the CMs (see Section II.4 of the full report). For this purpose, it is important to analyze the nonlinearity of the climate change response to different levels and time paths of forcing (including peak and decline pathways), using comparable CM simulations forced with multiple RCPs.
- *To explore the range of socioeconomic conditions consistent with a given concentration pathway*. It is an open research question as to how wide a range of socioeconomic conditions could be consistent with a given pathway of forcing, including its ultimate level, its pathway over time, and its spatial pattern. The RCPs will facilitate exploration of alternative development futures that may be consistent with each of the four RCPs.
- *To explore the climate implications of spatial forcing patterns*. Each RCP will have a particular spatial pattern of forcing due to differences in both spatial emissions and land use. The RCPs will provide a new focus for work on the open research question of how wide a range of spatial patterns of forcing could be consistent with a given climate change outcome.

There are a number of limitations to the use of RCPs that must be kept in mind in order to avoid inappropriate applications. These include:

- *They should not be considered forecasts or absolute bounds*. RCPs are representative of plausible alternative scenarios for the future but are not predictions or forecasts of future outcomes. No RCP is intended as a "best guess," most likely, or most plausible projection.
- *They should not be considered policy-prescriptive*. The RCPs are meant to support scientific research to examine various climate change futures and their implications for adaptation and mitigation without making any judgment as to their desirability.
- *The socioeconomic scenarios underlying each RCP should not be considered unique*. Each RCP is based on a scenario in the literature that includes a socioeconomic development pathway. However, the socioeconomic scenario underlying each RCP is just one of many possible scenarios that could be consistent with the concentration pathway.
- *The socioeconomic scenarios underlying the RCPs cannot be treated as a set with an overarching internal logic*. While each individual RCP was developed from its own internally consistent socioeconomic foundation, the four RCPs as a group were selected on the basis of their concentration and forcing outcomes to be compatible with the full range of emissions scenarios available in the literature. Therefore, there is no overarching logic or consistency to the set of socioeconomic assumptions or storylines associated with the set of RCPs. In particular, the socioeconomic scenario underlying one RCP should not be used in conjunction with that of another RCP, and cannot be freely used interchangeably with the assumptions underlying other RCPs. Furthermore, the set of underlying socioeconomic scenarios is not intended to span the range of plausible assumptions for any particular socioeconomic element (population, gross domestic product growth, rates of technological change, land use, etc.).
- *There are uncertainties in the translation of emissions profiles to concentrations and radiative forcing.* This is particularly true for the carbon cycle and atmospheric chemistry. Each RCP represents one possible set of assumptions with regard to this translation. Both the development of new techniques and tools for translating emissions to concentrations and uncertainty analyses should be coordinated in subsequent phases by the CM community and IAMC. See Section II of the full report for discussion of research plans in this area.

The remainder of this section of the Summary describes the process by which RCPs were identified from the literature.

III.2 Desirable characteristics

The preferences of end- and intermediate-user communities regarding the general features of the RCPs are reflected in the following "desirable characteristics" for the scenarios, which include range, number, separation and shape, robustness, comprehensiveness, and near-term resolution.

- *Range:* The IPCC, reflecting the interests of policy users, requested that the RCPs "should be compatible with the full range of stabilization, mitigation, and baseline emission scenarios available in the current scientific literature." The research and user communities have also expressed a clear interest in a set of concentration and radiative forcing pathways that spans from a high pathway to a low pathway and facilitates research on and insights into potential futures between the high and low pathways, as well as the uncertainties in the high and low pathways themselves. The lowest radiative forcing pathways available in the literature peak and then decline. Participants at the expert meeting expressed an interest in the peak and decline shape of these pathways, as well as their low radiative forcing levels.

- *Number:* The research and user communities concluded that four RCPs should be produced, although it is not expected that all CM groups will carry out simulations based on all four RCPs. Four RCPs were deemed appropriate in that the number of scenarios was even (which avoids the natural inclination to select the intermediate case as the "best estimate"), more than two scenarios would be available (to allow for intermediate pathways in addition to a high and low), and the number of scenarios was small (reflecting resource constraints within the CM community due to the high cost of model simulations).
- *Separation and shape*: The interpretation of AOGCM runs is most effective when the climate change signal to be detected is large compared to the noise of inherent climate variability. For climate change outcomes to be statistically distinguishable by models, the radiative forcing pathways should be well separated by the end of the 21st century and/or have distinctive shapes. Clearly distinguishable climate change outcomes will facilitate research associating impacts with particular ranges of climate change and assessments of the costs and benefits of avoided impacts.
- *Robustness:* Given the substantial resource requirements associated with running CMs, it is prudent that the RCPs and the scenarios on which they are based be considered robust by the scientific community. In this context, robustness means that a scenario is technically sound in that it employs sound assumptions, logic, and associated calculations; and its level of radiative forcing over time could be independently replicated by other models, which represent other sets of assumptions,[5] with scenarios that are considered to be technically sound. In general, scientifically peer-reviewed publication is considered to be an implicit judgment of technical soundness.[6]
- *Comprehensiveness*: Anthropogenic climate change is driven by a number of factors, all of which contribute to radiative forcing of the climate system. The RCPs need to model all of these factors so that they are internally consistent. The radiative forcing factors include the full suite of GHGs, aerosols, chemically active gases, and land use. The CM community will require gridded emissions for aerosols, chemically active gases, and methane, as well as land use/land cover data.
- *Near-term high-resolution scenarios*: One of the RCPs will be used to produce climate change projections at an increased spatial resolution (e.g., 0.5° latitude x longitude) for the first 30 years (to 2035). Using one of the RCPs, rather than a separate scenario, provides near- and long-term continuity.

III.3 Scenarios in the literature and types of RCPs

In the IPCC Fourth Assessment Report (AR4), Working Group III assessed the literature on baseline and stabilization scenarios published since the Special Report on Emissions Scenarios (SRES) and the Third Assessment Report (TAR). More than 300 scenarios were identified in AR4, 147 and 177 of which were baseline and stabilization scenarios, respectively. A significant development since the TAR is the extension of many IAMs beyond carbon dioxide (CO_2) to other GHGs. This innovation has permitted the assessment of multigas mitigation strategies. About half of the scenarios assessed in AR4 were multigas scenarios, including 71 multigas baseline scenarios and 76 stabilization scenarios. While many IAMs

[5] Assumptions can vary across models in terms of, among other things, socioeconomics, technologies, economic structure, atmospheric chemistry, climate modeling, and the carbon cycle.
[6] There are several definitions of robustness in both common and scientific usage. In the context of the RCPs, we use it to mean "well supported," consistent with one of its definitions as "strong or sturdy." The criteria used to establish whether a scenario is well supported are technical soundness and replicability. Earlier in the Technical Summary, robustness is used in a different sense in the context of describing policies that perform well under a variety of assumptions. This usage is based on an alternative definition of robustness as relatively invariant under a wide range of conditions.

have been extended to other gases, to date only a few comprehensively account for the major components of radiative forcing. For the purpose of this report, the radiative forcing trajectories of more than 30 of these comprehensive scenarios were collected to facilitate the identification of candidates for the RCPs.[7] The left panel of Figure 4 shows the range of global average radiative forcing across these scenarios, while the right panel provides a comparison of the CO_2 emissions pathways associated with the comprehensive scenarios in the left panel to the full range of CO_2 emissions pathways in the literature. The right panel therefore provides perspective on the compatibility of the published comprehensive radiative forcing scenarios with the entire published emissions scenarios literature. In general, the CO_2 pathways associated with scenarios providing comprehensive radiative forcing pathways effectively represent more than the 10th to 90th percentile range of CO_2 emissions pathways across the post-SRES literature.[8] This percentile range is not used as a criterion for scenario selection, but provides a useful descriptive measure of the overlap between the ranges of the two sets of scenarios.

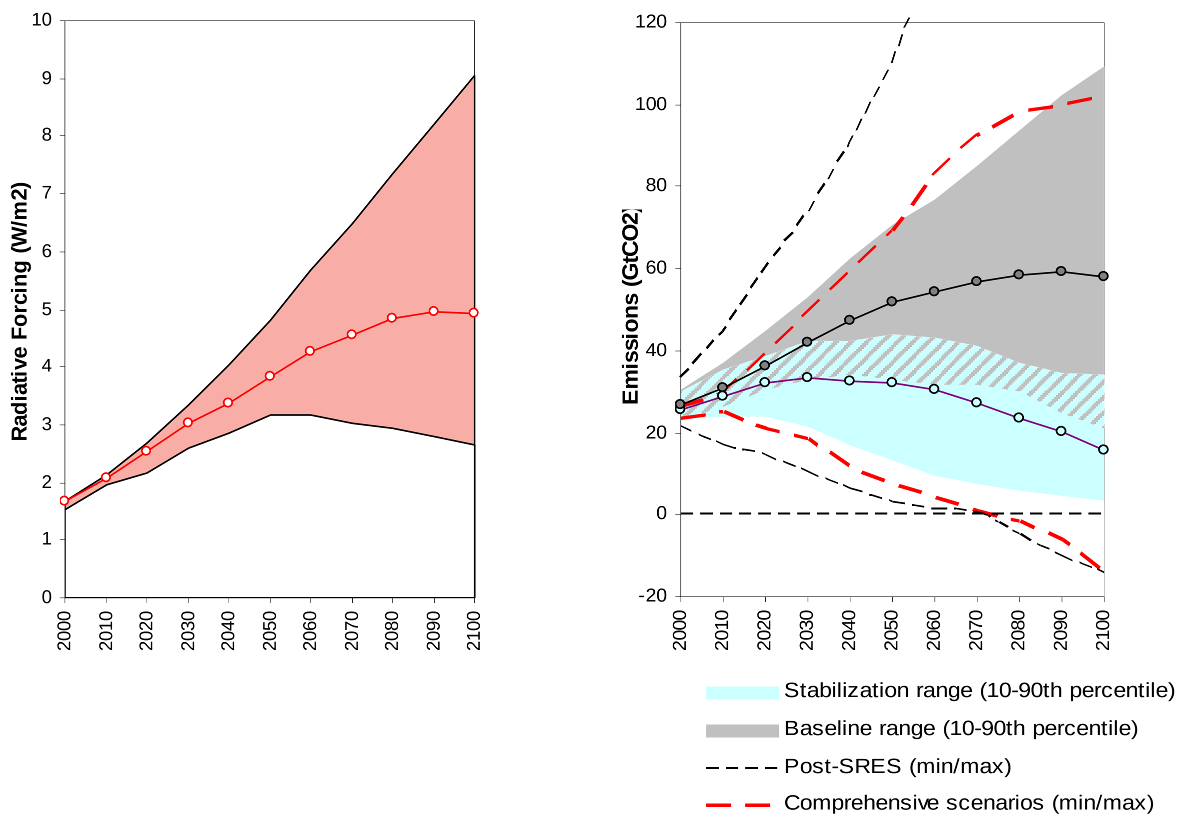


Figure 4. Full range and median of the comprehensive radiative forcing pathways (left panel) and CO_2 emissions pathways for various ranges and medians (right panel). In the right panel, the lines connecting the filled and open circles are medians of the range of baseline and stabilization scenarios, respectively. The red dashed lines denote the full range of energy and industry CO_2 emissions pathways associated with the comprehensive scenarios from the left panel. Data published for these scenarios extend only to 2100; RCPs will need to extend data to 2300.[9]

---

[7] IAMs in this class compute internally consistent projections of radiative forcing and its major components—the full suite of GHG and non-GHG emissions and concentrations, land use/land cover, and climate, as well as the terrestrial and oceanic carbon cycle (see Table A1.1 in Appendix 1 of the full report). Note that radiative forcing was not available in a comparable format for all 37 scenarios in the literature. Hence, Figure 4 includes forcing for 32 of these scenarios only.

[8] "Post-SRES" scenarios are those published in the literature after publication of the SRES in 2000.

[9] Note that it was not possible to clearly distinguish between energy/industry and land use emissions for all scenarios in the literature. Therefore, the CO_2 emissions ranges in Figure 4 (denoted by the blue and gray shaded areas in the right panel) include scenarios with both energy/industry and land use CO_2 emissions.

The scenario literature was reviewed with respect to the desirable characteristics of range, number, separation and shape, robustness, and comprehensiveness in order to define types of RCPs. Four RCP types were defined in terms of a radiative forcing level and pathway shape to match the desirable characteristics given the available literature (Table 1).

The set of pathways in Table 1 are representative of the range of baseline and stabilization radiative forcing, concentration, and emissions pathways in the literature, with the full range of available radiative forcing and concentration pathways covered and from the 90th percentile down to below the 10th percentile of GHG emissions covered.[10]

Table 1. *Types of representative concentration pathways.*

Name	Radiative Forcing[1]	Concentration[2]	Pathway shape
RCP8.5	>8.5 W/m^2 in 2100	> ~1370 CO_2-eq in 2100	Rising
RCP6	~6 W/m^2 at stabilization after 2100	~850 CO_2-eq (at stabilization after 2100)	Stabilization without overshoot
RCP4.5	~4.5 W/m^2 at stabilization after 2100	~650 CO_2-eq (at stabilization after 2100)	Stabilization without overshoot
RCP3-PD[3]	peak at ~3W/m^2 before 2100 and then decline	peak at ~490 CO_2-eq before 2100 and then decline	Peak and decline

Notes:
[1] Approximate radiative forcing levels were defined as ±5% of the stated level in W/m^2. Radiative forcing values include the net effect of all anthropogenic GHGs and other forcing agents.
[2] Approximate CO_2 equivalent (CO_2-eq) concentrations. The CO_2-eq concentrations were calculated with the simple formula Conc = 278 * exp(forcing/5.325). Note that the best estimate of CO_2-eq concentration in 2005 for long-lived GHGs only is about 455 ppm, while the corresponding value including the net effect of all anthropogenic forcing agents (consistent with the table) would be 375 ppm CO_2-eq.
[3] PD = peak and decline.

III.4 Climate modeling community prioritization

Given the scientific and computing limitations, and different resource constraints across CM teams, some CM teams may only be able to run a subset of the proposed RCPs. Therefore, the CM community has assigned a preferred order to RCP runs. The priority order for CM RCP simulations is:

1. Both the high and low RCPs at a minimum (RCP8.5 and RCP3-PD);
2. The intermediate-range RCP with near-term resolution (RCP4.5); and
3. RCP6.

[10] The set of scenarios in this literature has been strongly influenced by specifications of intercomparison exercises and continuity with earlier experiments, so it should not be considered a frequency distribution of independent analyses from which relative robustness, likelihood, or feasibility can be deduced.

III.5 Criteria

Based on the identified RCP pathway types and required data, a set of criteria was defined to identify candidate scenarios from the literature. Box 1 summarizes the criteria for selecting candidate scenarios in the peer-reviewed literature that could serve as RCPs. These criteria reflect the desirable characteristics, identified types of RCPs, and data requirements discussed in this report.

III.6 Candidates

Based on the criteria in Box 1, the IAM community identified 20 RCP candidates from the literature, which are listed in Table 2. Note that each asterisk in Table 2 can represent more than one scenario, and some modeling teams produced more than one scenario over time that would satisfy an RCP type definition. Each model and institution listed in Table 2 has scenarios that satisfy all of the criteria for at least one of the RCP levels requested, which was confirmed via consultation with the modeling teams.

Box 1: Criteria for consideration as an RCP candidate

1) Peer-reviewed and published: the pathway must be reported in the current peer-reviewed literature.
2) Types of RCPs: the pathway must correspond to one of the four RCP types that satisfy the desirable characteristics:
    a) RCP8.5 (>8.5 W/m^2 in 2100, rising)
    b) RCP6 (~6 W/m^2 at stabilization after 2100, stabilization without overshoot)
    c) RCP4.5 (~4.5 W/m^2 at stabilization after 2100, stabilization without overshoot)
    d) RCP3-PD (peak at ~3W/m^2 before 2100 and then decline)
3) Data requirements:
    a) Variables: The IAM scenario must project pathways for all of the required variables through 2100—the full suite of GHGs, aerosols, chemically active gases, and land use/land cover.
    b) Long-term/near-term resolution: the existing data and the modeling team must be amenable to finalizing the data as needed for the required resolution using the methods defined from the technical consultations between the IAM and CM communities. These include harmonization of output and base year data, downscaling, and extending published data to 2300 (see Appendix 1 of the full report).
4) Modeling requirement: for reliability, radiative forcing results must have been generated with an IAM that contained carbon cycle and atmospheric chemistry representations.
5) Timeline: the modeling team must be able to deliver the data in a timely manner. Dates will be coordinated with the CM community with the expectation that:
    a) Initial data will be available by the summer of 2008, including (i) a draft full resolution of the data, and (ii) a fully documented scenario.
    b) Final data will be delivered to the CM community no later than the fall of 2008.

It must be stressed that the requirement that scenarios meet the criteria only applies to the selection of RCPs in the preparatory phase. In subsequent phases of the open scenario development process, these criteria will not apply—all models will have full opportunity to participate in all subsequent research phases.

Table 2. *RCP candidates. Asterisks indicate that at least one scenario is available, although there may be more than one.*

IAM (affiliation)[1]	**RCP8.5**	**RCP6**	**RCP4.5**	**RCP3-PD**	**Reference(s)**
AIM (NIES)		*[2]	*	*[2]	Fujino et al. (2006), Hijioka et al. (2008)
GRAPE (IAE)			*		Kurosawa (2006)
IGSM (MIT)	*	*	*		Reilly et al. (2006), Clarke et al. (2007)
IMAGE (MNP)	*	*	*	*	van Vuuren et al. (2006, 2007)
IPAC (ERI)		*[2]	*		Jiang et al. (2006)
MESSAGE (IIASA)	*	*	*	*	Rao and Riahi (2006), Riahi et al. (2007)
MiniCAM (PNNL)		*	*		Smith and Wigley (2006), Clarke et al. (2007)

Notes:
[1] AIM = Asia-Pacific Integrated Model, NIES = National Institute for Environmental Studies, GRAPE = Global Relationship to Protect the Environment, IAE = Institute of Applied Energy, IGSM = Integrated Global System Model, MIT = Massachusetts Institute of Technology, IMAGE = Integrated Model to Assess the Global Environment, MNP = Netherlands Environmental Assessment Agency, IPAC = Integrated Policy Assessment Model for China, ERI = Energy Resource Institute, MESSAGE = Model for Energy Supply Strategy Alternatives and their General Environmental Impact, MiniCAM = Mini-Climate Assessment Model, PNNL = Pacific Northwest National Laboratory.
[2] These scenarios are available, but would require revisions to meet the RCP forcing criteria.

III.7 The RCPs

Based on an assessment of the candidates to meet the identified data requirements, the initial proposed RCPs presented to the expert meeting, and input from the research and user communities at the meeting, the Steering Committee has identified the following sources and models for the RCPs:[11]

RCP	**Publication – IAM**
RCP8.5:	Riahi et al. (2007) – MESSAGE
RCP6:	Fujino et al. (2006) – AIM[12]
RCP4.5:	Clarke et al. (2007) – MiniCAM[13]
RCP3-PD:	van Vuuren et al. (2006, 2007) – IMAGE

The four specific RCPs are based on several considerations:

- All of the candidates have been peer reviewed and published and can provide the required consistent set of data;
- Not all modeling groups whose scenarios were identified as candidates (Table 2) confirmed their willingness to participate in this activity;

[11] See Table 2 notes for definition of model acronyms.
[12] The AIM modeling team revised this scenario slightly to comply with the 6 W/m^2 stabilization criterion. The revised stabilization scenario is published in Hijioka et al. (2008).
[13] The ERI IPAC team is collaborating with the PNNL MiniCAM team on data finalization as it relates to Asia.

- The selected set of models are those capable of satisfying the data requirements and the modeling teams have substantial experience relevant to developing the required data sets;
- The forcing profiles of these models have been analyzed thoroughly, using simple CMs with updated IPCC AR4 parameterization;
- Among the modeling teams represented in Table 2 who are willing to participate, the MESSAGE and IMAGE models can produce scenarios on the high and low end (RCP3-PD and RCP8.5). The IMAGE model was selected for the low pathway, due to the larger number of low stabilization scenarios available from the model. The MESSAGE model was selected for the high scenario, since it can provide an updated and revised A2-like scenario, which would allow comparisons with earlier climate assessments and thus continuity from the perspective of the CM community. This scenario includes features requested by the IAV community, namely a high magnitude of climate change and factors related to higher vulnerability (e.g., higher population growth and lower levels of economic development);
- Both the AIM and the MiniCAM models could provide the required data for the intermediate levels. The MiniCAM model was chosen for RCP4.5, while AIM was chosen for RCP6.

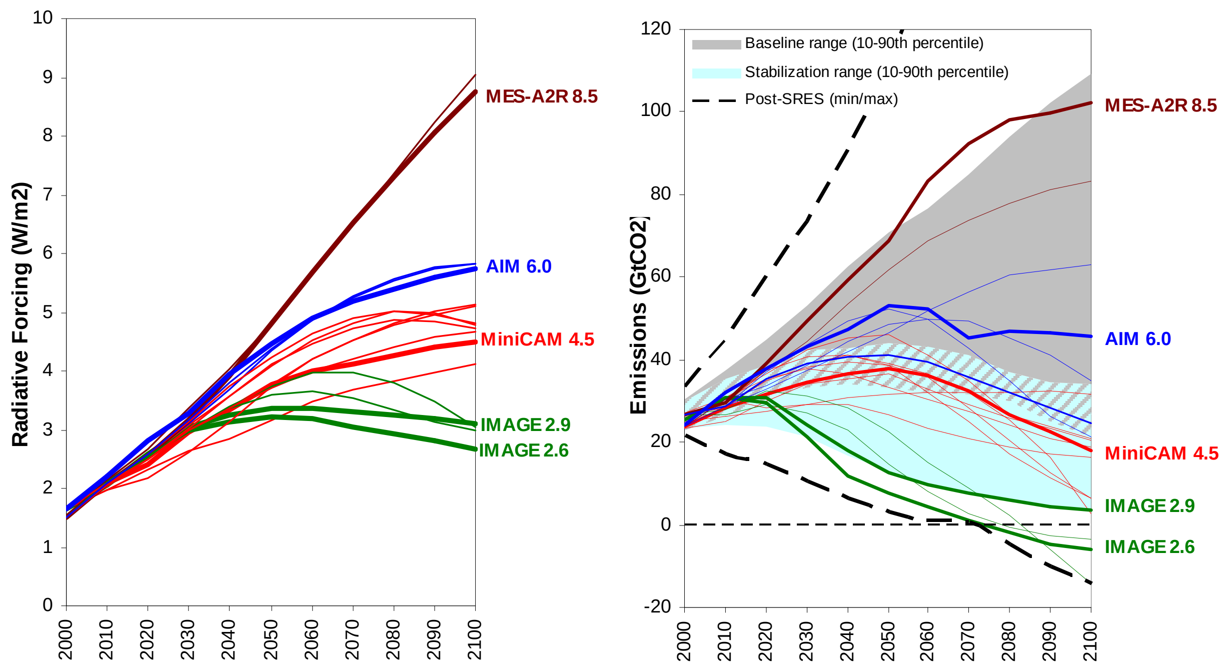


Figure 5. Radiative forcing compared to pre-industrial (left panel) and energy and industry CO_2 emissions (right panel) for the RCP candidates (colored lines), and for the maximum and minimum (dashed lines) and 10th to 90th percentile (shaded area) in the post-SRES literature. These percentiles reflect the frequency distribution of existing scenarios and should not be considered probabilities. Blue shaded area indicates mitigation scenarios; gray shaded area indicates baseline scenarios.[14]

[14] Note that it was not possible to clearly distinguish between energy/industry and land-use emissions for all scenarios in the literature. Therefore, the CO_2 emissions ranges in Figure 5 (denoted by the blue and gray shaded areas in the left panel) include scenarios with both energy/industry and land-use CO_2 emissions.

Figure 5 provides an illustrative overview of how the identified RCPs represent the literature—in terms of radiative forcing pathways (left panel) and energy and industry CO_2 emissions pathways (right panel). The four selected RCPs are highlighted as thick colored lines. Thin colored lines represent the 20 candidate RCP scenarios from Table 2. The different colors correspond to the different RCP forcing levels in 2100 (green <3 W/m^2; red ~4.5 W/m^2; blue ~6 W/m^2; brown ~8.5 W/m^2). RCP8.5 (MES-A2R8.5) and RCP3-PD (either IMAGE2.6 or IMAGE 2.9) are at the upper and lower boundaries of the radiative forcing pathways available. However, they are not at the absolute boundaries of emissions pathways published since the TAR. The RCP8.5 is representative of the 90th percentile of the baseline CO_2 emissions range. The RCP3-PD, on the other hand, is representative of CO_2 emissions pathways at or below the 10th percentile. See the main report for the non-CO_2 emissions pathway figures. The two IMAGE model pathways in Figure 5 are discussed next.

III.8 IMAGE 2.6 or IMAGE 2.9 for the low pathway

Based on the expert meeting discussions, the IMAGE 2.6 scenario (van Vuuren et al., 2006, 2007) is conditionally identified as the selection for the RCP3-PD pathway, but its robustness needs to be assessed. If the robustness of the scenario is established by the process outlined below and discussed further in the full report, the IMAGE 2.6 scenario will be used for the low pathway. Otherwise, the IMAGE 2.9 pathway (van Vuuren et al., 2006, 2007) will be chosen. The robustness evaluation will ensure delivery of one of the two pathways via a scientifically rigorous process. Agreement on the nature of the robustness evaluation was reached through consultations between the Steering Committee and the IAMC following the expert meeting (see Appendix 2 of the full report).

The background paper to the expert meeting proposed the IMAGE 2.9 scenario. However, meeting participants expressed an interest in the lowest radiative forcing scenario in the available literature from this class of IAMs.[7,15] The lowest radiative forcing scenario is the IMAGE 2.6 scenario.

The IMAGE 2.6 scenario has radiative forcing that peaks rapidly near 3 W/m^2 and declines to a radiative forcing of 2.6 W/m^2 in 2100. The IMAGE 2.9 scenario peaks at over 3 W/m^2 and declines to a radiative forcing level of 2.9 W/m^2 in 2100.[16] The emissions, concentration, and radiative forcing pathways to 2100 for both scenarios are presented in Figures III.2 to III.6 in the full report. Data finalization requires extension of these scenarios to the year 2300. There is significant policy and scientific interest in radiative forcing pathways that continue to decline. The IAM and CM communities recognize this interest, and have already begun coordinating in order to develop data finalization methods, including methods for extension to 2300. Discussions on how to carry out the extension are ongoing. The planned methods resulting from those discussions are expected to be available for comment through the IAMC.

Meeting participants expressed an interest in scenarios that show a clear peak in radiative forcing and explore the lowest stabilization scenarios published in the literature, as they offer unique scientific and policy insights. A variety of points were made in support of the IMAGE 2.6 scenario for use as the RCP3-PD. First, the IMAGE 2.6 CO_2 emissions pathway, which reaches 7.6 $GtCO_2$ in 2050 as

---

[15] See Appendix 4 of the full report for some position papers that were distributed at the meeting discussing this point.
[16] Both of the van Vuuren et al. (2006, 2007) scenarios are stabilization scenarios that stabilize by the middle of the 22nd century at radiative forcing levels below 2100 levels. This information was not available in the scenario publications but was obtained through consultation with the IMAGE modeling team. The post-2100 radiative forcing and emissions characteristics of these scenarios may change with the extension to 2300.

compared to 12.8 $GtCO_2$ for IMAGE 2.9, was argued to be more consistent with political discussions regarding particular 2050 emissions reduction objectives and long-run objectives for limiting increases in global mean surface temperature. Second, combined with RCP8.5, the IMAGE 2.6 scenario would span a broader range of radiative forcing and more fully encompass the scenarios literature from all classes of models.[17] Finally, the research communities as a whole found the IMAGE 2.6 peak-and-decline shape, very low radiative forcing pathway, and negative CO_2 emissions scientifically interesting.

However, there was concern about the IMAGE 2.6 scenario because, as presented in the literature, it was exploratory in nature. Like some other very low scenarios, the scenario requires rapid investment in mitigation early in the century and deployment of negative emissions technologies later in the century;[18] however, there were technical concerns about the IMAGE 2.6 characterization of the negative emissions technology. Moreover, recent focus on the diverse consequences of widespread use of bioenergy (including associated nitrous oxide emissions), a requirement in the IMAGE 2.6 scenario, may have important implications. Finally, the IAM community has not yet evaluated the technical feasibility of reaching such low radiative forcing levels. Specifically, the radiative forcing scenario has not yet been reproduced by other models in this class of IAMs (i.e., those that model radiative forcing and its components). In contrast, the IMAGE 2.9 pathway is considered robust in that other models in this class of IAMs published similar peer reviewed results. In this context, recall that robustness means that a scenario is technically sound in that it employs sound assumptions, logic, and associated calculations; and its level of radiative forcing over time could be independently replicated by other models, which represent other sets of assumptions, with scenarios that are considered to be technically sound.

During the meeting discussion, the IAM community noted that the IMAGE 2.9 scenario also satisfies many of the various interests. Both IMAGE 2.6 and 2.9 are overshoot scenarios with peaking and declining radiative forcing, where the peak and decline of IMAGE 2.6 is more pronounced. Both scenarios are included in the lowest class of stabilization scenarios assessed by the IPCC in the AR4 in terms of total radiative forcing (this class contains only three multigas scenarios). Both the IMAGE 2.6 and 2.9 pathways could achieve the target of limiting the global mean temperature increase to 2°C. Based on different probability density functions for climate sensitivity, Meinshausen et al. (2006) estimate the probability of not exceeding 2°C global average temperature increase as 30 to 80% for the 2.9 scenario and 50 to 90% for the 2.6 scenario.

Given the level of interest in the IMAGE 2.6 scenario, the IAMC offered to organize a scientific IAM community exercise and assessment panel for evaluating the robustness of the IMAGE 2.6 scenario for selection as the RCP3-PD. Given the scientific and technical questions raised, the IAMC believes that it is vital to evaluate the scientific question of whether the IMAGE 2.6 scenario is robust before substantial CM community resources are applied in evaluating its climate and atmospheric chemistry implications.[19] The intent of the evaluation is to provide the IMAGE 2.6 scenario if found to be robust.

---

[17] An additional point was made that IMAGE 2.6 was preferable for climate pattern scaling. However, pattern scaling techniques allow for scaling up or down (see the discussion in Section II.4 of the full report). The full validity of pattern scaling requires further research.

[18] The negative emissions technology is bioenergy combined with CO_2 capture and storage (CCS) that *ceteris paribus* has a net negative effect on atmospheric concentrations of GHGs. While bioenergy-based mitigation strategies are assumed in both the IMAGE 2.6 and 2.9 scenarios, it is the combination of bioenergy with CCS that is novel in IMAGE 2.6.

[19] Technical concerns were not raised about the other proposed RCPs, and each has been replicated.

Should the exercise be unable to establish the robustness of the IMAGE 2.6 scenario, the published (and replicated) IMAGE 2.9 overshoot scenario will be provided to the CM community instead to serve as the low RCP. So as not to delay the hand-off of data to the CM community, the IMAGE modeling team will be preparing the required CM input data from both the published IMAGE 2.6 and 2.9 scenarios.

Agreement on the nature of the robustness evaluation was reached through consultations between the Steering Committee and the IAMC following the expert meeting through a series of four letters (see Appendix 2 of the full report). To ensure the scientific credibility and transparency of the evaluation, the IAMC will appoint a panel that will be responsible for providing a consensus recommendation on the robustness of the IMAGE 2.6 scenario. Based on its robustness assessment, the panel will provide a single recommendation on whether the IMAGE 2.6 or IMAGE 2.9 scenario should be used for the lowest RCP. While panel members may not necessarily agree on all aspects of the robustness of the IMAGE 2.6 scenario, they are asked to provide a single recommendation on whether or not it should be considered robust to the IAMC as the convening body, which will then transmit the finding to the Steering Committee for expected confirmation of the recommendation. The conclusions of the evaluation panel will be provided to the IPCC in a letter report that will provide a detailed description of the full evaluation process and results.

The assessment process will be based on two general criteria, both of which must be met by the IMAGE 2.6 scenario: technical soundness and replicability. For the former, the IAMC will ask the modeling teams to (a) review the published IMAGE 2.6 scenario for technical soundness (i.e., assumptions, logic, and associated calculations), and (b) address any technical issues that arise from that review. The IMAGE modeling team will lead an evaluation of the technical components of the IMAGE 2.6 scenario, particularly those that distinguish the scenario from the IMAGE 2.9 scenario, namely the representation of bioenergy combined with CO_2 capture and storage (CCS). If the team review reveals fundamental problems with the IMAGE 2.6 scenario that have significant bearing on the scenario and cannot be addressed with minor revisions, it will not be selected as an RCP. The findings from this assessment will be made available to the review panel for consideration.

For replicability, the IAMC will ask all the IAM teams working with this class of models to participate in the design and development of low stabilization scenarios that replicate key radiative forcing features of the IMAGE 2.6 pathway shape (i.e., peaking rapidly near 3 W/m^2 and declining to around 2.6 W/m^2 in 2100). The modeling teams will be asked to employ their standard assumptions and include bioenergy and CCS, but avoid non-traditional assumptions like geo-engineering, dramatic dietary changes, or severe economic collapse. This term of reference provides some structure for the modeling that is broadly consistent with the IMAGE 2.6 scenario. Replication will be deemed successful if both of the following occur: (a) the IMAGE team, after addressing any modest technical issues identified in their assessment of the IMAGE 2.6 scenario, is able to generate the scenario using the latest version of the IMAGE model; and (b) at least two of the other IAM models in this class are able to generate a scenario with a similar radiative forcing pathway that is considered to be technically sound.

The panel will ensure that the evaluation is conducted in a careful, scientific, and unbiased manner, and will develop and apply a set of broad criteria to be considered in the evaluation of the technical soundness of the replication scenarios. The panel is invited to consider, among other things, technical soundness of the representation of key technologies, internal plausibility and consistency of the technology portfolio, GHG and carbon cycle accounting, land use implications, and economic considerations relative to the 2.9 W/m^2 pathway. In addition, scenario analysis by the modeling teams might identify important new criteria, in which case these would be clearly communicated by the panel in its letter report.

III.9 Further research on scenarios with very low radiative forcing levels

Given the growing interest of the international community in scenarios with a clear peak and decline in radiative forcing and very low stabilization levels, it is strongly recommended that governments and funding agencies support further research on scenarios that peak and then decline to very low stabilization levels.

IV. Institutional and Coordination Issues

Because the new scenario development and implementation process outlined in this report is innovative in so many ways—including its approaches to scenario development and elaboration, its linkages among a range of contributors to climate change research, and its linkages between them and users of the scenarios and other interested stakeholders—it raises a number of issues for coordination, data management and exchange, and institutional development. Resolving these issues will require the active involvement of existing research coordination mechanisms such as the Earth System Science Partnership, the World Climate Research Programme, the International Geosphere-Biosphere Programme, the International Human Dimensions Programme, and the IAMC. It may also be necessary to create new mechanisms where institutions are lacking, for example, to improve coordination and problem solving within the IAV community (see Section IV.4 of the full report).

IV.1 Coordinating with end users

Many national and international organizations think about the future from their own perspectives, and this necessarily entails considering the potential implications of climate change for a diverse range of activities such as development planning, food production and distribution, provision of water resources, conservation of protected environments, and management of other environmental issues as diverse as reducing local air pollution and slowing desertification of soils.

A further issue to explore is whether there is value in bringing together like-minded international organizations to contribute to climate-change related scenario development, and to consider a common core of assumed futures around which individual organizations can develop more detailed assumptions for their own specific purposes. The IPCC could convene a group on global change scenarios among organizations such as the UNFCCC, the United Nations Food and Agriculture Organization, the World Bank, the United Nations Environment Programme, the World Health Organization, the United Nations Development Program, and major NGOs and private sector organizations that require climate change and associated socioeconomic scenarios for their own planning purposes.

Other possible ways of organizing the end user–scenario developer dialogue can also be envisioned. These include, for example, having a set of meetings with selected stakeholder groups (rather than organized user groups) over the course of the scenario development process. Another option would be for the IPCC bureau to undertake facilitation of the dialogue during IPCC plenaries and other meetings of interested parties. Designing a scenario process website in an open and interactive way could also encourage feedback from potential users. A final option that has proved useful in other environmental science and policy subject areas is to identify technically proficient members of user groups to be linked individually with scenario development and implementation as "bridges" between the core scenario science and potential uses of the scenarios. Outlining the resources that will be required for these coordination efforts is a critical component for successfully integrating other potential users into the process. It is also important to consider these coordination issues in the context of progress towards a possible AR5.

IV.2 Coordinating across the research communities

Developing a new international climate change scenario infrastructure, built on full collaboration among the CM, IAM, and IAV scientific communities, is clearly essential for supporting climate change response decisions in the future. It requires, however, connecting three research communities that in most regards lack a tradition of working together and in some cases may not automatically see such close coordination as a high priority for their time and resources. An example that highlights a community priority for coordination is recent developments in the evolution of the physical climate models to new ESMs that include, for instance, dynamic vegetation and biochemistry. These new, coupled biophysical-climate models may produce conflicting land cover and emissions estimates relative to the IAM scenario projections. It will be important for these communities to develop a consistent strategy with regard to land use and emissions for a possible AR5. The parallel process described in this document provides a strategy for explicit engagement between the communities. Overcoming obstacles to inter-group coordination is therefore key.

In support of the new international climate change scenario infrastructure, several steps are needed and under consideration by the research community that will require communication with, between, and across sector experts for action by the middle of calendar year 2008:

(1) An IAM/IAV meeting to develop a joint strategy for storyline development, including plans for regional participation, encouraging especially more participation of developing country/economies in transition (DC/EIT) researchers;
(2) An IAV expert workshop to propose steps to build structure and add coherence to the work of that community, especially as it relates to new scenario development, and facilitating in particular the participation of DC/EIT researchers;
(3) An IAM/IAV meeting to develop plans for the scenario library; and
(4) A joint IAM/IAV/CM discussion that provides shared insights into model assumptions and requirements within and across modeling groups.

Several other steps are also needed over the coming two years in order to address a variety of challenges in moving toward new integrated scenarios of broad value to the climate change research, policy, and stakeholder communities:

(1) A CM/IAM/IAV community expert workshop to pursue a collaborative approach to climate change downscaling and its relationships with bottom-up regional and local storyline development, with the participation of DC/EIT researchers encouraged. In addition, challenges regarding nonlinearities and lags related to pattern scaling will need to be addressed.
(2) An IAM/IAV community meeting to develop strategies for improving the integration of mitigation into IAV analyses;

(3) A joint CM/IAM/IAV community meeting with selected stakeholder groups to assure sensitivity to stakeholder concerns and information needs, with a special focus on DC/EIT countries particularly prone to severe climate change impacts in the near term;
(4) A CM/IAM/IAV community meeting to exchange information about current data management assets and practices and to identify steps that would improve prospects for data integration, with active participation of DC/EIT country experts; and
(5) A CM/IAM/IAV community expert workshop on a topic of interest to all three communities, using that topic both to advance understanding of the subject and to enhance communication among the communities (e.g., sea ice/sea level rise/coastal impacts and adaptation).

V. Increasing Developing Country Participation

Many policymakers and stakeholders in developing countries are now considering their own climate change response strategies and assessing their particular vulnerabilities and potential impacts. Since the IPCC AR4 indicated that developing countries are likely to bear a disproportionate share of climate change impacts, the development of more representative models, scenarios, land use/land cover monitoring, and other planning tools has taken on special urgency there. Intensified efforts to involve scientists from developing countries in the scenario creation process will be needed to ensure that the representation of developing regions in key models and scenarios has sufficient resolution and accuracy to support sound climate change responses in these areas.

Through its decision on further work on emissions scenarios at its 25th Session (April 2006, Mauritius) the IPCC requested that the expert meeting consider the ongoing problem of identifying and involving sufficient expertise from Africa, Asia, Latin America, island states, and from countries with economies in transition, principally in Central Europe and the former Soviet Union.

Future efforts to increase and sustain DC/EIT participation in climate change assessments must address a series of challenges that have contributed to their under-representation to date. Among these is the need for the expansion of expert and institutional scientific capacity in developing regions. There is significant variance in current levels of scientific capacity within and among developing regions, resulting in a corresponding variance in capacity for participation in international scenario development efforts and climate change assessments. Likewise, there is an ongoing need for more funding and for new funding mechanisms to support the continued participation of DC/EIT representatives in international scientific activities related to climate change. Addressing capacity and funding limitations to enhanced DC/EIT participation will demand concerted outreach and integration initiatives on the part of the broader international research and policy communities.

V.1 Recommended Actions

The following proposed actions constitute the elements of a plan to promote the accelerated development of DC/EIT capacity and enhance the participation of these regions in future scenario development and climate change assessment. The recommendations are grouped according to their relevance to each of the specific challenges mentioned above, although there is inevitably and necessarily overlap among recommendations in each area.

A principal recommendation is that the IPCC sponsor a workshop in 2008 dedicated to addressing the manifold challenges associated with efforts to expand DC/EIT scientific capacity and participation in international scenario development and climate assessment activities. Such a workshop would provide an opportunity for key members of the research community to begin discussing and prioritizing the actions listed below, to identify additional or alternative recommendations, and to initiate the development of new inter-/intra-regional networks for sustained DC/EIT capacity building and deeper participation in the international research community.

Additional specific recommendations include:

1. Modeling and Scenario Development

- Inventory and assess current intraregional modeling representation in DC/EIT countries and identify data and institutional needs, capacity limitations, and opportunities for/barriers to intraregional coordination and linkage among IAM and ESM teams.
- Inventory and assess current DC/EIT representation in key global IAMs and ESMs. Key issues to address include key variables, data sources and availability, scalability, and questions of intraregional aggregation.
- Foster collaboration among DC/EIT modelers for intraregional model integration and for collaborative efforts with global modelers for the improvement of DC/EIT representation, the development of new regional storylines and scenarios, and for scenario downscaling/upscaling and pattern scaling in preparation for a possible AR5.

2. Expert and Institutional Capacity Development

- Establish and sustain DC/EIT scientific peer groups to identify key areas for capacity development and expansion, and for the nomination of peers as potential participants in future modeling and scenario development institutions.
- Promote intra- and trans-regional DC/EIT modeling and scenario development initiatives, modeled on existing programs such as those managed by the System for Research, Analysis, and Training and other institutions with training and capacity-building missions, to develop deeper and broader scientific capacity in DC/EIT regions and to expand data development and availability, as described in the 2005 Task Group on Data and Scenario Support for Impact and Climate Analysis framework proposal. Capacity building for downscaling and upscaling of model results should be a key area of emphasis.
- Establish an online network/clearinghouse of DC experts and institutions to familiarize the international scientific community with existing capacities, foster communication among individual researchers and modeling groups, and call attention to geographic and disciplinary areas in which additional capacity building is needed.

3. Funding DC/EIT participation and capacity development

- Identify potential donor institutions for sustained financial sponsorship of capacity building efforts. These might include multilateral institutions (e.g., World Bank, regional development banks), international organizations such as the United Nations Development Programme, national governments, and private scientific and educational foundations such as the Gates Foundation.
- Identify potential collaborating centers and institutions to serve as lead agencies for the management of funding for future efforts to build DC/EIT capacity and participation and to serve as grantmaking and networking institutions.

- Establish a trust dedicated to funding fellowships for young scientists from DC/EIT regions to study and work abroad with leading modelers and scientific research groups.

4. Coordination and Outreach

- Identify key areas for capacity building, research, and storyline and scenario development; existing DC/EIT data limitations and needs; IAV assessment capacity needs; and potential avenues of inter-regional coordination and financial support for sustained efforts to address these problems.
- Promote stronger coordination between DC/EIT researchers and user community members beginning with new outreach efforts on the part of key data and research institutions. For example, the Program for Climate Model Diagnosis and Intercomparison and the IAMC could be primary vehicles for outreach to DC/EIT by the CM and IAM communities, respectively.
- Promote exchanges and collaborative efforts between DC/EIT regions and modeling groups in industrialized countries to develop capacity in regions and in areas currently receiving less attention in DC/EIT areas and to establish institutional relationships among younger modelers and emerging groups in key DC/EIT countries and established groups in industrialized countries.

VI. Key RCP References

Clarke, L., J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, and R. Richels, 2007. *Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations*. Sub-report 2.1A of Synthesis and Assessment Product 2.1 by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Department of Energy, Office of Biological & Environmental Research, Washington, DC, 154 pp.

Fujino, J., R. Nair, M. Kainuma, T. Masui, and Y. Matsuoka, 2006. Multigas mitigation analysis on stabilization scenarios using AIM global model. *Multigas Mitigation and Climate Policy. The Energy Journal Special Issue*. pp. 343–354.

Hijioka, Y., Y. Matsuoka, H. Nishimoto, M. Masui, and M. Kainuma, 2008. Global GHG emissions scenarios under GHG concentration stabilization targets. *Journal of Global Environmental Engineering*, **13**:97-108.

Jiang, K., X. Hu, and Z. Songli, 2006. Multi-gas mitigation analysis by IPAC. *Multigas Mitigation and Climate Policy. The Energy Journal Special Issue.*

Kurosawa, A., 2006. Multigas mitigation: an economic analysis using GRAPE model. *Multigas Mitigation and Climate Policy. The Energy Journal Special Issue.*

Meinshausen, M., B. Hare., T.M.L. Wigley, D. van Vuuren, M.G.J. den Elzen, and R. Swart, 2006. Multi-gas Emissions Pathways to Meet Climate Targets. *Climatic Change*, **75**:151.

Rao, S., and K. Riahi, 2006. The role of non-CO_2 greenhouse gases in climate change mitigation: long-term scenarios for the 21st century. *Multigas Mitigation and Climate Policy. The Energy Journal Special Issue.*

Reilly, J., M. Sarofim, S. Paltsev, and R. Prinn, 2006. The role of non-CO_2 GHGs in climate policy: analysis using the MIT IGSM. *Multigas Mitigation and Climate Policy. The Energy Journal Special Issue*.

Riahi, K., A. Gruebler, and N. Nakicenovic, 2007. Scenarios of long-term socioeconomic and environmental development under climate stabilization. *Greenhouse Gases - Integrated Assessment*. *Special Issue of Technological Forecasting and Social Change*, **74**(7):887–935, doi:10.1016/j.techfore.2006.05.026.

Smith, S.J., and T.M.L. Wigley, 2006. Multi-gas forcing stabilization with the MiniCAM. *Multigas Mitigation and Climate Policy*. *The Energy Journal Special Issue.*

van Vuuren, D.P., B. Eickhout, P.L. Lucas, and M.G.J. den Elzen, 2006. Long-term multi-gas scenarios to stabilise radiative forcing - Exploring costs and benefits within an integrated assessment framework. *Multigas Mitigation and Climate Policy*. *The Energy Journal Special Issue.*

van Vuuren, D.P., M.G.J. den Elzen, P.L. Lucas, B. Eickhout, B.J. Strengers, B. van Ruijven, S. Wonink, and R. van Houdt, 2007. Stabilizing greenhouse gas concentrations at low levels: an assessment of reduction strategies and costs. *Climatic Change*, **81**:119–159.

TOWARDS NEW SCENARIOS FOR ANALYSIS OF EMISSIONS, CLIMATE CHANGE, IMPACTS, AND RESPONSE STRATEGIES

IPCC EXPERT MEETING REPORT

Lead Authors:

Richard Moss, Mustafa Babiker, Sander Brinkman, Eduardo Calvo, Tim Carter, Jae Edmonds, Ismail Elgizouli, Seita Emori, Lin Erda, Kathy Hibbard, Roger Jones, Mikiko Kainuma, Jessica Kelleher, Jean Francois Lamarque, Martin Manning, Ben Matthews, Jerry Meehl, Leo Meyer, John Mitchell, Nebojsa Nakicenovic, Brian O'Neill, Ramon Pichs, Keywan Riahi, Steven Rose, Paul Runci, Ron Stouffer, Detlef van Vuuren, John Weyant, Tom Wilbanks, Jean Pascal van Ypersele, Monika Zurek.

Contributing Authors:

Fatih Birol, Peter Bosch Olivier Boucher, Johannes Feddema, Amit Garg, Amadou Gaye, Maria Ibarraran, Emilio La Rovere, Bert Metz, Shuzo Nishioka, Hugh Pitcher, Drew Shindell, P.R. Shukla, Anond Snidvongs, Peter Thorton, Virginia Vilariño.

Steering Committee:

Richard Moss and Ismail Elgizouli (Co-Chairs); Mustafa Babiker, Olivier Boucher, Eduardo Calvo, Tim Carter, Jae Edmonds, Seita Emori, Amit Garg, Martin Manning, Jose Marengo, Jerry Meehl, Bert Metz, Leo Meyer, Nebojsa Nakicenovic, Shuzo Nishioka, Martin Parry, Paul Runci, Ronald Stouffer, Jean Pascal van Ypersele, Monica Zurek.

I. Introduction

I.1 Background

Scenarios of future conditions relevant to analyzing different aspects of the climate change issue have always been an important component of the work of the Intergovernmental Panel on Climate Change (IPCC) because of their utility for representing uncertainties associated with anthropogenic climate change.[1] In the past, the IPCC coordinated the process of developing scenarios for its assessments. The IPCC provided the terms of reference, reviewed the scenarios, and ultimately approved them, while modeling teams around the world prepared the scenarios. Previous sets of IPCC scenarios were prepared in this fashion and published in 1990, 1992, and 2000. These scenarios were widely used by the research and policy communities in the analysis of possible climate change, its impacts, and options for adaptation and mitigation, not only feeding into the IPCC process, but also in the context of other national and international programs and activities.

During its 24th session (Montreal, 26–28 September 2006), the IPCC concluded that new scenarios would be developed for a future assessment report by the scientific community, with a coordination or facilitation role played by the IPCC. It was suggested that these scenarios include adaptation, economic growth, demographic, and other societal variables that lead to emission scenarios, and that greater participation of experts from developing countries and countries with an economy in transition should be encouraged in the scenario development process. During its 25th session (Mauritius, 26–28 April 2006), the IPCC further specified the nature of its involvement in the preparation of new scenarios. Rather than having the IPCC directly coordinate and approve new scenarios, the research community itself will now coordinate the process of scenario development. Under the new arrangement, the immediate objective of the IPCC's involvement is to "catalyze" the timely production by others of new scenarios for a possible Fifth Assessment Report (AR5). The decision to change the process in this manner was the culmination of much discussion about the question of new scenarios that took place at previous sessions of the Panel and in workshops in Washington, DC, United States (January 2005), Laxenburg, Austria (July 2005), and Seville, Spain (March 2006).[2]

The Panel's Mauritius decision included two components: 1) the identification of a small number of "benchmark" emissions scenarios (referred to in this report as "representative concentration pathways"—RCPs—for reasons discussed below) for potential use by climate modeling groups, which was to be undertaken through a technical paper; and 2) the convening of an IPCC expert meeting to consider how plans for developing new scenarios were progressing within the scientific community. The Panel asked the expert meeting to consider:

---

[1] For the purposes of this report, "scenario" is defined as a plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a "narrative storyline" (IPCC, 2007a).

[2] For further information on these previous meetings and associated recommendations and decisions, see: http://www.ipcc.ch/pdf/supporting-material/expert-meeting-2005-01.pdf (Washington), http://www.mnp.nl/ipcc/pages_media/meeting_report_workshop_new_emission_scenarios.pdf (Laxenburg), and http://www.ipcc.ch/meetings/session25/doc11.pdf (Seville).

- Comparability of scenarios to serve the various user communities;
- The results of scenario activities undertaken by the World Bank, the Food and Agriculture Organization (FAO), the Organisation for Economic Cooperation and Development (OECD), the International Energy Agency (IEA), the World Meteorological Organization (WMO), and the UN Environment Programme (UNEP), and the possible future involvement of these organizations in scenario development;
- Transparency and openness of the scenario development process; and
- Increased involvement of experts from developing countries and countries with economies in transition in the scenario development process.

In response to further inputs from the scientific community, the IPCC decided at its 26th meeting in Bangkok, Thailand (4 May 2007) that instead of identifying the benchmark scenarios through a technical paper, it would ask the Steering Committee of the expert meeting to identify a set of benchmark scenarios through the meeting. This decision, reproduced in Box I.1, indicated that the benchmark scenarios should be described in a report summarizing the outcome of the meeting. After being peer reviewed, this report would have the status of IPCC "Supporting Material."

Box I.1: Further Work of the IPCC on Emissions Scenarios
Decision taken by the Panel at its 26th Session

1) The Panel recalls its support for decoupling the climate modeling work from the emissions scenario development work, in order to allow climate modelers a quick start with their work after the completion of the AR4 [AR4 = Fourth Assessment Report].
2) As an appropriate option to the development of an IPCC Technical Paper on Benchmark Emission Scenarios as decided at its 25th Session, the Panel now requests the Steering Committee on New Scenarios to prepare a few benchmark concentration scenarios through the IPCC Expert Meeting 19–21 September 2007 in Noordwijkerhout, The Netherlands. These benchmark concentration scenarios should be compatible with the full range of stabilization, mitigation and baseline emission scenarios available in the current scientific literature.
3) The Steering Committee for the expert meeting on new scenarios should produce a report on concentration benchmark scenarios originating from this Expert meeting that:
   a) adequately address the role of aerosols, short-lived greenhouse gases, land use, and the socioeconomic background of the benchmarks;
   b) takes into account the needs of the user communities including the impact, adaptation and vulnerability modelers
   c) enables access to relevant data for the climate modelers
4) The Steering Committee on the expert meeting on new scenarios should arrange an expert review of its draft meeting report on benchmark concentration scenarios and finalize the report if possible in early 2008. The report would have the status of "Supporting Material" to the IPCC in keeping with established practice.
5) The summary of the meeting report on benchmark concentration scenarios should be translated into all UN languages.

This report was prepared by a team of lead authors who participated in the expert meeting, under the guidance of the Steering Committee, to fulfill the request of the Panel (see the title page for the list of lead authors and members of the Steering Committee). The report integrates extensive preparations before the meeting, discussions during sessions, and subsequent activity on the part of the Steering Committee and the research community.

I.2 This Expert Meeting

The expert meeting on new scenarios was held in Noordwijkerhout, The Netherlands, from 19–21 September 2007. The expert meeting was organized by the Steering Committee to prepare the following specific deliverables:

- A proposed set of "benchmark concentration pathways" that will be used in initial climate model runs. These pathways will be selected from the existing scientific literature and will cover a representative range of stabilization, mitigation, and reference scenarios. They will be used in climate models to provide simulated climate outputs;
- A description of key scientific and technical issues for coordinated development of new integrated scenarios, including scenario activities of international organizations that use climate-change related scenarios and their possible future involvement in scenario development;
- Plans for the relevant research communities to coordinate, organize, and communicate further actions towards the development of new integrated scenarios, including institutional arrangements for coordinating and scheduling activities; and
- A plan for increasing involvement of experts from developing countries and countries with economies in transition in the development of new scenarios, including funding and organizational aspects.

The meeting brought together representatives of the user community with many of the principal research communities involved in development and application of scenarios. The representatives of the scenario user community included officials from national governments (including many participating in the UN Framework Convention on Climate Change—UNFCCC), international organizations, multilateral lending institutions, and nongovernmental organizations. The principal research communities represented at the expert meeting were

- the integrated assessment modeling (IAM) community;[3]
- the climate modeling (CM) community;[4] and

[3] Integrated Assessment Models (IAMs) incorporate quantitative representations of physical, biological, economic, and social processes, and make possible the quantitative analysis of interactions between these components in a consistent framework to evaluate the status and the consequences of environmental change and the policy responses to it. While information from all contributing disciplines is included, the IAM community is primarily comprised of individuals from the social sciences (including economics) and energy technology fields.

[4] Comprising researchers who work with models of climate, the carbon cycle, atmospheric chemistry, and other components of the Earth system.

- the impacts, adaptation, and vulnerability (IAV) community.[5]

Because of this broad participation, the meeting provided a unique opportunity for the segments of the research community involved in scenario development and application to discuss their respective requirements and coordinate the planning process accordingly. For example, there was an opportunity to conduct technically oriented discussions of the characteristics of emissions scenarios required as inputs for CM simulations. Similarly, climate modelers and IAV researchers were able to consider the key variables, data formats, delivery mechanisms, and other issues related to the use of CM outputs in research on impacts, adaptation, and mitigation. In addition, the meeting also provided an opportunity to continue previous interactions between representatives of the user community and the research community over desired scenario characteristics from a user perspective. There was extensive discussion of a proposed set of RCPs as well as opportunities for ongoing interactions between producers and users of scenarios.

Over 130 participants were selected by the Steering Committee after a careful review of a much larger number of individuals who expressed interest in attending. Thirty-four participants were from developing countries or countries with economies in transition. Approximately 32 participants were from the CM community, 32 from the IAV community, 47 from the IAM community, and 23 from the user community.

The Steering Committee was able to draw on recent scientific developments and closer coordination across the CM, IAV, and IAM research communities (see Box I.2). This coordination has evolved because of the realization that improvements in our understanding of climate change, its implications, and how it can be addressed in the context of sustainable development require integration across diverse research areas. Improved integration is spurring scientific advance, making it possible to incorporate new components and capabilities in the next generation of CMs and IAMs, as well as continuing to make advances in the areas of IAV research. These developments include, for example, the incorporation of carbon cycle models and additional components including aerosols, non-carbon dioxide (CO_2) greenhouse gases, atmospheric chemistry, dynamic vegetation, and land use into Earth system models. Section II explains how these advances are being incorporated into the scenario development process.

[5] In this report, the climate change impact and adaptation research community is referred to by the acronym IAV—for impacts, adaptation, and vulnerability—because this notation is familiar across the climate change research communities. Within the impact/adaptation research community, whether or not this usage is adequate is under active discussion. At the expert meeting, some attendees from this community preferred "vulnerabilities, impacts, mitigation, and adaptation" (VIMA) for two reasons: (1) the dominant concern is with analyzing vulnerabilities and risks rather than projecting impacts and adaptation, therefore V should be the first letter, not the last; and (2) analyses of vulnerabilities, impacts, and adaptation cannot be separated from analyses of mitigation contexts and outcomes. Mitigation and adaptation should be viewed in an integrated way by the IAV community in collaboration with the IAM community, which will be modeling feedbacks and interactions between impacts and mitigation at a more aggregated level of analysis.

Box I.2: Related Meetings and Background Documents

There has been considerable effort within the scientific community to coordinate integrated scenarios. In addition to the earlier IPCC workshops,[2] the coordination process has also been discussed and advanced at a number of recent scientific meetings, including:

- A "summer institute" held under the auspices of the Aspen Global Change Institute (AGCI)[6] in July 2006 that included researchers from the World Climate Research Programme (WCRP), the International Geosphere-Biosphere Programme (IGBP), the former IPCC Task Group on New Emissions Scenarios (TGNES), the IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA), and IPCC Working Groups I, II, and III. The experimental design developed at this meeting, and upon which the scenario development strategy described in this report is based, is summarized in a meeting report prepared by Meehl et al. (2007b) and in Hibbard et al. (2007).
- A joint meeting of the WCRP's Working Group on Coupled Models (WGCM) and the IGBP's Analysis, Integration and Modeling of the Earth System (AIMES) core project in September 2006, which further considered the proposed experimental design.
- An additional summer workshop that was held under the auspices of the Energy Modeling Forum (EMF) in Snowmass, Colorado in July 2007 that involved many in the IAM community, a number of those who participated in the AGCI session, plus some members of the Steering Committee for this IPCC expert meeting.
- A meeting of the WGCM in Hamburg, Germany from 3–5 September 2007, which included review of the experimental design from the perspective of the CM community.

An extensive background paper prepared by members of the Steering Committee, speakers, and other participants integrates information from all these meetings and was made available to participants before this expert meeting.[7]

Developing an integrated perspective for decision support and assessment also requires consistent scenarios for application in climate change impacts, adaptation, and mitigation analysis. For IPCC assessments, this means that its three Working Groups should use a common base so that:

- Assessments of impacts, adaptation, and vulnerability are consistent with views of the evolution of climate change, which in turn should be consistent with views of emissions trajectories;
- Assessments of emissions are consistent with views of socioeconomic drivers and land use change and account for feedbacks from climate change impacts and policies to reduce both emissions and adverse impacts; and
- Impacts, adaptation, and vulnerability are assessed in a way that uses consistent information about socioeconomic drivers, technology, and land use change.

On the morning of the first day of the expert meeting, presentations focused on needs for scenarios as seen from a policymaking perspective, a review of past IPCC scenarios, overviews of evolving plans in the research community for coordinated preparation of new scenarios from several different

[6] http://www.agci.org.
[7] http://www.mnp.nl/ipcc/docs/index0407/Backgroundpaper_2007Sept11_final.pdf.

disciplinary perspectives, and a review of options for the RCPs. Afternoon talks focused on needs and opportunities for scenarios on two different time scales ("near term"—to 2035, and "long term"—to 2100, extended to 2300 for some applications), institutional issues, and regional issues of special importance to developing and transition-economy countries. The remainder of the meeting was organized around a series of breakout groups that provided an opportunity for the research communities to further coordinate their plans, to refine the proposal for the RCPs, and to consider additional cross-cutting issues such as institutional needs and development of higher resolution information suitable for analyzing adaptation and mitigation options. A series of additional breakout group and plenary sessions followed to allow meeting participants to discuss the coordination and scenario development issues from both disciplinary and interdisciplinary perspectives. These sessions provided valuable information to improve the scenario development process, and their details are addressed throughout this report. Appendix 3 provides the detailed meeting agenda and Appendix 5 lists the participants.

I.3 Scenario characteristics and needs from an end-user perspective

The characteristics and types of scenarios required must be determined in light of the needs of users of those scenarios. During earlier IPCC meetings and the planning process for this expert meeting, two broad groups of users emerged: "end users," policy- and decisionmakers who use scenario outputs and insights in various decision processes; and "intermediate users," researchers who use scenarios from a segment of the research community other than their own as inputs into their work (e.g., climate modelers are "intermediate" users of emission scenarios when these are used to drive CM simulations). This section and Section IV of the report focus on needs for and characteristics of scenarios from an end-user perspective. Intermediate uses of scenarios across the scientific community are discussed throughout the remainder of the report.

As new scenarios are developed, members of the research community will need to coordinate with a broad range of potential end users on an ongoing basis. For scenario-based information to be useful to decisionmaking processes, a great deal of thought is required regarding who the end users are, what information is required, and how best to supply information so that it is relevant to these processes. Section IV includes, *inter alia*, suggestions developed at the expert meeting for improving interactions between end users and producers of scenarios.

Potential end users of scenarios include:

- The international conventions (e.g., UNFCCC, Convention on Biodiversity);
- Global public and intergovernmental organizations (e.g., FAO, the World Health Organization (WHO), UNEP, IEA);
- Sub-global multinational decisionmaking bodies (e.g., the European Union);
- National governments;
- Regional and local governments;
- Private sector organizations at various scales;
- Nongovernmental organizations (NGOs) and Civil Society Organizations (CSOs);
- Local communities;
- The research community at large (beyond intermediate users in the climate change community itself); and
- Other assessment processes and exercises.

During this expert meeting and previous IPCC workshops on scenarios, users were invited to participate and offer their views on the type of scenarios that they need. In particular, scenario needs were a major focus of the IPCC expert meeting on scenarios in Laxenburg, Austria.[8] User needs vary widely between different stakeholders, and even information requirements within a given group are not homogenous. The report of the IPCC TGNES[9] synthesized the needs of diverse end users and distinguished among three broad categories of emissions scenarios: (1) long-term, global emissions scenarios (150 years or more); (2) short- to mid-term global emissions scenarios (projecting 20–40 years ahead); and (3) short-term emissions scenarios (projecting up to 30 years ahead) for specific regions or nations with considerable detail.

This report focuses on global scenarios for two time periods:

- "near-term" scenarios that cover the period to about 2035; and
- "long-term" scenarios that cover the period to 2100 and, in a more stylized way, can be extended to 2300.

Development of regional or national near-term socioeconomic scenarios in a manner that is consistent with global scenarios but that also reflects unique local conditions is very much at the "cutting edge" of research. This topic seems especially important as increasing attention is focused on regional and national implementation of adaptation and mitigation options, and on how these two response classes can be effectively integrated in climate risk management. This important topic was considered in two breakout groups on information for IAV and mitigation analysis at regional/national scales. These issues are also addressed in Section VI.

The distinction between near- and long-term scenarios[10] is important because the nature of policy- and decisionmaking changes with time scale. Near-term adaptation and mitigation management issues include identifying immediate risks; developing corresponding adaptive capacity, reducing vulnerability; making efficient investments to cope with climate change; and implementing investments in low-emission technologies, energy conservation, and sink preservation and/or enhancement. The longer term policy focus shifts towards evaluating climate targets to avoid risks from climate change impacts, improving the understanding of risks of major geophysical change and feedback effects, and adopting strategies for mitigation and development that are robust to remaining uncertainties.

I.3.1 Need for near-term scenarios (to 2035)

A primary aim of near-term scenarios is to develop better projections of regional climate change and associated impacts, and to evaluate potential adaptation options. Scenarios on this time scale are also useful to explore opportunities and constraints on mitigation, taking account of economic, technological, and institutional factors. This includes issues such as benefits of mitigation

[8] See http://www.mnp.nl/ipcc/pages_media/meeting_report_workshop_new_emission_scenarios.pdf.

[9] See http://www.ipcc.ch/meetings/session25/doc11.pdf.

[10] Scenarios used in climate change research also have different characteristics over the near and longer term. In particular, both the climate system and the anthropogenic drivers of climate change are subject to inertia so that near-term change is constrained by the present and by recent history. Such constraints diminish further into the future. Examples of inertia occur in social behavioral change, population growth and demographics, infrastructure and energy systems, the time scales for removal of radiative forcing agents from the atmosphere, and the time required for the ocean–atmosphere–land–cryosphere system to adjust to a particular level of forcing. These various sources of inertia combine to mean that scenarios for the near term are generally more specific, and for some factors cover a narrower range of possibilities, than scenarios for the longer term.

(e.g., improvement in air quality), as well as synergies between adaptation, mitigation, and development strategies.

Use of higher resolution CMs allows for more physical components (i.e., atmospheric chemistry) to be included, and shorter simulations have lower CM costs and thus become more practical. On the other hand, an emphasis on diagnosing changes in the frequency or magnitude of extreme events, probabilistic identification of the greatest areas of risk, and the achievement of a more robust response signal leads to a requirement for larger ensembles of simulations starting from different initial conditions. Higher spatial resolution in climate change scenarios can also be achieved through nested regional models, and in the near term, when the magnitude of change is still small, downscaling using relationships determined from current climate statistics is more reliable.

Initialization of CMs is a more significant issue for the near term than the longer term. It is anticipated that using initial conditions that are consistent with the current phase of natural variability of climate system may reduce the spread in ensembles of simulations over the next one or two decades. This is, however, an area of active research and investigation within the CM community.

For both IAV and IAM studies, there is also a near-term focus on regional scales. As the detailed nature of impacts is often specific to different regions, their characteristics need to be considered in close connection with local opportunities for adaptation and reducing vulnerability. Similarly, the capacities for mitigation, and the socioeconomic effects of mitigation policies and technologies, have important regional characteristics.

Near-term IAM and IAV analyses can be matched to standard planning time scales and thus play an important role in integrating climate change considerations into other areas of management and policy. However, in this context it becomes very important that near-term scenarios at the regional scale accurately reflect current trends in socioeconomic factors. When this is achieved, information from local planning processes can be used in bottom-up studies linked to near-term regional-scale scenarios.

Near-term IAM analyses also include transition scenarios that go beyond idealized assumptions about policies and measures and explore opportunities and constraints on mitigation at the scale of countries or regions, taking account of both economic growth and technological and institutional inertia. Such studies also cover different potential international regimes, including incomplete participation in mitigation agreements. These types of analyses are more feasible for the near term than the longer term. In addition, near-term studies are expected to link more closely to traditional economic analyses and can complement those by linking them to the climate change implications of economic policy. This will potentially involve a much larger analytical community, and enable more specific analyses of changes in the distribution of wealth across different economic sectors.

Near-term scenarios also have the potential to explore the implications of changes in air quality occurring more rapidly than changes in climate in response to emission changes.

I.3.2 Need for long-term scenarios (to 2100 and beyond)

Long-term scenarios tend to focus on considering options for the stabilization of anthropogenic influences on climate or the consequences of not doing so. They are often used for comparative analysis of the long-term climate, economic, environmental, and policy implications of different mitigation scenarios or pathways. In addition to the direct response of the climate system to forcing, the role of feedbacks between climate and biogeochemistry, and nonlinearities in the climate system as well as in affected systems, become more important than in the near term. Earth system model (ESM) experiments that will investigate climate–carbon cycle feedbacks are discussed in more detail in Section II and in Hibbard et al. (2007).

Scenarios of different rates and magnitudes of climate change provide a basis for assessing the risk of crossing identifiable thresholds in both physical change and impacts on biological and human systems. Hence, they can also help to identify the damaging impacts avoided at different levels of stabilization. In this context, large ensembles of climate simulations provide key information about uncertainty in projections. There is arguably a lower requirement for high spatial resolution in longer-term climate simulations, particularly as the ability to construct spatially detailed inputs for CMs becomes reduced over time (information about climate variability and weather extremes is still very important in some studies over the long term, however, and in these cases a “time slice” approach in which high resolution models are used to simulate only limited periods in a future climate can be used to render the computational expenses more feasible (Govindasamy et al., 2003). The generation of regional- and subregional-scale climate change scenarios may use different techniques than those used in near-term studies (e.g., with more reliance on high-resolution models and less on statistical downscaling).

Longer-term analyses with IAMs consider options for achieving different stabilization levels, including the possibility of “overshoot” scenarios that stabilize radiative forcing at a specified level but are not constrained never to exceed it. Stabilization and overshoot scenarios can also be complemented with “peak and decline” scenarios that are designed to peak at a maximum level and then decline in forcing. There are still wide spreads in model estimates of the economic costs of achieving particular stabilization levels, and understanding the reasons for such spreads and how they might be narrowed is clearly an ongoing concern. Many analytical questions also remain in this area, such as how to represent technology performance and availability in IAMs.

At the expert meeting, representatives of the policy community expressed a strong interest in very low radiative forcing profiles (e.g., radiative forcing that peaks at around 3 W/m^2 before 2100 and then declines). It is evident that the policy discussion is moving towards increasingly stringent emissions reductions targets, and that policymakers will need information about the implications of these targets for climate change, unavoidable impacts of even low trajectories, and economic and technological pathways for achieving these targets. How best to reflect this interest in the choice of RCPs, which must be drawn from the existing literature that is only beginning to address this issue, was a major topic of discussion at the meeting.

The introduction of overshoot and peak and decline scenarios raises additional questions about the relationship of peak concentrations to their eventual stabilized values, the length of time above stabilization, as well as the climate, biogeochemistry, and ecosystem recovery once concentrations start to decline. While there are characteristics of overshoot scenarios that may reduce short-term economic costs, the potential for irreversible change (e.g., in ecosystems or biodiversity) and uncertain effects of impacts in the longer term are also clearly key considerations. This will require increasing use of analyses of time-dependent impacts.

Because some aspects of the climate system are expected to change slowly (e.g., sea level and ice sheets), it is necessary to consider climate projections extending beyond 2100. Development of socioeconomic scenarios beyond 2100 would be a new endeavor, however, because of pervasive uncertainties. Climate simulations extending to 2300, based on simplified extensions of pre-2100 scenarios, provide important information about long-term change in climate. For example, sea level rise realized by 2100 is only a small fraction of the long-term commitment implied by stabilization of climate forcing at 2100 conditions. Long-term simulations are also necessary to assess the risk that actions taken during the 21st century might set in motion irreversible processes leading to major geophysical changes such as large reductions in the Greenland Ice Sheet.

I.4 Representative Concentration Pathways (RCPs) to support a parallel process

Coordination of new integrated socioeconomic, emissions, and climate scenarios depends critically on the early identification of a set of "Representative Concentration Pathways" (RCPs). As indicated in the IPCC decision (see Box I.1), the main rationale for the identification of RCPs is to expedite the development of integrated scenarios by enabling modeling the response of the climate system to human activities to proceed in parallel to emissions scenario development (see Figure I.1).

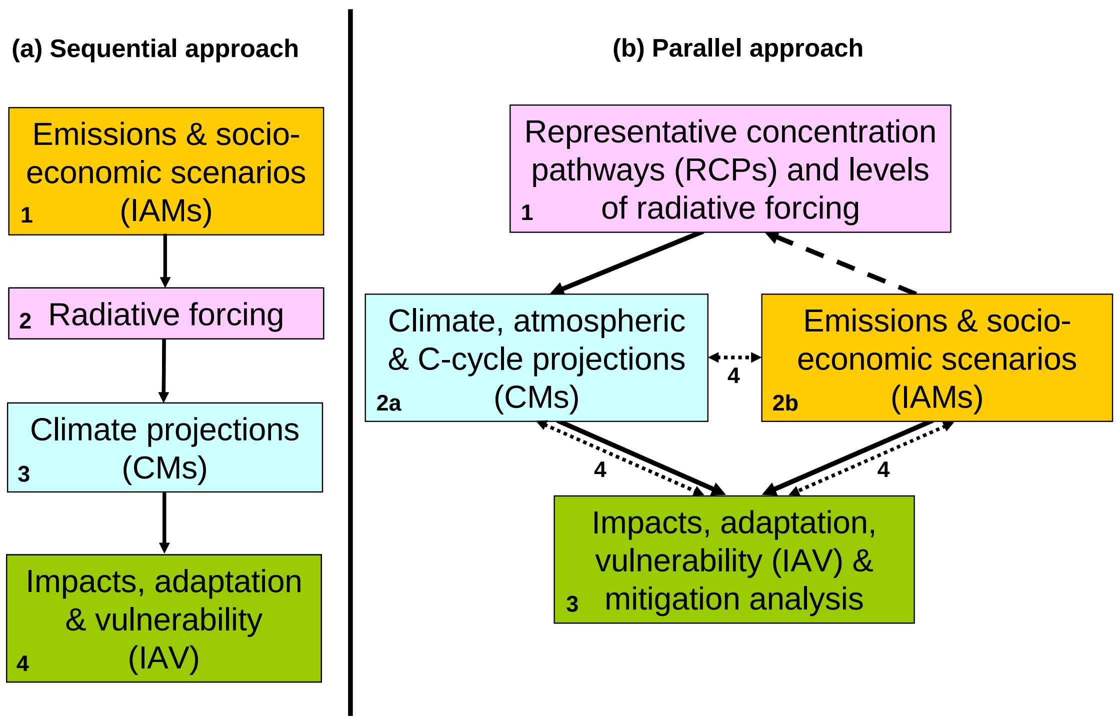


Figure I.1. Approaches to the development of global scenarios: (a) previous *sequential* approach; (b) proposed *parallel* approach. Numbers indicate analytical steps (2a and 2b proceed concurrently). Arrows indicate transfers of information (solid), selection of RCPs (dashed), and integration of information and feedbacks (dotted).

I.4.1 A parallel process for scenario development

Past scenario development has been conducted in a mainly sequential form, with socioeconomic and emissions scenarios developed first and climate change projections based on those scenarios carried out next. Some substantial drawbacks to the sequential approach that IPCC has used in the past have been noted. First, there is a long time lag between developing scenarios, having them approved, using them in CM simulations, and distributing the results to IAV groups, so that the scenarios become out of date long before the related IAV studies are completed. This sequential process slows the integration of information across the three research communities. As a result, it impedes the development of truly integrated scenarios and has limited the possibility for IPCC assessments to be based on a consistent set of scenarios across the three Working Groups. Second, in the sequential approach, the CM simulations are "hard-wired" to the socioeconomic scenarios. When the socioeconomic scenarios are modified, the model simulations have to be run again, even though the changes seldom result in meaningful (i.e., detectable) alterations to the modeled future climates. In addition, if questions are raised about socioeconomic assumptions or methods underlying the emissions scenarios, the debate can speciously reduce the credibility of the CM simulations.

In contrast, the alternative process proposed here, beginning with identification of RCPs, will enable the CM community to proceed with new climate change projections at the same time that new work is carried out in the IAM and IAV communities. The RCPs will serve a limited role as inputs to various classes of CMs. The IAM community will simultaneously develop a range of completely new socioeconomic and emissions scenarios. Production of some new scenarios that are consistent with the RCPs will enable different teams of integrated assessment modelers to explore alternative technological, socioeconomic, and policy futures that are consistent with a given stabilization level, an approach that seems both promising and important given the interest of decisionmakers in exploring how to attain different stabilization levels. Not all of the new scenarios will be developed to be consistent with the RCPs, however. Another feature of this alternative process is that the IAM community has total freedom to develop scenarios across the full range of possibilities. As a result, some new scenarios may fall in between or outside the emissions pathways and radiative forcing levels described by the RCPs. Impacts, adaptation, and vulnerability studies will be carried out as results become available from both the CM and IAM communities. Thus the RCPs will provide some common reference points upon which research in all three communities can build, shortening the time before results can be brought together to produce new, fully integrated scenarios.

This parallel process is an advance from the prior sequential approach for other reasons as well. The approach will allow better use of the expensive and time-consuming simulations carried out by the CM community, as these no longer need to be rerun each time the emissions scenarios are changed. A parallel approach using RCPs partially decouples climate science from the issues of socioeconomics because a given concentration trajectory can result from different socioeconomic projections and IAM model outcomes. In the past, when the socioeconomic scenarios were modified, the model simulations had to be run again, even though the changes seldom resulted in meaningful (i.e., detectable) alterations to the modeled future climates. In the future, updated CMs can be run using the same RCPs, allowing modelers to isolate the effects of changes in the CMs themselves. New forcing scenarios can be used to scale the existing CM simulations using simple models that have been calibrated to give comparable results to the full three-dimensional CMs (this approach has already been used in WGI assessments of global mean temperature and sea level). There would be no need to rerun models for each new scenario. The saving in computing time could be used to generate larger ensembles at higher resolution, hopefully leading to refined simulations of regional change and extreme events, and a more robust representation of uncertainties and/or probabilities. Of course, the use of pattern scaling always yields an approximation to the output that would have been produced by a state-of-the-art climate model had it been run, and the resulting approximation is better for some variables than for others. The savings in cost and time for climate model set up and runs is therefore purchased at the price of approximation.

I.4.2 Explanation of RCP terminology

The name "representative concentration pathways" was chosen to emphasize the rationale behind their use. The IPCC decision (Box I.1) indicates that the RCPs "should be compatible with the full range of stabilization, mitigation and baseline emission scenarios available in the current scientific literature," and that they should include information on a range of factors beyond concentrations and emissions of long-lived greenhouse gases, including emissions of other radiatively active gases and aerosols (and their precursors), land use, and socioeconomic conditions (see Appendix 1 for a detailed description of the data requirements). This information must be sufficient to meet user needs, in particular the data needs for climate modeling.

In order to take into account the effects of emissions of all greenhouse gases and aerosols, the RCPs have been selected based primarily on their emissions and associated concentration outcomes, measured as the net radiative forcing of greenhouse gases and aerosols. The group of four RCPs is intended to be representative of the full range of scenarios currently available, including high reference scenarios, low mitigation scenarios, and intermediate scenarios. The term "benchmark," used in the IPCC decision, was considered less desirable as it implies that a particular scenario has a special status relative to others in the literature, rather than simply being representative of them.

RCPs are referred to as *concentration* pathways in order to emphasize that while they are based on existing scenarios in the literature that have underlying socioeconomic assumptions and emissions outcomes, they are being selected on the basis of their emissions pathways and associated concentrations of radiatively active gases and aerosols, and their primary purpose is to provide these concentration pathways to the CM community to produce new climate change projections. The radiative forcing effects of the various gases and aerosols can be summed to produce a net global forcing pathway for each RCP. This net forcing can be expressed in terms of W/m^2 or as an equivalent CO_2 concentration (that is, the concentration of CO_2 that, by itself, would produce the same forcing as the net effect of all the individual gases and aerosols).

Although each of the individual RCPs is part of an internally consistent and plausible scenario including the underlying socioeconomic assumptions, RCPs are referred to as *pathways*[11] in order to re-emphasize that their primary purpose is to provide time-dependent projections of atmospheric greenhouse gas concentrations. In addition, the term pathway is meant to emphasize that it is not only a specific long-term concentration or radiative forcing outcome, such as a stabilization level, that is of interest, but also the trajectory that is taken over time to reach that outcome.

[11] For the purposes of this report, "pathway" is defined as a time-dependent projection of atmospheric greenhouse gas concentrations that emphasizes the shape of the trajectory that is taken over time to reach a specific long-term concentration or radiative forcing outcome, such as a stabilization level.

I.5 Incorporating perspectives from developing and transition-economy countries

The IPCC's decision on further work on emissions scenarios at its 25th Session (April 2006, Mauritius) requested that the expert meeting consider the enhancement of developing country (DC) participation in the scenario development process. The decision's recommendation underscored the ongoing problem of identifying and involving sufficient expertise from Africa, Asia, Latin America, island states, and from countries with an economy in transition (EIT), principally in Central Europe and the former Soviet Union. It also underscores the importance of developing data, tools, and methods that are appropriate to the needs and capacity of these countries. In response to this decision, the New Scenarios Steering Committee included the enhancement of DC/EIT participation and capacity among its main agenda topics at the September New Scenarios Expert Meeting in Noordwijkerhout, The Netherlands. Interdisciplinary breakout groups focused on development of regional information for both IAV and mitigation analysis that touched on the special needs of developing and EIT countries in these areas.

As Section V of this report discusses in detail, there are several persistent barriers to deeper and broader DC/EIT participation in the scenario process—and more generally in international climate research—that future efforts to increase and sustain DC/EIT participation in climate change assessments must address. Section V also outlines a strategy for fundable opportunities to address barriers. Three areas of particular concern were identified in Noordwijkerhout. Perhaps the most fundamental issue is the need for the expansion of expert and institutional scientific capacity in lower-income DCs, which lag behind both industrialized countries and larger DCs. The variance in current levels of scientific capacity within and among developing regions results in a corresponding variance in capacity for participation in international scenario development efforts and, subsequently, in uneven representation in climate change assessments.

Second, in the cases of DCs with more extensive scientific and modeling capacity, those resources are most often directed toward more pressing short-term energy and environmental problems rather than long-term problems such as climate change. The resulting misalignment between the missions of scientists in industrialized and developing countries can serve as a *de facto* barrier to DC representation in climate change scenarios, even in cases where the level of participation on the part of scientists from DCs may be relatively high. While differences in time horizon and level of analysis present opportunities for downscaling of global models and upscaling of regional/national models, these opportunities have yet to be fully exploited.

Third, there is an ongoing need for more funding and for new funding mechanisms to support the continued participation of DC/EIT representatives in international scientific activities related to climate change. Addressing capacity and funding limitations to enhanced DC/EIT participation will demand concerted outreach and integration initiatives on the part of the broader international research and policy communities. Institutions such as the IPCC trust fund, which supports the participation of DC/EIT scientists in IPCC-sponsored events, are indispensable yet insufficient responses to the need for ongoing financial support. The implementation of ambitious proposals, such as that prepared by the IPCC's TGICA for the expansion of DC/EIT scientific capacity (IPCC/TGICA, 2005), will be needed to sustain adequate levels of capacity and participation in the long term. Section V of this report discusses these and other findings on the question of DC/EIT capacity development and participation and offers a series of recommendations in response to them.

I.6 Key cross-cutting questions

The development of new scenarios integrating the work and perspectives of multiple scientific communities inevitably raises complex and fundamental scientific and institutional questions. Answers to these questions are explored in Section VI of this report, drawing on discussions during the expert meeting.

1. Can new integrated scenarios that meet user needs be produced with the available resources and completed in time for consideration in a possible future IPCC assessment? Since each of the research communities involved in this process faces time and financial resource constraints, a key issue is whether the specified activities and process make effective use of the resources available. This question is of particular concern considering the high costs and computing demands associated with climate model runs. In addition, since the proposed parallel modeling process is untested, its strengths, weaknesses, and potential risks remain unknown.

2. To what extent can concentration pathways be usefully abstracted from underlying emissions and socioeconomic changes? In theory, any individual emissions scenario or concentration pathway is only one of many potential pathways to a particular greenhouse gas concentration level and could be realized by a wide range of combinations of socioeconomic and technological assumptions. But some components of emissions and socioeconomic scenarios, such as the pattern of aerosols and other short-lived species, or land use changes, are very specific to a given IAM or set of assumptions and exert a strong influence over climate, carbon cycling, and other important processes and variables. Thus, it is currently an open question whether the concentration pathways should be abstracted from specific emissions scenarios and the socioeconomic assumptions from which they are derived for the purpose of forcing CM integrations.

3. To what extent can climate changes be scaled between forcing levels? In order to reduce the computational requirements of the scenario development strategy, a limited number of scenarios and hence years of CM integrations are proposed. The strategy assumes that for the purposes of IAV research and policy analysis, patterns of climate change from the selected scenarios can be scaled for intermediate levels of forcing, or for entirely new scenarios. A key question is whether the results of scaling different atmosphere–ocean general circulation model (AOGCM)-derived climate scenarios will be sufficiently comparable to full AOGCM runs designed to achieve similar outcomes. The usefulness of scaled results for IAV and policy analysis also remains an open question as does the possibility of conducting a limited set of AOGCM simulations (without full carbon cycle coupling) for intermediate levels of forcing.

4. What information can be provided in the form of downscaled climate and socioeconomic information for use by the IAV community? Information at scales finer than the current set of global models (both CMs and IAMs) have produced will be required for improved analyses of IAV at regional and subregional scales. The interpretation of global or large-region socioeconomic and technological scenarios for the purposes of local quantification and application may require the development of regional narrative storylines that are consistent with the global picture but are also relevant to local conditions and concerns. Moreover, no globally comprehensive intercomparison process currently exists for producing climate and other environmental change information at regional scales. The research and user communities must still specify the needs, uses, and limits of available techniques, and the priorities for downscaling given currently limited resources.

5. How can disaggregated analyses of mitigation opportunities at the scales of large countries (e.g., China, India, and the United States) or regions (e.g., European Union) be undertaken in a way that can be related to more highly aggregated global scenario studies using IAMs? This question relates to improved incorporation of higher resolution information about the current energy infrastructure, economic conditions, and policy environments of specific countries, and to the need to place such studies in the broader context of global economic, technology, energy, and policy trends. These analyses will be particularly important in light of the need to accelerate mitigation efforts, since current actual emissions trajectories exceed the reference case assumptions of scenarios produced even just a few years ago.

6. How can the proposed scenario process be strengthened to evaluate key dimensions of uncertainty (e.g., in our understanding of key natural processes or socioeconomic futures)? The design seeks to address uncertainty about future forcing and climate change by studying the implications of low and high levels of forcing, and establishes an open process for the assessment of many policy, economic, and technological futures to achieve those levels. It also seeks to facilitate application of different types of probabilistic analysis. Can approaches to analysis of uncertainty using scenarios be improved further? Are there other opportunities for analysis of uncertainty that should be included?

I.7 Overview of the report

This report outlines a framework for moving forward with new scenario development. Section II describes a new parallel scenario development process. Section III focuses on the RCPs, how they will be prepared, and how they will subsequently be used throughout the broad user communities in the years ahead. Institutional and coordination issues are addressed in Section IV along with a list of proposed next steps for the various communities. Section V provides a discussion of the need for DC/EIT participation, and outlines a series of fundable opportunities at the regional scale that will ensure a new level of balance. Finally, Section VI provides some preliminary reflections on answers to the key cross-cutting questions identified above.

II. An Overview of Integrated Scenario Development, Application, and Synthesis

II.1 Overview

This section provides an overview of activities that will facilitate the development of scenarios and their timely application ahead of a possible AR5. That work involves three research communities: the IAM community, the CM community, and the IAV community. The process focuses on developing scenarios for use in a possible AR5. Scenario development is only one component of research that would be assessed in an AR5. Other research activities, while important, lie beyond the scope of this report and are mentioned only to the extent that they bear on scenario development.

The planned scenario development exercise comprises three phases: a preparatory phase and two main phases of scenario development—a parallel phase for modeling and developing new scenarios and an integration, dissemination, and application phase. This section introduces the phases of the process.

The brief descriptions provided here are intended to give readers an overview of activities currently expected to occur over the coming years leading up to a possible AR5. Five principal scenario products are anticipated to be developed in the years leading up to the publication of a possible AR5:

1. Representative concentration pathways (RCPs) and their associated emissions, produced by IAM teams and taken from the existing literature, discussed in Section III and anticipated to be completed by the fall of 2008;
2. Ensemble climate projections and pattern scaling anticipated to be available in the fall of 2010; these scenarios will be used for pattern scaling;
3. New scenarios developed by the IAM community anticipated to be available in the fall of 2010;
4. Global narrative storylines developed by the IAM and IAV communities anticipated to be available in the fall of 2010; and
5. Integrated new IAM scenarios consistent with the storylines with associated pattern-scaled climate scenarios anticipated to be available in spring 2012.

The IAV community will use all of these products as inputs for research, including both the scenarios of changes in climate and the scenarios of changes in socioeconomic conditions that could affect impacts and responses. Product 5, as will be discussed later, will be developed as a collaboration between the IAM and IAV communities.

Table II.1 provides an overview of the principal scenario development activities that are anticipated to precede a possible AR5 and associated timetables. Products 2, 3, and 4 will be produced in parallel as described in Section I and illustrated in Figure I.1. Figure II.1 depicts the anticipated timeline for generating these five products and Figure II.2 shows interactions across research communities.

Table II.1. *Overview of scenario development activities*

Product	Phase	Time to Produce	Short Description
Product 1: Representative Concentration Pathways (RCPs)	Preparatory Phase	12 months	Four RCPs will be produced from IAM pathways available in the published literature: one higher RCP in which radiative forcing reaches ~8.5 W/m^2 by 2100 and continues to rise for some amount of time;[1] and two "intermediate pathways" in which radiative forcing is stabilized at approximately 6 W/m^2 and 4.5 W/m^2 after 2100, and one lower RCP in which radiative forcing peaks at approximately 3 W/m^2 before 2100 and then declines. These scenarios will include time paths for emissions and concentrations of the full suite of greenhouse gases, aerosols, and chemically active gases, as well as land use/land cover (see Table A1.1).
Product 2: RCP-based Climate Model Ensembles and Pattern Scaling	Parallel Phase	<24 months	Ensembles of gridded, time-dependent projections of climate change produced by multiple CMs including AOGCMs, ESMs, Earth system models of intermediate complexity, and regional climate models for the four long-term RCPs, and high-resolution, near-term projections to 2035 (for the 4.5 W/m^2 stabilization scenario only). The long-term scenarios are expected to be run at approximately 2° resolution, while the near-term scenarios may have higher (0.5° to 1°) resolution. These projections can be scaled upward or downward according to the ratio of simulated global mean temperature for the RCP and the temperature change defined in simple CMs forced with different scenarios. Section III describes CM priorities and constraints for long-term scenarios.
Product 3: New IAM Scenarios	Parallel Phase	24 months	New scenarios developed by the IAM research community in consultation with the IAV research community that explore a wide range of dimensions associated with anthropogenic climate forcing. Anticipated outputs include alternative socioeconomic backgrounds, alternative technology availability regimes, alternative realizations of Earth system science research, alternative stabilization scenarios including both traditional "not-to-exceed" scenarios and "overshoot" scenarios, and alternative representations of regionally heterogeneous mitigation policies and measures, as well as local and regional societies, economies, and policies.
Product 4: Global Narrative Storylines	Parallel Phase	24 months	Detailed descriptions associated with the four RCPs produced in the preparatory phase and those scenarios developed by the IAM and IAV communities as part of Product 3. These global and large-region storylines should be able to inform IAV and other researchers. New narrative storylines will also be developed as new reference scenarios emerge within Product 3, potentially extending narrative storyline development into the integration phase. Regional storyline development will also continue beyond 24 months. Narrative storyline development will be a joint undertaking employing researchers from both the IAM and IAV communities.
Product 5: Integrated Scenarios	Integration Phase	18 months	RCP-based climate model ensembles and pattern scaling (Product 2) will be associated with combinations of new IAM scenario pathways (Product 3) to create combinations of ensembles. These scenarios will be available for use in new IAV assessments. In addition, IAM research will begin to incorporate IAV results, models, and feedbacks to produce comprehensively synthesized reference, climate change, and IAM results

Notes:
[1] As discussed in Section III, this reference pathway is not common to the other (stabilization) pathways. Each of these will be derived from its own reference pathway.

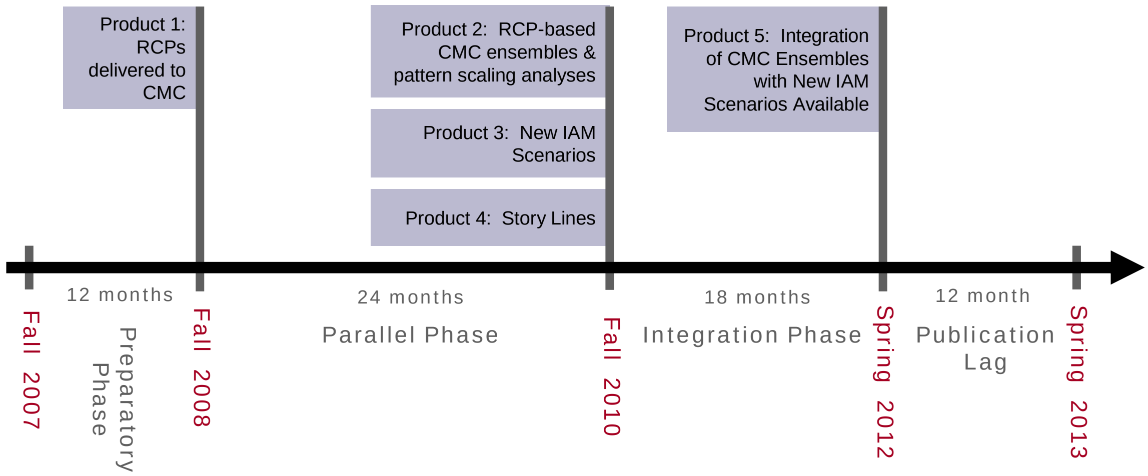


Figure II.1. Timeline of key scenario development products (CMC = climate modeling community).

The approach taken here contrasts with the earlier "sequential" approach to the development of scenario-based research as discussed in Section I (see Figure I.1). The "sequential" approach required that emissions scenarios be completed prior to their use in the development of climate scenarios, which in turn required the completion of climate modeling before work on IAV could begin. The three-phase "parallel" approach described in this section is designed to accelerate the process by which a consistent set of research results from IAM researchers, climate modelers, and IAV researchers becomes available. The following sections elaborate the scenario-related research activities and research products that might be anticipated leading up to the publication of a potential AR5.

As with all multi-year research plans, this plan is subject to review and revision throughout the process.

II.2 The Preparatory Phase—The First 12 Months

The preparatory phase is the first of three phases in the scenario development process. The principal product of the preparatory phase will be four RCPs. As discussed in Section II.3, these four RCPs are the first of potentially many scenarios that will be available for assessment in a potential AR5. They will also be the first of potentially many scenarios that will be available to be paired with the output of CMs to produce complete scenarios encompassing socioeconomic conditions; human activities (including land use) generating emissions and land cover change; concentrations of greenhouse gases (GHGs) and short-lived species (SLS); and climate, sea level, and other Earth system change.

The RCPs are scenarios of anthropogenic forcing, and will be based on scenarios found in the published literature. The primary purpose of the RCPs is providing data on forcing to the CM community that can be used to generate decadal- and centennial-scale climate projections. The RCPs provide vectors of geographically disaggregated, gridded emissions and concentrations of GHGs, and SLS, as well as land use/land cover extending from the present to 2300. These data are useful to a range of CMs including AOGCMs, ESMs, Earth system models of intermediate complexity (EMICs), and regional climate models (RCMs). Socioeconomic data (regionally disaggregated demographic and economic data) will be provided by the RCPs as well, but uncertainties in socioeconomic projections and their implications are research questions that will be explored in the parallel phase, described in Section II.3.

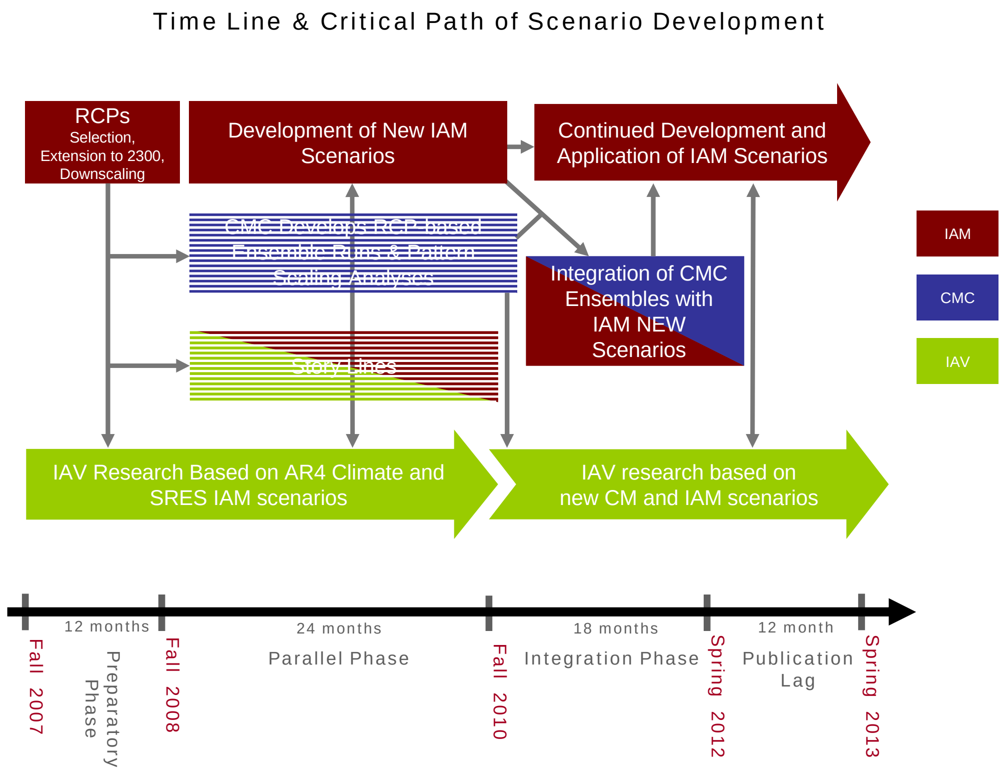


Figure II.2. Some of the major scenario-related activities across the IAV, IAM, and climate modeling (CMC) research communities and the relationships among them, showing the preparatory phase and two subsequent phases. The boundaries between these phases are not precisely defined, although near-term deadlines, such as the fall 2008 deadline for availability of RCPs, are relatively more precise. The preparatory phase will produce four RCPs based on quantitative socioeconomic scenarios of forcings taken from the peer-reviewed literature. In the parallel phase, three activities proceed concurrently. First, CMs employ the RCPs and associated emissions to develop scenarios of changes in the atmosphere, climate, and related conditions (e.g., ocean acidity or sea level rise) over two time horizons: near term (to 2035) and long term (to 2300). The long-term scenarios are expected to be run at approximately 2° resolution, while the near-term scenarios may have higher (0.5° to 1°) resolution. Second, the IAM research community begins developing a new suite of scenarios that revisit reference, stabilization, technology, and policy issues to create a "library" of new scenarios. Third, the IAM and IAV research communities work to develop "global narrative storylines" that can be used by IAV researchers in conjunction with the new scenarios including the RCPs. In the integration phase, new ensemble climate scenarios developed during the parallel phase will be integrated with the parallel phase IAM emissions and socioeconomic scenarios as an input to new IAV studies. To ensure appropriate pairing of CM outputs with new socioeconomic scenarios, interpolation and pattern scaling of CM results will also be undertaken. Results will be compiled in a proposed IAV research archive that will facilitate intercomparison and synthesis of results. In the integration phase, IAM researchers will begin the process of integrating IAV research tools directly into IAMs, and IAV researchers will increase the integration of scenarios into their analyses. The goal is to produce internally consistent representations of human activities conducted within the context of changing climate, oceans, and ecosystems. Similarly, climate modelers will also incorporate insights from IAM and IAV research into a new generation of ESMs, to provide a more realistic representation of the effects of human drivers on the physical and biogeochemical systems being modeled. A lag between final results and their publication is also accounted for. (SRES = Special Report on Emissions Scenarios.)

The RCPs will be produced by IAMs to satisfy the data requirements of the CM community and respond to the IPCC's request for "benchmark scenarios" from the research community. Each RCP will be created by a single modeling team based on a previously published emissions scenario. The RCPs will not share a single reference scenario; rather, each RCP will have its own reference scenario that is not part of the RCP set for development of new CM simulations.

Development of the RCPs entails a number of challenges that are the focus of current research across the IAM community. Progressing from AOGCMs to ESMs introduces new input demands on the IAM community and new requirements for modeling teams to coordinate the treatment of the carbon cycle, land use, and atmospheric chemistry. The set of data provided with each RCP will need to be extended from SLS, gaseous, and aerosol emissions to include land use/land cover change. Much of those data need to be provided at a fine spatial (and temporal for the near-term scenario) resolution. The long-term scenarios are expected to be run at approximately 2° resolution, while the near-term scenarios may have higher (0.5° to 1°) resolution. Another important challenge is to extend the RCPs from 2100, the typical end-point for much IAM scenario modeling, to the year 2300. Given the large socioeconomic uncertainties at this time scale, a variety of stylized approaches for producing emissions and concentrations data for CMs is under discussion. (See Appendix 1, section A.4 for additional discussion of the extension to 2300.) Another important early step in the process will be the development of data reporting standards by the IAM community in conjunction with the CM and IAV communities.

The IAM community will produce the required data for CM groups. A careful review and cross-check of the data by participating IAM and CM groups will be included as part of the process. All data associated with the RCPs will be made available to those interested in using them.

To help coordinate this work across the IAM teams and between them and other communities involved in global change research, an Integrated Assessment Modeling Consortium (IAMC) has been formed.[1]

II.3 The Parallel Phase—The Middle 24 Months

Following the delivery of the RCPs to the CM and IAV communities, three activities will proceed concurrently during the parallel phase, which consists of the following:

- Product 2: Development by climate modelers of ensembles of near-term (to 2035) and long-term (to 2300) RCP-based climate scenarios;
- Product 3: Development of new demographic, socio-economic, technological, land use/land cover and emissions scenarios for the 21st century and beyond by the IAM community in consultation with the IAV community; and
- Product 4: Development of global “narrative storylines.”

II.3.1 Product 2: The Parallel Process—RCP-based Climate Scenarios

Climate modelers will, as computational and human resources allow, evaluate as many of the RCPs as feasible. Some groups will also examine decadal processes in detail to 2035 using a mid-range (e.g., 4.5 W/m^2) stabilization scenario.

[1] The IAMC was established in November 2006. So far, 37 groups have joined the consortium. See Section IV of the report for further information.

These ensembles of long-term and near-term CM simulation outputs, in combination with the RCPs' associated socioeconomic elements and the storylines, described in Section II.3.3, will be made available to the IAM and IAV communities through scenario providers.

II.3.2 Product 3: The Parallel Process—New IAM Scenarios

IAM groups will prepare new scenarios intended to serve several purposes simultaneously, including laying down the foundations for the next generation of analyses of forces that drive anthropogenic climate forcing, shedding light on the global and regional implications of stabilization and regimes focused on emissions mitigation, and providing foundations for the next generation of IAV research.

Scenarios will be developed to shed light on a broad array of key scenario uncertainties. These include, but are not limited to the following issues:

- *Reference scenarios* that explore alternative demographic, socioeconomic, land use, and technology scenario backgrounds;
- *Stabilization scenarios* that explore alternative stabilization levels, including scenarios that explore the traditional "not to exceed" paradigm and the "overshoot" paradigm;
- *Technology scenarios* that explore the effect of technology and mechanisms of technological change on the profiles of reference and stabilization scenarios;
- *Climate science scenarios* that explore alternative realizations of scientific uncertainty in key scientific processes such as the terrestrial carbon cycle, the ocean carbon cycle, and the atmospheric chemistry of aerosols;
- *Heterogeneous regional and local emissions mitigation regimes* that examine the implications of alternative local, regional, and international institutional regimes and the application of alternative emissions mitigation policy tools for stabilization including regimes that are less than perfectly efficient; and
- *Regional scenarios* that employ regional models to explore key uncertainties associated with human contributions to radiative forcing. Regional modeling teams will have IAM scenario results available for external reference input data. It is important to encourage participation by developing region modeling teams as well as developed country modelers.

The process by which new scenarios will be produced and the nature of coordination across IAM research teams is not specified here. Such terms of reference remain to be worked out by the IAM research community as it develops its community research agenda in consultation with the IAV research community.

While details remain to be determined, the process is intended to be open. Participation will have conditions, but in general those conditions are not anticipated to be as restrictive as for the development of the RCPs. It is anticipated that both global and regional modeling teams will participate in the development of new scenarios. Researchers from developing nations will be particularly encouraged.

Most new IAM scenarios will not have any relationship to the RCPs, given that an RCP is only one scenario created by a single modeling team. However, some of the new IAM scenarios may be developed to approximate the concentration pathway of an RCP. This will facilitate exploration of alternative socioeconomic/technological/policy pathways for achieving different stabilization targets and may prove to be particularly useful for exploring conditions under which stabilization at very low levels could be achieved.

Scenarios, including the RCPs, will be archived in a "library" to facilitate use by other research communities. The library will provide data quality checking, standardize scenario data, and create a central point of contact for scenario users.

To be useful to the IAV community, new scenarios will need to be consistent with IAV research regarding socioeconomic change and address several important issues including methodologies to provide downscaled and multi-century IAM scenarios. The development of methodologies to downscale and extend scenarios in time will be the subject of research throughout the preparatory and parallel phases.

II.3.3 Product 4: The Parallel Process—Global Narrative Storylines

The new scenarios to be developed by the IAM community, as well as the scenarios underpinning the RCPs used to drive the CMs, are quantitative, time-dependent global-scale scenarios (see Section II.3.1). These global scenarios are sometimes referred to as "top-down" approaches because they start from global assumptions about economic, technological, and political conditions. They can only provide limited regional- or local-scale information that is often crucial for IAV researchers, however, and thus it is necessary to develop approaches that link the global scenarios to regional/local trends and to assure that top-down perspectives are consistent with bottom-up perspectives. Qualitative, narrative descriptions, often referred to as "storylines,"[2] provide an explanation of the conditions and relationships among key driving forces and their evolution over time that underlie the quantitative scenario. The storyline explains the relationships among different trends and developments assumed in the scenario, for example why rates of economic and demographic change are high or low, why labor productivity increases rapidly in one region while lagging in another, or why local air pollutant emissions increase or decrease over time. The storylines can be used with quantitative scenario information to infer additional, more detailed but nonetheless consistent, representation of local and regional conditions necessary for IAV analyses of vulnerabilities, impacts, and adaptation potentials.

The IAV research community is not necessarily focused on scenario-based projections of climate change. Vulnerabilities are not always very sensitive to differences in quantitative projections. As the integration process evolves, however, uses of scenarios by the IAV community should increase. On the other hand, the IAV community cannot evaluate an unlimited number of scenarios. While the RCPs represent a small, finite number of scenarios,[3] the new scenarios produced as part of Product 3 will constitute an impractically large number of pathways. At the end of the parallel phase, the IAV community will be able to draw on a set of CM projections for each of the four RCP forcings, as well as a multitude of alternative socioeconomic futures from the new IAM runs, four of which will be based on the RCPs themselves. As well as facing problems of matching new socioeconomic scenarios

[2] For the purposes of this report, "storyline" is defined as a narrative description of a scenario (or a family of scenarios) that highlights the scenario's main characteristics, relationships between key driving forces, and the dynamics of the scenarios (IPCC, 2007b).

[3] At present, no set of "storylines" is available for the RCPs, to say nothing of the yet to be created new scenarios. It is therefore not even clear whether, setting aside differences in the limits that define stabilization pathway goals, the four RCPs spring from four different "storylines" or from one, two, or three different storylines.

that are not based on the RCPs to climate projections (e.g., through scaling methods), IAV researchers will need to have a means of establishing priorities for the scenarios to be evaluated. An important element of new work that the IAM and IAV research communities must tackle together is the number, nature, and priority of storylines to be prepared for use in anticipation of a potential AR5.

During the parallel process phase, researchers from the IAM and IAV communities will document the storyline descriptions, and attempt to classify these according to criteria that are of interest to potential users of the scenarios. For example, it may be useful for IAV analysts to explore a range of assumptions about future socioeconomic conditions (such as the level and dispersal of income, population size and structure, types of governance, the strength of institutions, and technological development), because these will be important in conditioning future regional vulnerability to a changing climate. The storylines to be classified during this phase (Product 4) will all be global in scope, though many will also be broken down into regional-scale narratives. They should cover the full range of new scenarios in the database, including the limited cases of the four RCPs. Methods of classifying the storylines remain to be discussed and agreed between the different research communities.

A storyline classification of this kind could offer important information for potential users of scenarios, as it can help to distinguish different sources of uncertainty in future outcomes. For example, it is well known that a wide array of combinations of regional demographic, economic, institutional, and technological assumptions can produce a given radiative forcing on a given date. One need look no further than any Monte Carlo emissions uncertainty analysis to see that, even within the confines of a single mathematical modeling framework, a multiplicity of “reasonable” input assumption bundles can produce the same level of emissions or concentrations. Conversely, similar underlying assumptions about future socioeconomic conditions described in storylines can be associated with quite different emissions or concentration levels, for instance if radically different energy technologies or contrasting land uses are assumed.

As noted above, the development of global storylines and scenarios is sometimes referred to as a “top-down” approach, but there are alternative approaches to scenario development. Many regional studies of vulnerability to climate change may use completely different sources of information than the top-down models, framing future climate in the context of present-day and past climate variability, and making assumptions about future developments based on national and regional plans, local knowledge, and practical experience (“bottom-up” approaches) from both governments and businesses. Impacts, adaptation, vulnerability, and mitigation researchers working at the regional scale are commonly faced with the challenge of reconciling top-down scenarios developed from global models with quite different, and often inconsistent, bottom-up scenarios developed locally. A major challenge of the scenario development process will be to address these scale issues.

One approach is to develop regional narrative storylines that are consistent with the global storylines but also account for regional characteristics and processes. The advantage of developing regional storylines is that these can subsequently be used for quantifying regional scenarios that would not otherwise be available (or sufficiently reliable) from global scenarios based on IAMs. A crucial element of such exercises is stakeholder participation, which is required to ensure that regional scenarios and storylines are both credible and relevant for local needs.

Two breakout groups at the expert meeting that focused on regional issues relating to IAV and mitigation analysis both identified a need for the research community to build a link between global top-down and regional bottom-up analyses. Storyline development at the national and regional level is expected to proceed throughout the parallel process and integration phases of scenario development (see Figure II.1). Workshops were suggested in the breakout groups for pursuing the issue of storyline development (see Section IV.6). Work of this kind is regarded as essential for enhancing the relevance and credibility of scenarios applied in climate-change related research at the regional scale.

II.3.4 Other activities during the Parallel Process

Impacts, assessment, and vulnerability groups and groups studying regional and local emissions mitigation need to prepare to apply the scenarios produced during the parallel phase in a new set of impact assessments. This could involve establishing a steering committee for coordination, beginning to prepare storylines, and planning for distribution of integrated scenarios to interested users. Members of the IAV community will work with IAM results from the IAM library to identify detailed demographic, socioeconomic, technology, and related scenarios that have been associated with the forcing levels for the various RCPs. Since integrated scenarios using the CM and IAM results will be created for use in IAV studies during the integration phase (see Section II.4), it will be crucial for IAV groups to interact with both the climate modelers and IAM groups during this phase to ensure that the information being developed meets data requirements for future IAV research and assessment (see Section IV).

II.4 The Integration Phase—18 Months

At the conclusion of the parallel process, new IAM scenarios and new CM ensembles (based on the four RCPs) will be available to be assessed and for the IAV community to use as the foundation of new work. Because the new IAM scenarios will go beyond the limits of the four RCPs in exploring both reference and stabilization scenarios, it is desirable to find a way to employ the CM community's ensemble projections with the new scenarios without the time delay of asking the community for yet another round of CM runs.

Simple models of the climate system can produce estimates of radiative forcing from the concentration of GHGs and SLS. However, moving from radiative forcing to regional climate change, including time-dependent temperature and precipitation change, and all of the other weather statistics that define climate, requires CMs.

An innovative approach has been proposed to accelerate the process of "marrying" the RCP-based CM ensembles with the new IAM scenarios. This approach employs a technique called "pattern scaling." Pattern scaling assumes that within limits, the regional pattern of change in some variables (e.g., temperature) can be tuned to correspond with a higher or lower level of forcing than the one used in the original simulation. Thus, if simple CMs can be used to define the global mean temperature response to a given radiative forcing, the pattern of climate changes produced by AOGCMs or ESMs for the RCP giving the closest radiative forcing to the target can be scaled linearly upward or downward according to the ratio of the simulated global mean temperature change for the RCP and the temperature change defined in the simple CM for the target radiative forcing—"pattern scaling."[4]

[4] For a longer discussion of pattern-scaling see IPCC/TGICA (2007, p. 44). See also Mitchell, et al. (1999), Mitchell (2003), and Ruosteenoja et al. (2007).

There is no substitute for having climate model output that corresponds to a particular emissions–land cover scenario. Pattern scaling is a "second-best" approach that approximates the expected spatial pattern of regional climate under a given scenario of forcing using available CM information. Inevitably, there will be limits to pattern scaling. Transient responses to forcing can be problematic for scaling (e.g., due to differential regional responses to stabilization of atmospheric forcing, to local ice dynamics, and to regional land use change). Some climate variables cannot readily be scaled (e.g., frost days). The applicability of pattern scaling requires further investigation by the CM community, and the findings of this research will need to be communicated rapidly to potential users in the IAM and IAV communities.

Integrated assessment models include simple models that can produce emissions and concentrations of GHGs and SLS, radiative forcing, and global mean surface temperature change. They would therefore be amenable to the application of pattern-scaling techniques to derive regional climate change for a given IAM emissions/concentration pathway. Of course, the individual IAM emissions/concentration pathway would be associated with a unique "pattern scaling" associated with a particular CM. Thus, each new IAM emissions/concentration pathway could be associated with as many regionally disaggregated climate change projections as there are CMs represented in the ensemble set.

As noted above, pattern scaling only approximates the behavior of a particular CM, and it is not clear that all climate statistics (e.g., extreme events) scale to the same degree.

An important research challenge will be incorporating the terrestrial ecosystem and carbon cycle feedback processes in the IAMs in a way that is consistent with the climate scenarios. Incorporation of the processes, as opposed to the results themselves, will allow the new IAM scenarios developed during the parallel phase to capture the essential behavior of this generation of CMs. Similarly important will be the challenge of representing other climate feedbacks such as how changes in land cover alter albedo.

As noted in the discussion of storylines, the process of developing new IAM-based scenarios will generate a large number of new scenarios. Each CM participating in the production of RCP-based climate scenarios represents a source of a climate change scenario that could potentially be associated with each new IAM scenario. The number of combinations of IAM scenarios with alternative pattern-scaled CM approximations will be very large indeed. If we refer to each combination of IAM scenario with a particular alternative pattern-scaled CM approximation as an integrated scenario, then an important item of business will be to establish some priority order in the IAV community for examining new integrated scenarios, while still being able to represent CM uncertainties based on the widest range of ensemble results.

During the integration phase, the CM community will continue to conduct research. One element of scenario-related research will be continuing the standard RCP-forced simulations as well as downscaling AOGCM outputs using RCMs and statistical downscaling methods, perhaps including probabilistic representations of ensemble results.

Several issues are likely to arise that will require additional research. These include downscaling from standard output to the local scale for both the IAM and CM outputs and integrating important new developments in climate modeling that may not scale in the same way that temperature and precipitation scale (e.g., sea ice, climate–ecosystem–aerosol feedback interactions, and climate–ecosystem–terrestrial carbon cycle–albedo feedback interactions).

The availability of climate scenarios that are consistent with the new IAM scenarios, developed during the parallel phase, creates an opportunity for IAV researchers to access a far richer set of scenarios than are captured in the four RCPs. During the integration phase, a new set of IAV assessments will be undertaken and it has been suggested that an archive or repository of IAV studies and results will be established. This would enable IAV groups to begin to share results with one another and with interested modeling teams in the IAM and CM communities. Close communication with the IAM research community will lay the groundwork for incorporating feedbacks into IAM and CM research.

One problem with the traditional linear approach that starts with socioeconomics, moves to emissions and concentrations of GHGs and SLS, then to climate change, and finally supports IAV research is that there is no guarantee that the human activities described in the emissions/concentration pathways are consistent with the climate change or human adaptation to climate change. This is a particular problem with regard to land use/land cover change. For example, will the bioenergy assumed to be grown as part of a stabilization scenario be as productive under a changing climate as would otherwise be assumed? Will the land assumed to be available for the production of bioenergy be available if crops are adversely affected by the climate change and food becomes a priority?[5]

The IAM research community is moving toward the development of models that will allow fully internally consistent scenarios that include socioeconomics, emissions and emissions mitigation and its cost, climate change, climate change impacts, and adaptation to climate change. Accomplishing this goal requires collaboration between the IAM and IAV research communities. Promoting integrated analysis of vulnerability, impacts, adaptation, and mitigation at local and regional scales will also help address this goal.

An important activity during the integration phase is archiving and distributing data to potential users. The integration phase begins with the availability of ensemble scenarios of long- and near-term CM simulation outputs to the IAV and IAM communities through scenario providers such as the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the IPCC Data Distribution Centre (DDC). Discussions are underway for a future distributed data system that would be internationally coordinated for the IPCC through such organizations as PCMDI, the National Center for Atmospheric Research (NCAR), the Max Planck Institute, (MPI), the British Atmospheric Data Centre (BADC), and the Geophysical Fluid Dynamics Laboratory (GFDL). In addition, an important role will be played by the TGICA, which is responsible within IPCC for data and scenario dissemination and which currently distributes both climate data and limited amounts/types of socioeconomic data through the IPCC DDC.

As in the other phases, an important challenge will be the inclusion of researchers from DC/EIT countries in the process. Dissemination of information at the regional scale, especially to DC/EIT research efforts, will require some sort of organizational framework along the lines of the TGICA.

[5] The present state-of-the-art assumes that bioenergy fuels grow in an unchanged climate. Similarly, the present state-of-the-art assumes that buildings' energy demands are not affected by climate. The proposal here is to link climate, energy, and other human activities and make them consistent with adaptation. Studies of adaptation presently allocate no land to the production of bioenergy fuels, yet in many mitigation scenarios bioenergy is the largest single human land use.

II.5 Publication Lag—12 Months

There is a time lag between the completion of research and its documentation and publication. Thus, while publication will proceed throughout the years leading up to a potential AR5, some time needs to be budgeted at the end of the process to accommodate those research products that emerge at the latest date. That time lag is about one year. The lag is presently unavoidable and should be incorporated in planning.

Under IPCC rules, material referenced in an assessment report must be published or otherwise made available to reviewers during the expert and government review periods. In practice, this means that draft versions of papers need to be available at the time of the first expert review, and final accepted versions at the time of the second expert and government review.

This is also likely to be the period during which initial plans for the next generation of research will begin.

III. Representative Concentration Pathways (RCPs)

This section describes the process by which RCPs were identified from the literature. The selection process began by defining the characteristics considered desirable by the research and user communities for RCPs. A set of criteria for identifying candidate RCPs was developed based on these characteristics, consideration of the scenarios literature, and specific requirements for providing data to CMs. The IAMC used these criteria to develop a list of candidates. The specific model runs for the RCPs were selected from the candidates. Each of these model runs comes from a different IAM and includes the concentration and radiative forcing pathways and corresponding emissions and land use pathways required by the CMs.

The proposed RCP selection process, criteria, and recommendation were presented, vetted, and finalized at the expert meeting in Noordwijkerhout. This section summarizes the process and outcomes. It describes the desirable characteristics of RCPs (Section III.1); the process for identifying the specific RCPs, including the selection criteria, RCP candidates, and the identified RCPs (Section III.2); and finally provides perspective and guidance in terms of the intended uses and limits of the RCPs, and their place in and representativeness of the scenarios literature (Section III.3). Appendix 1 provides specific details on the data requirements for RCPs.

III.1 Desirable characteristics of RCPs

This step identified preferences of the research and user communities regarding the general features of the RCPs. The desirable characteristics identified are grouped under the following headings: range, number, separation and shape, robustness, comprehensiveness, and near-term resolution.

III.1.1 Range

The IPCC, reflecting the interests of policy users, requested that the RCPs "should be compatible with the full range of stabilization, mitigation, and baseline emissions scenarios available in the current scientific literature" (see Box I.1). The research and user communities have also expressed a clear interest in a set of concentration and radiative forcing pathways that spans from a high pathway to a low pathway and facilitates research on and insights into potential futures between the high and low pathways, as well as the uncertainties in the high and low pathways themselves. The lowest radiative forcing pathways available in the literature peak and then decline. Participants at the expert meeting expressed an interest in the peak and decline shape of these pathways, as well as their low radiative forcing levels.

A high pathway would allow the CM community to explore climate system dynamics at high radiative forcing levels, and allow the IAV community to explore high-impact scenarios (and associated adaptation strategies and possible limits to adaptation). A low forcing/concentration pathway is useful to provide insight into the climate change and impacts resulting from pathways consistent with the lowest forcing scenarios currently in the literature. Intermediate-level pathways are useful to explore how climate responses to radiative forcing, as well as physical responses such as changes in ice sheets, scale between different forcing levels and what the impacts might be at these levels. Understanding whether climate response scales linearly between different pathways will be essential for the use of CM information by the IAV and IAM communities, which will explore scenarios with outcomes that differ from the RCPs.

III.1.2 Number

The research and user communities concluded that, ideally, the preferred number of RCPs is four, although it is unlikely that many CM groups will be able to carry out simulations for all RCPs. This preference is based on the desire that the number be even, that it be greater than two (to allow for intermediate pathways in addition to a high and low), and that it be small. An even number avoids the natural inclination to select the intermediate case as the "best estimate"; the same rationale was applied to the Special Report on Emissions Scenarios (SRES) scenarios. Intermediate pathways (in addition to a high and low) will facilitate exploration of nonlinearities in the interpolation of CM results between climate scenarios, results that will be important to the IAM and IAV communities.

The number must be small due to the computational demands of the climate modeling associated with each RCP. For the RCPs, the CMs will incorporate increased spatial resolution and, in the case of ESMs, incorporate land use, dynamic carbon cycles, aerosols, and atmospheric chemistry. Defining the ranges of uncertainty for each RCP will require large ensembles of these simulations. Because of the computational demands, the CM community has also prioritized the four RCPs so that those groups not able to carry out simulations for all four pathways will focus on those considered highest priority (see section III.2.2).

III.1.3 Separation and shape

The interpretation of AOGCM runs is most effective when the climate change signal to be detected is large compared to the noise of inherent climate variability. For climate change outcomes to be statistically distinguishable by models, the radiative forcing pathways should be well separated by the end of the 21st century and/or have distinctive shapes. Clearly distinguishable climate change outcomes will facilitate research associating impacts with particular ranges of climate change and assessments of the costs and benefits of avoided impacts. Needs for exploring the implications of smaller differences in radiative forcing can be met more efficiently by interpolating between a set of well-separated CM simulations, or by utilizing existing intermediate forcing level CM runs, as opposed to producing new simulations for intermediate paths.

III.1.4 Robustness

Given the substantial resource requirements associated with running CMs, it is prudent that the RCPs and the scenarios on which they are based be considered robust by the scientific community. In this context, robustness means that a scenario is technically sound in that it employs sound assumptions, logic, and associated calculations; and, its level of radiative forcing over time could be independently replicated by other models, which represent other sets of assumptions,[1] with scenarios that are considered to be technically sound. In general, scientifically peer reviewed publication is considered to

[1] Assumptions can vary across models in terms of, among other things, socioeconomics, technologies, economic structure, atmospheric chemistry, climate modeling, and the carbon cycle.

be an implicit judgment of technical soundness.[2] Thus a key criterion for judging robustness is whether several models can produce plausible scenarios with similar radiative forcing outcomes. This implies that there could potentially be a tradeoff between the desire that the RCPs be compatible with the full range in the literature and that the highest and lowest RCPs also be robust.

III.1.5 Comprehensiveness

Anthropogenic climate change is driven by a number of factors, all of which contribute to radiative forcing of the climate system. The RCPs need to model all of these factors so that they are internally consistent. The radiative forcing factors include the full suite of GHGs, aerosols, chemically active gases, and land use/land cover. Appendix 1 contains a table (Table A1.1) and a full discussion of the data that RCPs need to provide to the CM community to drive model simulations, including IAM data to 2300 and gridded emissions for aerosols, chemically active gases, methane, and land use/land cover. This list is the minimum set required to fulfill IPCC's call for adequately addressing aerosols, short-lived GHGs, and land use (see Box I.1). Note that many published scenario results do not extend past 2100 nor provide gridded results, in which case they would need to be extended. This point is raised in section III.2.3 and discussed in detail in Appendix 1.

III.1.6 Near-term resolution

The research and user communities also expressed an interest in using one of the RCPs to produce climate change projections at a higher spatial resolution for the first 30 years (to 2035). Using one of the RCPs, rather than a separate scenario, provides continuity between the near- and long-term simulations. These near-term, high-resolution simulations could have a number of purposes: (1) to understand the effect of emissions on air quality and regional climate in the near term; (2) to provide insight into trends and possibilities of extreme events; (3) to explore how initialization of CMs with observed climate may affect predictions of natural decadal variability; (4) to provide a framework for regional analyses, particularly by the IAV communities; and (5) to provide insight into possible near-term policy options by providing better information about near-term impacts and potential adaptation. This is a new activity for the CM community and as such, is a research issue in progress. Discussions are underway to identify an experimental design that is consistent with regards to the development of clear 'standard practices' that can be relied on. With regard to model evaluation of near-term simulations, because the modeling tasks are potentially quite different for these different purposes, and most CM groups do not have the resources to consider more than one, the CM community has asked potential users of near-term scenario runs to clarify their priorities for such work before making final decisions in this area.

III.2 Identification of RCPs

Section III.1 presented the qualitative desirable characteristics of RCPs. This section describes the process by which RCPs were identified, beginning with a review of the scenarios literature in order to define *types* of RCPs that would best capture the set of desirable characteristics. These types then

[2] There are several definitions of robustness in both common and scientific usage. In the context of the RCPs, we use it to mean "well supported," consistent with one of its definitions as "strong or sturdy." The criteria used to establish whether a scenario is well supported are technical soundness and replicability. Earlier in the report, robustness is used in a different sense in the context of describing policies that perform well under a variety of assumptions. This usage is based on an alternative definition of robustness as relatively invariant under a wide range of conditions.

became a key element in a larger set of criteria for identifying RCP candidate scenarios. Specific scenarios from among the group of candidates were then identified to be used as RCPs.

III.2.1 Scenarios in the literature

In the IPCC Fourth Assessment Report (AR4), Working Group III (WGIII) assessed the literature on baseline and stabilization scenarios published since the SRES and the Third Assessment Report (TAR). More than 300 scenarios were identified in AR4, 147 and 177 of which were baseline and stabilization scenarios, respectively. A significant development since the TAR is the extension of many IAMs beyond CO_2 to other GHGs. This innovation has permitted the assessment of multigas mitigation strategies. About half of the scenarios assessed in AR4 were multigas scenarios, including 71 multigas baseline scenarios and 76 stabilization scenarios. While many IAMs have been extended to other gases, to date only a few comprehensively account for the major components of radiative forcing. For the purpose of this report, the radiative forcing trajectories of more than 30 of these comprehensive scenarios were collected to facilitate the identification of candidates for the RCPs.[3] The left panel of Figure III.1 shows the range of global average radiative forcing from these scenarios, while the right panel provides a comparison of the CO_2 emissions pathways associated with the comprehensive scenarios in the left panel to the full range of CO_2 emissions pathways in the literature.

The right panel of Figure III.1 provides perspective on the compatibility of the published comprehensive scenarios capable of providing radiative forcing pathways with the entire published emissions scenarios literature. In general, the CO_2 pathways associated with scenarios providing comprehensive radiative forcing pathways effectively represent more than the 10th to 90th percentile range of CO_2 emissions pathways across the post-SRES literature.[4] This percentile range is not used as a criterion for scenario selection, but provides a useful descriptive measure of the overlap between the ranges of the two sets of scenarios. The comprehensive scenarios providing radiative forcing pathways also effectively represent the post-SRES 10th to 90th percentiles of the methane (CH_4) and nitrous oxide (N_2O) pathway ranges in the literature (see Figures III.3 and III.4 in Section III.3). However, they only partially represent the range of sulfur emissions pathways (see Figure III.5 in Section III.3), and the potential pathways for short-lived species have in general not been as thoroughly explored in IAMs as have those for long-lived gases.

[3] IAMs in this class compute internally consistent projections of radiative forcing and its major components—the full suite of GHG and non-GHG emissions and concentrations, land use/land cover, and climate, as well as the terrestrial and ocean carbon cycle (see Table A1.1 in Appendix 1). Note that radiative forcing was not available in a comparable format for all 37 scenarios in the literature. Hence, Figure III.1 includes forcing for 32 of these scenarios only.
[4] "Post-SRES" scenarios are those published in the literature after publication of the SRES in 2000.

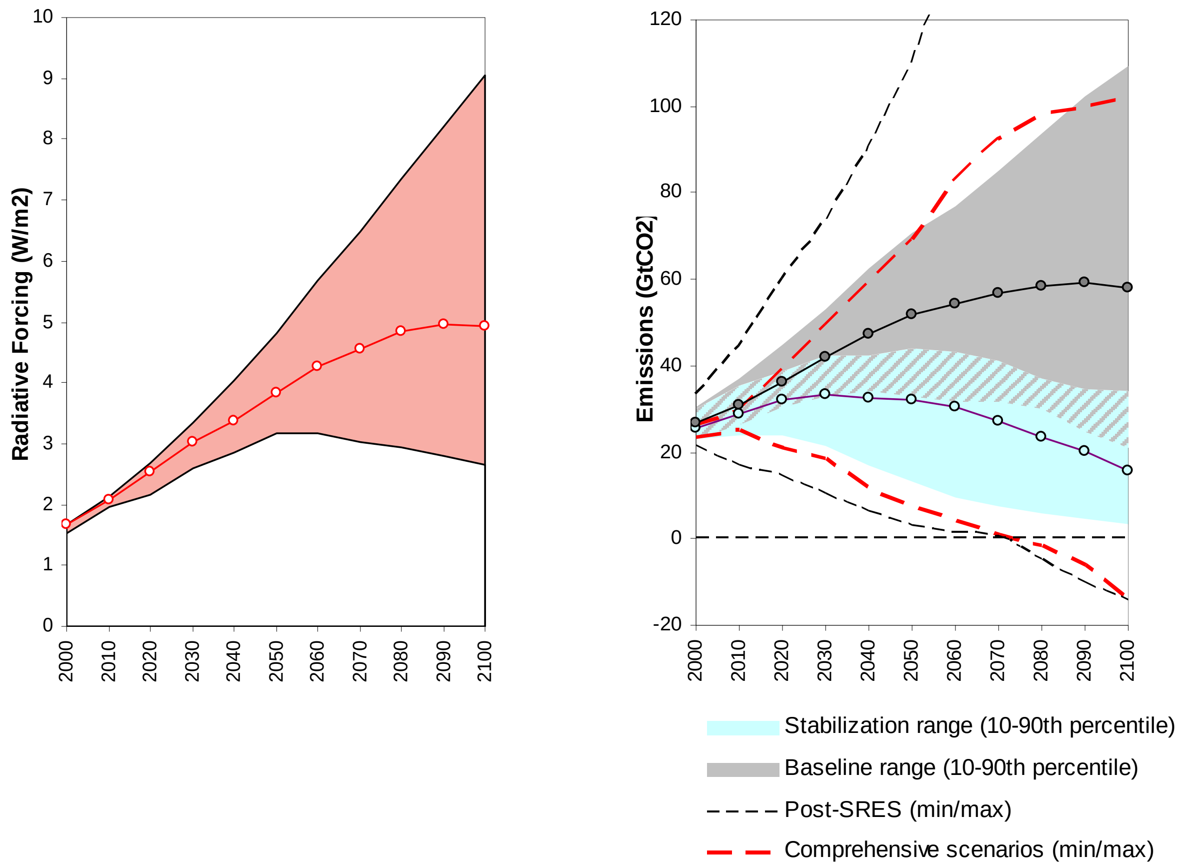


Figure III.1. Full range and median of the comprehensive radiative forcing pathways (left panel) and CO_2 emissions pathways for various ranges and medians (right panel). In the right panel, the lines connecting the filled and open circles are medians of the range of baseline and stabilization scenarios, respectively. The red dashed lines denote the full range of energy and industry CO_2 emissions pathways associated with the comprehensive scenarios from the left panel. Data published for these scenarios extend only to 2100; RCPs will need to extend data to 2300.[5]

It should be noted that AOGCMs (and therefore ESMs) do not use the same effective radiative forcing as simple CMs for a particular concentration pathway. Simple CMs are commonly used by IAMs and are calibrated to AOGCM results. AOGCMs and ESMs calculate radiative forcing based on their own simulations of three-dimensional time-varying atmospheric composition for the short-lived species, which may produce different values from simple CMs. These differences can be evaluated in the subsequent research phases.

III.2.2 Types of RCPs

The scenario literature was reviewed with respect to the desirable characteristics of range, number, separation and shape, robustness, and comprehensiveness in order to define types of RCPs. Four RCP types were defined in terms of a radiative forcing level and pathway shape so as to provide the best possible manifestation of the desirable characteristics given the available literature (Table III.1).

[5] Note that it was not possible to clearly distinguish between energy/industry and land use emissions for all scenarios in the literature. Therefore, the CO_2 emissions ranges in Figure III.1 (denoted by the blue and gray shaded areas in the right panel) include scenarios with both energy/industry and land use CO_2 emissions.

Table III.1. *Types of representative concentration pathways.*

Name	Radiative Forcing[1]	Concentration[2]	Pathway shape
RCP8.5	>8.5 W/m^2 in 2100	> ~1370 CO_2-eq in 2100	Rising
RCP6	~6 W/m^2 at stabilization after 2100	~850 CO_2-eq (at stabilization after 2100)	Stabilization without overshoot
RCP4.5	~4.5 W/m^2 at stabilization after 2100	~650 CO_2-eq (at stabilization after 2100)	Stabilization without overshoot
RCP3-PD[3]	peak at ~3W/m^2 before 2100 and then decline	peak at ~490 CO2-eq before 2100 and then decline	Peak and decline

Notes:
[1] Approximate radiative forcing levels were defined as ±5% of the stated level in W/m^2. Radiative forcing values include the net effect of all anthropogenic GHGs and other forcing agents.
[2] Approximate CO_2 equivalent (CO_2-eq) concentrations. The CO_2-eq concentrations were calculated with the simple formula Conc = 278 * exp(forcing/5.325). Note that the best estimate of CO_2-eq concentration in 2005 for long-lived GHGs only is about 455 ppm, while the corresponding value including the net effect of all anthropogenic forcing agents (consistent with the table) would be 375 ppm CO_2-eq.
[3] PD = peak and decline.

RCP8.5 is a high radiative forcing (and concentration) pathway, reaching more than 8.5 W/m^2 by 2100. RCP8.5 represents the high end of the radiative forcing range and approximately the 90th percentile of the CO_2 and non-CO_2 GHG emissions scenarios in the literature (see Section III.3). The radiative forcing pathway is similar to that of the SRES A2 and A1FI scenarios. The difference between a pathway of this type and a low pathway (e.g., RCP3-PD) also has a good signal-to-noise ratio for evaluating the climate response in AOGCM simulations.

RCP3-PD (peak and decline) is a low radiative forcing (and concentration) pathway that peaks at a maximal radiative forcing level of about 3 W/m^2 during the 21st century, declines during the second half of the 21st century, and then further declines. Scenarios in the literature that achieve this long-term level are typically overshoot scenarios in which radiative forcing peaks earlier in the century and then declines. The pathway type is at the low end of the radiative forcing scenarios and below the 10th percentile of the CO_2 and non-CO_2 GHG emissions scenario ranges in the literature. Forcing pathways that peak and decline are a relatively novel concept that the climate community has not thoroughly explored to date. Therefore, the scenario is expected to generate new scientific insights relevant for all communities regarding “reversibility” of climate changes and impacts.

RCP4.5 is an intermediate pathway that does not exceed a stabilization level of approximately 4.5 W/m^2 (stabilization in 2100–2150). RCP4.5 provides a good signal-to-noise ratio and separation from the high pathway. Another advantage of a 4.5 W/m^2 RCP is that there are a large number of published stabilization scenarios at this level.[6]

[6] The large number of published 4.5 W/m^2 scenarios reflects the fact that the level was prescribed in model intercomparison projects, and is not a reflection of independent scientific judgment.

RCP6 is a second intermediate pathway that does not exceed a stabilization level of approximately 6 W/m^2. Some baseline scenarios satisfy the radiative forcing requirement for RCP6 in 2100. Stabilization measures could be added to such scenarios in order to stabilize after 2100. For CM teams able to run all four RCPs, the two intermediate levels will facilitate exploration of nonlinearities in the scaling of climate change on the basis of radiative forcing.

It is considered desirable to have one of the intermediate RCPs be the basis for the higher resolution near-term simulation, because of their intermediate forcing levels. RCP4.5 is considered preferable because there are a substantial number of similar scenarios in the literature. It is worth noting that there is thought to be little variation in climate change outcomes across stabilization pathways over the first three decades.

In general, the expert meeting accepted the proposed types of RCP pathways. However, there was substantial interest in a low pathway with a pronounced peak-and-decline shape. At the meeting, agreement was reached on the general characteristics of the low pathway shown in Table III.1 (peak at ~3W/m^2 before 2100 and decline—"peak and decline") but further specification was still necessary (see Section III.2.5).

The set of pathways in Table III.1 are representative of the range of baseline and stabilization radiative forcing, concentration, and emissions pathways in the literature, with the full range of available radiative forcing and concentration pathways covered and from the 90th percentile down to below the 10th percentile of GHG emissions covered.[7]

It was deemed desirable that the RCPs should be robust across a range of alternative methodologies and in this sense should be reproducible with different modeling approaches (see III.1.4). RCP8.5 and RCP3-PD are at the upper and lower boundaries of the radiative forcing pathways available. However, they are not at the absolute boundaries of emissions pathways published since the TAR. The RCP8.5 is representative of the 90th percentile of the baseline range. The RCP3-PD, on the other hand, represents below the 10th percentile of emissions pathways. Given the low number of published pathways consistent with RCP3-PD, careful consideration of robustness was deemed necessary for RCP3-PD candidates (see Section III.2.4).

The expert meeting also illuminated an interest in future research evaluating high- and mid-range overshoot scenarios, as well as pairs of scenarios with an identical stabilization objective but different pathways to the objective—one overshoot and the other a pathway that does not exceed the long-run stabilization level (for example, 4.5 W/m^2 was proposed). However, for the purposes of characterizing the climate space, exploring nonlinearity, and calibrating pattern scaling, it was considered important that the RCPs represent the range of pathways in the literature and have distinguishable climate signatures. In addition, there was interest in high and low aerosol-loading scenarios to examine the influence of these pollutants, which respond rapidly to emissions changes relative to the long-lived gases.

[7] The set of scenarios in this literature has been strongly influenced by specifications of intercomparison exercises and continuity with earlier experiments, so it should not be considered a frequency distribution of independent analyses from which relative robustness, likelihood, or feasibility can be deduced. Moreover, in the short run some of the low scenarios (included in the percentiles) assume that climate policy starts in 2000.

Given the scientific and computing limitations, and different resource constraints across CM teams, some CM modeling teams may only be able to run a subset of the proposed RCPs. Therefore, the CM community has assigned a preferred order to RCP runs. The priority order for CM RCP simulations is:

1. Both the high and low RCPs at a minimum (RCP8.5 and RCP3-PD);
2. The intermediate-range RCP with near-term resolution (RCP4.5); and
3. RCP6.

Some computing costs and interpolation across scenarios may be mediated through the use of EMICs and the possibility of some modeling groups developing very coarse AOGCMs with state-of-the-art model components to generate multiple ensembles. It should also be noted that the near-term simulations depend on the CM community's ability to develop higher resolution versions of the models that can be initialized from real data (to save on the computing used in start up) and that do not have a substantial climate drift. These simulations will also require a relatively large number of ensemble members given that during the next 30 years the signal-to-noise ratio will be relatively small.

Box III.1: Criteria for consideration as an RCP candidate

1) Peer-reviewed and published: the pathway must be reported in the current peer-reviewed literature.
2) Types of RCPs: the pathway must correspond to one of the four RCP types that satisfy the desirable characteristics:
   a) RCP8.5 (>8.5 W/m^2 in 2100, rising)
   b) RCP6 (~6 W/m^2 at stabilization after 2100, stabilization without overshoot)
   c) RCP4.5 (~4.5 W/m^2 at stabilization after 2100, stabilization without overshoot)
   d) RCP3-PD (peak at ~3W/m^2 before 2100 and then decline)
3) Data requirements:
   a) Variables: The IAM scenario must project pathways for all of the required variables through 2100—the full suite of GHGs, aerosols, chemically active gases, and land use/land cover (see Appendix 1).
   b) Long-term/near-term resolution: the existing data and the modeling team must be amenable to finalizing the data as needed for the required resolution using the methods defined from the technical consultations between the IAM and CM communities. These include harmonization of output and base year data, downscaling, and extending published data to 2300 (see Appendix 1).
4) Modeling requirement: for reliability, radiative forcing results must have been generated with an IAM that contained carbon cycle and atmospheric chemistry representations.
5) Timeline: the modeling team must be able to deliver the data in a timely manner. Dates will be coordinated with the CM community with the expectation that:
   a) Initial data will be available by the summer of 2008, including (i) a draft full resolution of the data, and (ii) a fully documented scenario.
   b) Final data will be delivered to the CM community no later than the fall of 2008.

III.2.3 Criteria for identifying candidates for RCPs

Based on the identified RCP pathway types and required data, a set of criteria was defined to identify candidate scenarios from the literature. Box III.1 summarizes the criteria for selecting candidate scenarios in the peer-reviewed literature that could serve as RCPs. These criteria reflect the desirable characteristics, identified types of RCPs, and data requirements discussed in section III.2.2 and Appendix 1, and practical needs for the timely provision of IAM data to the CM community. Most published IAM scenarios results do not run past 2100 nor provide gridded results. Therefore, the IAM teams will need to extend their scenarios (temporally, beyond 2100, and spatially with respect to resolution) and standardize definitions and historic data in order to satisfy the full data requirement. For a scenario to be a viable RCP candidate, basic functionality to 2100 must be present in the IAM for carrying out the data extensions.

III.2.4 Candidates

Using the criteria listed in Box III.1, the IAM community identified 20 RCP candidates from the literature (Table III.2). Note that each asterisk in Table III.2 can represent more than one scenario, and some modeling teams produced more than one scenario over time that would satisfy an RCP type definition. Each model and institution listed in Table III.2 has scenarios that satisfy all of the criteria for at least one of the RCP levels requested, which was confirmed via consultation with the modeling teams. Numerous other IAMs exist and have published scenarios in the literature but, for various reasons, do not meet all the criteria. In particular, many do not currently project emissions of aerosols, chemically reactive gases, and/or land use. It must be stressed that the requirement that scenarios meet the criteria only applies to the selection of RCPs in the preparatory phase. In subsequent phases of the open scenario development process, these criteria will not apply—all models will have full opportunity to participate in all subsequent research phases.

III.2.5 The RCPs

Based on an assessment of the candidates to meet the identified data requirements, the initial proposed RCPs presented to the experts' meeting, and input from the research and user communities at the meeting, the Steering Committee has identified the following sources and models for the RCPs:[8]

RCP	Publication – IAM
RCP8.5:	Riahi et al. (2007) – MESSAGE
RCP6:	Fujino et al. (2006) – AIM[9]
RCP4.5:	Clarke et al. (2007) – MiniCAM[10]
RCP3-PD:	van Vuuren et al. (2006, 2007) – IMAGE

These identified RCPs are broadly consistent with the initial proposal. However, the substantial interest expressed at the expert meeting in a low pathway with a pronounced peak-and-decline shape (see Section III.2.2) led to a preference for an alternative IMAGE scenario to serve as the RCP3-PD, contingent on a robustness assessment (discussed below).

[8] See Table III.2 notes for definition of model acronyms.
[9] The AIM modeling team revised this scenario slightly to comply with the 6 W/m^2 stabilization criterion. The revised stabilization scenario is published in Hijioka et al. (2008).
[10] The ERI IPAC team is collaborating with the PNNL MiniCAM team on data finalization as it relates to Asia.

Table III.2. *RCP candidates. Asterisks indicate that at least one scenario is available, although there may be more than one.*

IAM (affiliation)[1]	**RCP8.5**	**RCP6**	**RCP4.5**	**RCP3-PD**	**Reference(s)**
AIM (NIES)		*[2]	*	*[2]	Fujino et al. (2006), Hijioka et al. (2008)
GRAPE (IAE)			*		Kurosawa (2006)
IGSM (MIT)	*	*	*		Reilly et al. (2006), Clarke et al. (2007)
IMAGE (MNP)	*	*	*	*	van Vuuren et al. (2006, 2007)
IPAC (ERI)		*[2]	*		Jiang et al. (2006)
MESSAGE (IIASA)	*	*	*	*	Rao and Riahi (2006), Riahi et al. (2007)
MiniCAM (PNNL)		*	*		Smith and Wigley (2006), Clarke et al. (2007)

Notes:
[1] AIM = Asia-Pacific Integrated Model, NIES = National Institute for Environmental Studies, GRAPE = Global Relationship to Protect the Environment, IAE = Institute of Applied Energy, IGSM = Integrated Global System Model, MIT = Massachusetts Institute of Technology, IMAGE = Integrated Model to Assess the Global Environment, MNP = Netherlands Environmental Assessment Agency, IPAC = Integrated Policy Assessment Model for China, ERI = Energy Resource Institute, MESSAGE = Model for Energy Supply Strategy Alternatives and their General Environmental Impact, MiniCAM = Mini-Climate Assessment Model, PNNL = Pacific Northwest National Laboratory.
[2] These scenarios are available, but would require revisions to meet the RCP forcing criteria.

The Riahi et al. (2007) MESSAGE scenario represents the upper end of the radiative forcing scenarios in the literature, and the van Vuuren et al. (2006, 2007) IMAGE scenario represents the lower end of the radiative forcing scenarios in the literature. The relationship between all four RCP radiative forcing scenarios and emissions scenarios in the literature is discussed in Section III.3. Section III.3 provides very important guidance on the uses and limits of the RCPs, as well as a graphical characterization of how the set of four RCPs represents the stabilization, mitigation, and baseline scenarios literature—in terms of radiative forcing, concentrations, and emissions.

Before the finalized RCP data are provided to the CMs, they will need to be reviewed, particularly the data extensions required for satisfying the full resolution of the data request (see Appendix 1). Review of the finalized data is expected to begin in the summer of 2008.

Note that, from a CM standpoint, there are some clear experimental design advantages in having a single model provide all the RCPs, since differences in IAM data across RCPs would be limited to differences in RCPs, and not include idiosyncrasies across IAMs as well. However, the IAMC felt it was important to select a different model for each RCP in order to have an RCP set that is more representative of the IAM uncertainties and the community. More controlled experiments with several IAMs may be explored in subsequent phases in order to identify the influence of model choice and particular factors, such as land use, as well as uncertainties within common scenarios.
The four specific RCPs are based on several considerations:

- All of the candidates have been peer reviewed and published and can provide the required consistent set of data;
- Not all modeling groups whose scenarios were identified as candidates (Table III.2) confirmed their willingness to participate in this activity;
- The selected set of models are those capable of satisfying the data requirements and the modeling teams have substantial experience relevant to developing the required data sets;
- The forcing profiles of these models have been analyzed thoroughly, using simple CMs with updated IPCC AR4 parameterization (van Vuuren et al., submitted);
- Among the modeling teams represented in Table III.2 who are willing to participate, the MESSAGE and IMAGE models can produce scenarios on the high and low end (RCP3-PD and RCP8.5). The IMAGE model was selected for the low pathway, due to the larger number of low stabilization scenarios available from the model. The MESSAGE model was selected for the high scenario, since it can provide an updated and revised A2-like scenario, which would allow comparisons with earlier climate assessments and thus continuity from the perspective of the CM community. This scenario includes features requested by the IAV community, namely a high magnitude of climate change and factors related to higher vulnerability (e.g., higher population growth and lower levels of economic development);
- Both the AIM and the MiniCAM models could provide the required data for the intermediate levels. The MiniCAM model was chosen for RCP4.5, while AIM was chosen for RCP6.

IMAGE 2.6 or IMAGE 2.9 for the low pathway

Based on the expert meeting discussions, the IMAGE 2.6 scenario (van Vuuren et al., 2006, 2007) is conditionally identified as the selection for the RCP3-PD pathway, but its robustness needs to be assessed. If the robustness of the scenario is established by the process outlined below and discussed further in Appendix 2, the IMAGE 2.6 scenario will be used for the low pathway. Otherwise, the IMAGE 2.9 pathway will be chosen. The robustness evaluation will ensure delivery of one of the two pathways via a scientifically rigorous process. This sub-section discusses the process by which this conditional decision was reached and describes the IMAGE 2.6 robustness evaluation. Agreement on the nature of the robustness evaluation was reached through consultations between the Steering Committee and the IAMC following the expert meeting (see Appendix 2).

The background paper to the expert meeting proposed the IMAGE 2.9 scenario from van Vuuren et al. (2006, 2007). However, meeting participants expressed an interest in the lowest radiative forcing scenario in the available literature from this class of IAMs.[3,11] The lowest radiative forcing scenario is the IMAGE 2.6 scenario (van Vuuren et al., 2006, 2007).

The IMAGE 2.6 scenario has radiative forcing that peaks rapidly near 3 W/m^2 and declines to a radiative forcing of 2.6 W/m^2 in 2100. The IMAGE 2.9 scenario peaks at over 3 W/m^2 and declines to a radiative forcing level of 2.9 W/m^2 in 2100.[12] The emissions, concentration, and radiative forcing pathways to 2100 for both scenarios are presented in Figures III.2 to III.6 in the next section. Data finalization requires extension of these scenarios to the year 2300. There is significant policy and

[11] See Appendix 4 for some position papers that were distributed at the meeting discussing this point.
[12] Both of the van Vuuren et al. (2006, 2007) scenarios are stabilization scenarios that stabilize by the middle of the 22nd century at radiative forcing levels below 2100 levels. This information was not available in the scenario publications but was obtained through consultation with the IMAGE modeling team. The post-2100 radiative forcing and emissions characteristics of these scenarios may change with the extension to 2300.

scientific interest in radiative forcing pathways that continue to decline. The IAMC and CM community recognize this interest, and have already begun coordinating in order to develop data finalization methods, including methods for extension to 2300. Discussions on how to carry out the extension are ongoing. The planned methods resulting from those discussions are expected to be available for comment through the IAMC.

The remainder of this section summarizes the discussion regarding consideration of IMAGE 2.6 for the RCP3-PD, including motivation, concerns, the relative characteristics of IMAGE 2.9, and the planned scientific evaluation of IMAGE 2.6 robustness.

Meeting participants expressed an interest in scenarios that show a clear peak in radiative forcing and explore the lowest stabilization scenarios published in the literature, as they offer unique scientific and policy insights. Various points were made in support of the IMAGE 2.6 scenario for use as the RCP3-PD. First, the IMAGE 2.6 CO_2 emissions pathway, which reaches 7.6 $GtCO_2$ in 2050 as compared to 12.8 $GtCO_2$ for IMAGE 2.9, was argued to be more consistent with political discussions regarding particular 2050 emissions reduction objectives and long-run objectives for limiting increases in global mean surface temperature. Second, combined with RCP8.5, the IMAGE 2.6 scenario would span a broader range of radiative forcing and more fully encompass the scenarios literature from all classes of models.[13] Finally, the research communities as a whole found the IMAGE 2.6 peak-and-decline shape, very low radiative forcing pathway, and negative CO_2 emissions scientifically interesting.

However, there was concern about the IMAGE 2.6 scenario because, as presented in the literature, it was exploratory in nature. Like some other very low scenarios, the scenario requires rapid investment in mitigation early in the century and deployment of negative emissions technologies later in the century;[14] however, there were technical concerns about the IMAGE 2.6 characterization of the negative emissions technology. Moreover, recent focus on the diverse consequences of widespread use of bioenergy (including associated N_2O emissions), a requirement in the IMAGE 2.6 scenario, may have important implications. Finally, the IAM community has not yet evaluated the technical feasibility of reaching such low radiative forcing levels. Specifically, the radiative forcing scenario has not yet been reproduced by other models in this class of IAMs (i.e., those that model radiative forcing and its components). In contrast, the IMAGE 2.9 pathway is considered robust in that other models in this class of IAMs have published similar peer-reviewed results. In this context, recall that robustness means that a scenario is technically sound if it employs sound assumptions, logic, and associated calculations; and its level of radiative forcing over time could be independently replicated by other models (see Section III.1.4).

During the meeting discussion, the IAM community noted that the IMAGE 2.9 scenario also satisfies many of the various interests. Both IMAGE 2.6 and 2.9 are overshoot scenarios with peaking and declining radiative forcing, where the peak and decline of IMAGE 2.6 is more pronounced. Both scenarios are included in the lowest class of stabilization scenarios assessed by the IPCC in the AR4

[13] An additional point was made that IMAGE 2.6 was preferable for climate pattern scaling. However, pattern scaling techniques allow for scaling up or down (see the discussion in Section II.4). The full validity of pattern scaling requires further research.

[14] The negative emissions technology is bioenergy combined with CO_2 capture and storage (CCS) that *ceteris paribus* has a net negative effect on atmospheric concentrations of GHGs. While biomass-based mitigation strategies are assumed in both the IMAGE 2.6 and 2.9 scenarios, it is the combination of bioenergy with CCS that is novel in IMAGE 2.6.

(this class contains only three multigas scenarios). Both the IMAGE 2.6 and 2.9 pathways could achieve the target of limiting global mean temperature increase to 2°C. Based on different probability density functions for climate sensitivity, Meinshausen et al. (2006) estimate the probability of not exceeding 2°C global average temperature increase as 30 to 80% for the 2.9 scenario and 50 to 90% for the 2.6 scenario.

Given the level of interest in the IMAGE 2.6 scenario, the IAMC offered to organize a scientific IAM community exercise and assessment panel for evaluating the robustness of the IMAGE 2.6 scenario for selection as the RCP3-PD. Given the scientific and technical questions raised, the IAMC believes that it is vital to evaluate the scientific question of whether the IMAGE 2.6 scenario is robust before substantial CM community resources are applied in evaluating its climate and atmospheric chemistry implications.[15] The intent of the evaluation is to provide the IMAGE 2.6 scenario if found to be robust. Should the exercise be unable to establish the robustness of the IMAGE 2.6 scenario, the published (and replicated) IMAGE 2.9 overshoot scenario will be provided to the CM community instead to serve as the low RCP. So as not to delay the hand-off of data to the CM community, the IMAGE modeling team will be preparing the required CM input data from both the published IMAGE 2.6 and 2.9 scenarios.

The IMAGE 2.6 assessment plan was agreed to by the IAMC and Steering Committee through a series of four letters, provided in Appendix 2. The discussion that follows briefly describes the plan. To ensure the scientific credibility and transparency of the evaluation, the IAMC will appoint a panel that will be responsible for providing a consensus recommendation on the robustness of the IMAGE 2.6 scenario. Based on its robustness assessment, the panel will provide a single recommendation on whether the IMAGE 2.6 or IMAGE 2.9 scenario should be used for the lowest RCP. While panel members may not necessarily agree on all aspects of the robustness of the IMAGE 2.6 scenario, they are asked to provide a single recommendation on whether or not it should be considered robust to the IAMC as the convening body, which will then transmit the finding to the Steering Committee for expected confirmation of the recommendation. The conclusions of the evaluation panel will be provided to the IPCC in a letter report that will provide a detailed description of the full evaluation process and results. The panel will consist of the following individuals: Mikiko Kainuma, Nebojsa Nakicenovic, John Weyant, Christian Azar, Gary Yohe, Kejun Jiang, P.R. Shukla, and Emilio La Rovere.

An assessment process will be set up to evaluate the robustness of the IMAGE 2.6 scenario. The assessment process will be based on two general criteria, both of which must be met by the IMAGE 2.6 scenario: technical soundness and replicability. For the former, the IAMC will ask the modeling teams to (a) review the published IMAGE 2.6 scenario for technical soundness (i.e., assumptions, logic, and associated calculations), and (b) address any technical issues that arise from that review. The IMAGE modeling team will lead an evaluation of the technical components of the IMAGE 2.6 scenario, particularly those that distinguish the scenario from the IMAGE 2.9 scenario, namely the representation of bioenergy combined with CO_2 capture and storage (CCS). If the team review reveals fundamental problems with the IMAGE 2.6 scenario that have significant bearing on the scenario and cannot be addressed with minor revisions, it will not be selected as an RCP. The findings from this assessment will be made available to the review panel for consideration.

[15] Technical concerns were not raised about the other proposed RCPs, and each has been replicated.

For replicability, the IAMC will ask all the IAM teams working with this class of models to participate in the design and development of low stabilization scenarios that replicate key radiative forcing features of the IMAGE 2.6 pathway shape (i.e., peaking rapidly near 3 W/m^2 and declining to around 2.6 W/m^2 in 2100). The modeling teams will be asked to employ their standard assumptions and include bioenergy and CCS, but avoid non-traditional assumptions like geo-engineering, dramatic dietary changes, or severe economic collapse. This term of reference provides some structure for the modeling that is broadly consistent with the IMAGE 2.6 scenario. Replication will be deemed successful if both of the following occur: (a) the IMAGE team, after addressing any modest technical issues identified in their assessment of the IMAGE 2.6 scenario, is able to generate the scenario using the latest version of the IMAGE model; and (b) at least two of the other IAM models in this class are able to generate a scenario with a similar radiative forcing pathway that is considered to be technically sound.

The panel will ensure that the evaluation is conducted in a careful, scientific, and unbiased manner, and will develop and apply a set of broad criteria to be considered in the evaluation of the technical soundness of the replication scenarios. The panel is invited to consider, among other things, technical soundness of the representation of key technologies, internal plausibility and consistency of the technology portfolio, GHG and carbon cycle accounting, land use implications, and economic considerations relative to the 2.9 W/m^2 pathway. It is important to acknowledge that the scenario analysis by the modeling teams might identify important new criteria. In such a case, these would be clearly communicated by the panel in its letter report.

Finally, given the renewed interest of the international community in lower pathway scenarios, it is strongly recommended that further research be conducted on scenarios that have radiative forcing levels by the end of the 21st century in the range of 2.5 to 3 W/m^2 and lower.

III.3 RCPs in perspective

This section puts the proposed RCPs in perspective in two ways. First, it discusses their intended uses and limits. As described in Section II, the RCPs are intended primarily to serve as concentration pathways to drive climate modeling, but are based on fully articulated scenarios in the literature. This gives rise to important distinctions between the intended use of the RCPs and limitations to using them. Second, it shows how the emissions and radiative forcing pathways associated with the RCPs compare to other candidate pathways from Table III.2 as well as to the wider scenario literature, and provides pointers to the socioeconomic information associated with the RCPs.

III.3.1 Intended uses

The core uses of RCPs and the CM outcomes associated with them are:

- *Input to CMs*. As discussed in Section II, RCPs are mainly intended to facilitate the development of integrated scenarios by jump-starting the CM process through the provision of data on emissions, concentrations, and land use/land cover needed by CMs. Results from these CM simulations will then be used to recalibrate the climate system components of IAMs, to inform IAV studies, and to incorporate feedbacks from climate impacts back into the socioeconomic drivers during later phases of the scenario development process.
- *To facilitate pattern scaling of climate model outcomes*. Climate change projections based on RCPs will cover a wide range of outcomes. These outcomes, together with control runs with no anthropogenic radiative forcing, will be used to investigate the extent to which they can be

scaled to provide climate change outcomes for intermediate forcing levels without re-running the CMs (see Section II.4). For this purpose, it is important to analyze the nonlinearity of the climate change response to different levels and time paths of forcing (including peak and decline pathways), using comparable CM simulations from multiple RCPs.

- *To explore the range of socioeconomic conditions consistent with a given concentration pathway*. It is an open research question as to how wide a range of socioeconomic conditions could be consistent with a given pathway of forcing, including its ultimate level, its pathway over time, and its spatial pattern. The RCPs will facilitate exploration of alternative development futures that may be consistent with each of the four RCPs.
- *To explore the climate implications of spatial forcing patterns*. Each RCP will have a particular spatial pattern of forcing due to differences in both spatial emissions and land use. The RCPs will provide a new focus for work on the open research question of how wide a range of spatial patterns of forcing could be consistent with a given climate change outcome.

Although emissions, concentration, and land use are the primary outcomes of the RCPs to be used as inputs to CMs, the RCPs are based on full scenarios in the literature that include socioeconomic driving forces (see Section III.3.3). Therefore, the RCPs can also serve as a starting point for IAV and IAM analyses that need to draw on this underlying socioeconomic information. Users will need to account for the limitations of the RCPs in this regard, as discussed in the next section.

III.3.2 Limits

There are a number of limitations to the use of RCPs that must be kept in mind in order to avoid inappropriate applications. These include:

- *They should not be considered forecasts or absolute bounds*. RCPs are representative of plausible alternative scenarios for the future but are not predictions or forecasts of future outcomes. For example, no RCP is intended as a “best guess,” most likely, or most plausible projection. The high and low RCPs are representative of the upper and lower ends of the range in the literature, but are not intended to be the maximum and minimum radiative forcing outcomes considered plausible. In addition, RCPs were chosen based on their medium- and long-term forcing levels. The similarity of the RCPs in the near term should not be interpreted to mean that mitigation cannot affect forcing over the next several decades.
- *They should not be considered policy-prescriptive*. The RCPs are meant to support scientific research to examine various climate change futures and their implications for adaptation and mitigation without making any judgment as to their desirability. The range from the higher to the lower RCP was chosen to be policy-relevant, not policy-prescriptive.
- *The socioeconomic scenarios underlying each RCP should not be considered unique*. Each RCP is based on a scenario in the literature that includes a socioeconomic development pathway. However, the socioeconomic scenario underlying each RCP is just one of many possible scenarios that could be consistent with the concentration pathway. Subsequent work carried out as part of the parallel phase of the new scenario development process (Section II) will explore a wide range of other socioeconomic assumptions that could be consistent with the RCPs, as well as develop emissions, concentration, and climate change scenarios that are altogether different from the RCPs. Thus, RCPs are only a small part of a much larger scenario development enterprise.
- *The socioeconomic scenarios underlying the RCPs cannot be treated as a set with an overarching internal logic*. While each individual RCP was developed from its own internally consistent socioeconomic foundation, the four RCPs as a group were selected on the basis of

their concentration and forcing outcomes to be compatible with the full range of emissions scenarios available in the current scientific literature. Therefore, there is no overarching logic or consistency to the set of socioeconomic assumptions or storylines associated with the set of RCPs. This implies several limitations on their use:

  - The set of underlying socioeconomic scenarios is not intended to span the range of plausible assumptions for any particular socioeconomic element (population, gross domestic product growth, rates of technological change, land use, etc.).
  - The socioeconomic and technology assumptions are not consistent between the RCPs and thus the socioeconomic scenario underlying one RCP should not be used in conjunction with that of another RCP. For instance, the high RCP cannot be considered a baseline against which lower RCPs can be directly compared.
  - The socioeconomic assumptions underlying a particular RCP cannot be freely used interchangeably with the assumptions underlying other RCPs.

  The development of consistent and comparable alternative socioeconomic assumptions, including an assessment of the uncertainties for each RCP, is a research question to be explored during the scenario development phase.

- *There are uncertainties in the translation of emissions profiles to concentrations and radiative forcing.* This is particularly true for the carbon cycle and atmospheric chemistry. Each RCP represents one possible set of assumptions with regard to this translation. Both the development of new techniques and tools for translating emissions to concentrations and uncertainty analyses should be coordinated in subsequent phases by the CM community and IAMC. See Section II for discussion of research plans in this area.

III.3.3 Comparison to the literature

Several publications can put the RCPs in perspective. These include the scenario overview in Chapter 3 of the IPCC WGIII AR4 (Fisher et al., 2007), the comparison of selected scenarios by van Vuuren et al. (submitted), and the publication by the US Climate Change Science Program (Clarke et al., 2007). Figures III.2 through III.6 provide an illustrative overview of how the RCP candidates and the identified RCPs represent the literature. In the figures, the range of the scenarios in the underlying post-SRES literature is indicated by dashed lines showing the maximum and minimum and by shaded areas showing the 10th to 90th percentile. These percentiles reflect the frequency distribution of existing scenarios and should not be considered probabilities. The range of the baseline scenarios is shown in gray, and the range for the stabilization scenarios is shown in light blue. Cross-hatched areas indicate the overlap between baseline and stabilization scenarios.

The number of scenarios represented by the ranges in each figure differs. Figure III.2 (CO_2 emissions and concentrations) includes 307 scenarios that report CO_2 emissions, including both CO_2-only and multigas scenarios; 147 of these are reference scenarios and 160 are mitigation scenarios. In Figures III.3 through III.5 (non-CO_2 gases and sulfur) the shaded ranges represent subsets of multigas scenarios; the range for CH_4 includes 147 scenarios (71 reference and 76 mitigation), the range for N_2O includes 138 scenarios (71 reference and 67 mitigation), and the range for sulfur includes 44 scenarios (15 reference and 29 mitigation).

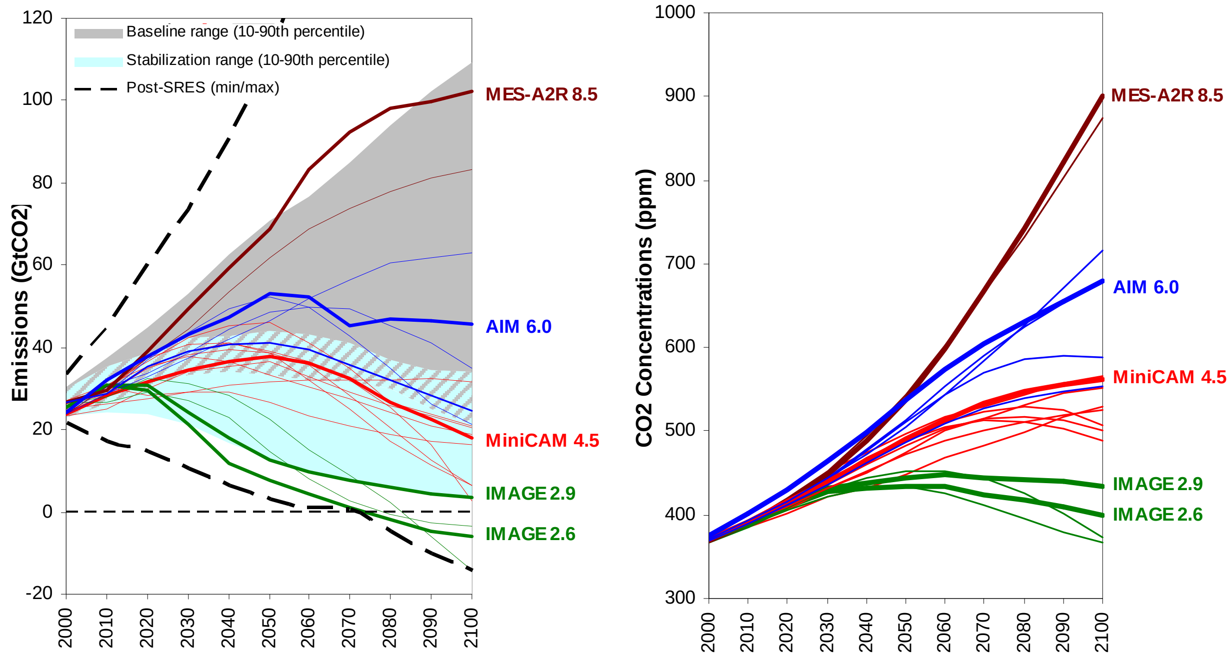


Figure III.2. Energy and industry CO_2 emissions and concentrations for RCP candidates (colored lines), and for the maximum and minimum (dashed lines) and 10th to 90th percentile (shaded area) in the post-SRES literature. Blue shaded area indicates mitigation scenarios; gray shaded area indicates baseline scenarios.[16]

In addition, thin colored lines represent the 20 candidate RCP scenarios from Table III.2 (note that each asterisk in Table III.2 can represent more than one scenario). The different colors correspond to the different RCP forcing levels in 2100 (green <3 W/m^2; red ~4.5 W/m^2; blue ~6 W/m^2; brown ~8.5 W/m^2). The four selected RCPs are highlighted as thick colored lines.

Figure III.6 shows radiative forcing pathways for the RCP candidates. Forcing includes all GHGs and radiatively active gases. For three of the RCP candidates forcing values for all of the gases were not available, so only 17 of the 20 candidate pathways are plotted. Forcing and concentration data shown in the figures are taken from three main sources: (1) simple CM estimates of Van Vuuren et al. (submitted) for the IMAGE, IPAC, and AIM scenarios using the Bern model (Plattner et al., 2001) and the Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC; Wigley and Raper, 2001); (2) Clarke et al. (2007) for the CCSP scenarios; and (3) Riahi et al. (2007) MAGICC estimates for the MESSAGE scenarios.

[16] Note that it was not possible to clearly distinguish between energy/industry and land-use emissions for all scenarios in the literature. Therefore, the CO_2 emissions ranges in Figure III.2 (denoted by the blue and gray shaded areas in the left panel) include scenarios with both energy/industry and land-use CO_2 emissions.

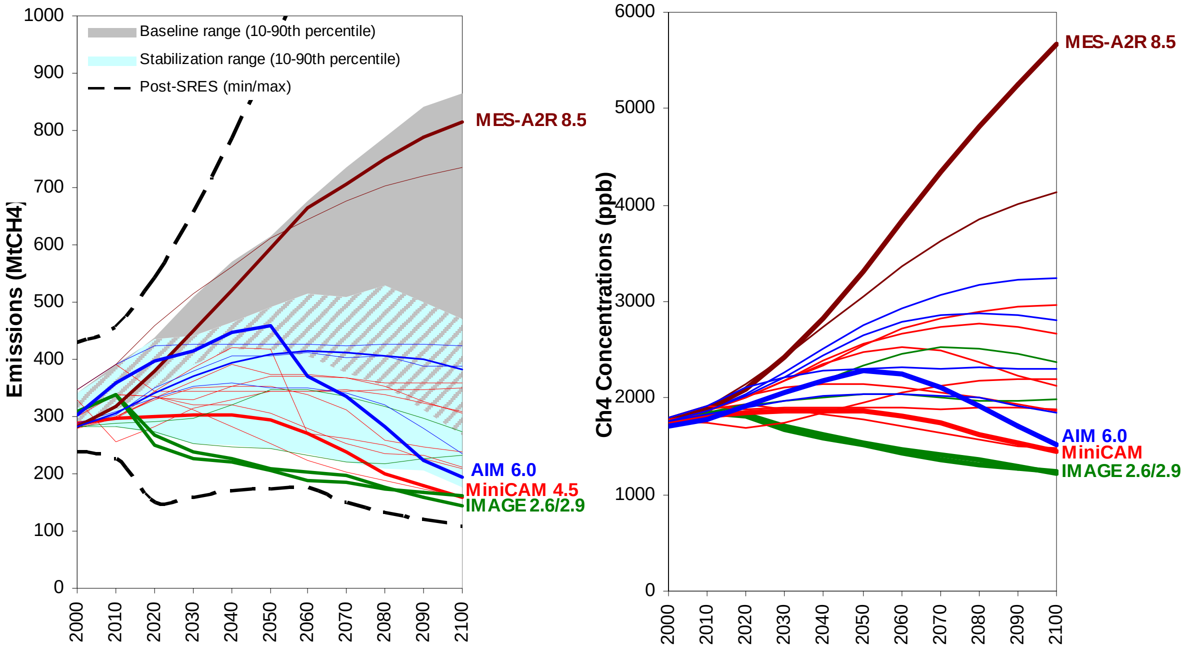


Figure III.3. CH_4 emissions and concentrations for RCP candidates (colored lines), and for the maximum and minimum (dashed lines) and 10th to 90th percentile (shaded area) in the post-SRES literature. Blue shaded area indicates mitigation scenarios; gray shaded area indicates baseline scenarios.

Socioeconomic information such as population and GDP assumptions from the four RCPs are available in the papers originally reporting these scenarios in the literature. In addition, for some of the RCPs detailed information on regional emissions and associated drivers, such as economic, demographic, and sector-specific data, may be accessed through databases on the web:

- The RCP8.5 (MESSAGE-A2R scenario) was published in Riahi et al. (2007). Scenario information is accessible via an interactive web database at http://www.iiasa.ac.at/web-apps/ggi/GgiDb.
- The RCP6 (AIM-6.0 scenario) was published in Fujino et al. (2006). A revised version was published in Hijioka et al. (2008).
- The RCP4.5 (MiniCam 4.5 scenario) was published in Clarke et al. (2007). Scenario information is accessible via a database at http://www.climatescience.gov/Library/sap/sap2-1/finalreport/default.htm.
- The conditionally recommended candidate for the RCP3-PD (IMAGE 2.6 scenario) and the IMAGE 2.9 scenario were both published in Van Vuuren et al. (2007). Both scenarios are available in the IPCC database.

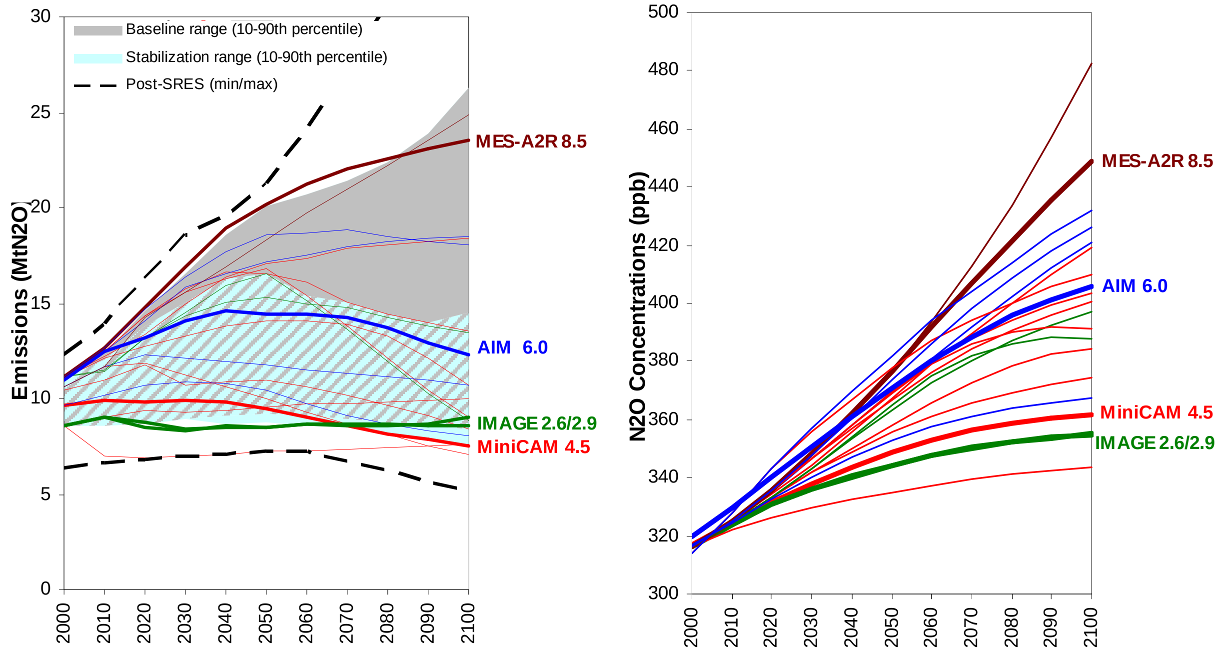


Figure III.4. N_2O emissions and concentrations for RCP candidates (colored lines), and for the maximum and minimum (dashed lines) and 10th to 90th percentile (shaded area) in the post-SRES literature. Blue shaded area indicates mitigation scenarios; gray shaded area indicates baseline scenarios.

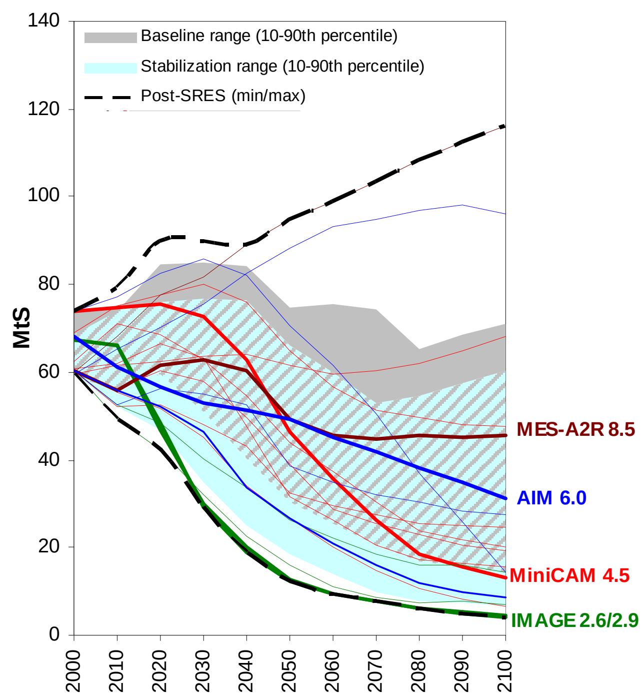


Figure III.5. Sulfur emissions for RCP candidates (colored lines), and for the maximum and minimum (dashed lines) and 10th to 90th percentile (shaded area) in the post-SRES literature. Blue shaded area indicates mitigation scenarios; gray shaded area indicates baseline scenarios.

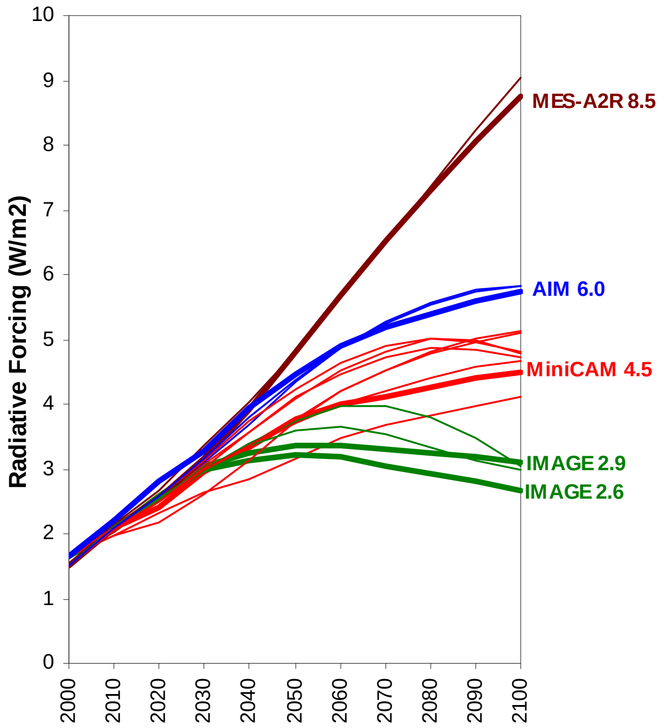


Figure III.6. Radiative forcing compared to pre-industrial for the RCP candidates. The AIM 6.0 scenario was revised slightly, as noted in the main text.

IV. Institutional and Coordination Issues

Because the new scenario development and implementation process outlined in this report is innovative in so many ways—including its approaches to scenario development and elaboration, its linkages among a range of contributors to climate change research, and its linkages between them and users of the scenarios and other interested stakeholders—it raises a number of issues for coordination, data management and exchange, and institutional development. This section summarizes these issues within and among the major groups in the research community, and proposes next steps to address the issues.

IV.1 Coordinating with stakeholders

Many national and international organizations think about the future from their own perspectives, and this now necessarily entails considering the potential implications of climate change for a diverse range of activities such as development planning, food production and distribution, provision of water resources, conservation of protected environments, and management of other environmental issues as diverse as reducing local air pollution and slowing desertification of soils. Up to now, even international organizations within the United Nations system have not effectively cooperated in developing climate change scenarios. Typically, each organization produces its own set, which may be desirable from their individual point of view but which makes it difficult (a) to compare results and conclusions and (b) to synthesize information in processes such as an IPCC assessment.

In addition, many policymakers and stakeholders in developing countries are now considering their own climate change response strategies and assessing their particular vulnerabilities and potential impacts. Since the IPCC AR4 indicated that DCs are likely to bear a disproportionate share of climate change impacts, the development of more representative models, scenarios, and other planning tools has taken on special urgency there. Intensified efforts to involve scientists from DCs in the scenario creation process (discussed in greater detail in Section V) will be needed to ensure that the representation of developing regions in key models and scenarios has sufficient resolution and accuracy to support sound climate change responses in these areas.

The main coordination issue between the scientific communities and different stakeholder groups is a function of different requirements regarding information from climate change scenarios. In addition, there are different ways that the generated information feeds into decisionmaking processes at various geographical scales. As many stakeholders do not work at the global but rather at a regional or local scale, disseminating disaggregated information when reporting scenario analysis results is an important issue. In addition, designing a process that allows engagement of stakeholders during the scenario development process, including receiving their input and feedback, is crucial to producing a set of policy-relevant and credible scenarios. Scenario developers should consider this in the research planning process.

There are various possibilities for designing a dialogue between scenario builders and user communities. One model, built along the lines of the Millennium Ecosystem Assessment process, is to develop a platform consisting of representatives of the various user communities and regions within which they can meet regularly to discuss their respective information needs, inputs, and outputs of the scenarios work.

In this context, a further issue to explore is whether there is value in bringing together like-minded international organizations to coordinate climate-change related scenario development, and to develop a common core of assumed futures around which individual organizations can develop more detailed assumptions for their own specific purposes. The IPCC could convene a standing liaison committee on global change scenarios among organizations such as the UNFCCC, FAO, the World Bank, UNEP, WHO, the United Nations Development Programme (UNDP), and major NGOs and private sector organizations that require climate change and associated socioeconomic scenarios for their own planning purposes.

It will be important to decide who the users are and how both global (e.g., international organizations) and regional (e.g., the EU, local communities) interests can be best represented. Scenario developers will need to consider who can best represent their various communities and how careful facilitation of the dialogue can be assured to avoid inefficient diversions specific to each independent community.

Another question arises about how the results of discussions can be fed back to the respective communities (i.e., how, for example, the scenario community can be informed of requests or possible inputs from the user communities). One option is to convene specific smaller meetings during scientific conferences.

Other possible ways of organizing the user–scenario developer dialogue can also be envisioned. These include, for example, having a set of meetings with selected stakeholder groups (rather than organized user groups) over the course of the scenario development process. Another option would be for the IPCC bureau to undertake facilitation of the dialogue during IPCC plenaries and other meetings of interested parties. Designing a scenario process website in an open and interactive way could also encourage feedback from potential users. A final option that has proved useful in other environmental science and policy areas is to identify technically proficient members of user groups to be involved individually with scenario development and implementation as “bridges” between the core scenario science and potential uses of the scenarios. Outlining the resources that will be required for these coordination efforts is a critical component for successfully integrating other potential users into the process. It is also important to consider these coordination issues in the context of progress towards a possible AR5.

IV.2 Climate modeling community coordination methods and infrastructure

In the early 1990s, the CM community recognized a need to coordinate and quantify model results across various modeling strategies. At that time, the World Climate Research Programme (WCRP) CLImate VARiability and Predictability (CLIVAR) project organized the Steering Group on Global Coupled Models (SGGCM) to formulate a strategy for developing global coupled models. Its membership consisted of representatives from most of the major international groups developing such models. From the beginning, it was clear that there was a need for intercomparing results from different modeling efforts, giving rise to the Coupled Model Intercomparison Project (CMIP),[1] which started in 1994. This project evolved into the current Working Group on Coupled Models (WGCM) and subsequent incarnations of coupled model intercomparisons.

A joint activity between the previous Global Analysis, Interpretation and Modelling (GAIM) task force of the International Geosphere-Biosphere Programme (IGBP) and the WGCM started in 2000 as a

[1] http://www-pcmdi.llnl.gov/projects/cmip/index.php.

strategy to couple the global carbon cycle with general circulation models (GCMs), giving rise to ESMs. As such, ESMs represent new developments in the coupled climate system modeling community. This first joint coupling coordination gave rise to the Coupled Carbon Cycle-Climate Model Intercomparison Project (C^4MIP). Initial activities of C^4MIP included the development and implementation of the carbon cycle in physical and biophysical global climate system models. The C^4MIP activity continues to develop under the joint auspices of the WCRP and the IGBP. Eleven models participated in a recent evaluation of C^4MIP (Friedlingstein et al., 2006), and contributed to Chapters 7 (Denman et al., 2007) and 10 (Meehl et al., 2007b) of the AR4.

The WGCM continues to contribute to international coupled modeling groups by evaluating climate change projections, with a focus on anthropogenic climate change, improving models, understanding feedbacks, and other applications (e.g., paleoclimate modeling). Coordinated experiments for assessment by the IPCC continue through representation of modeling groups from both the WGCM and the IGBP's Analysis, Integration and Modeling of the Earth System (AIMES) communities. It should be mentioned that while the actual model development, testing, and evaluation is performed by individual institutions, the model evaluation protocols and implementation are almost entirely reliant on voluntary contributions from the international communities as coordinated by WGCM and AIMES, highlighting the importance of coordinated collaboration and communication across the modeling communities.

One recognized challenge that is highly relevant to the new scenarios process is CM-related data management, transfer, and interpretation. As one mechanism for meeting this need, the PCMDI was established in 1989 at the Lawrence Livermore National Laboratory with the mission of developing improved methods and tools for the diagnosis and intercomparison of GCMs. In 2005, PCMDI volunteered to collect model output contributed by leading modeling centers around the world. The WGCM organized this activity in part to enable those outside the major modeling centers to perform research of relevance to climate scientists preparing for the IPCC AR4. The CMIP3 archive used by AR4 can be found at http://www-pcmdi.llnl.gov/projects/cmip/index.php.

In previous IPCC assessments, the WGCM was the group that coordinated CM research for WGI. It was clear from the AR4 that additional tools will be necessary to facilitate use of archived climate data for other communities beyond the CM community represented by IPCC's WGI. To that end, discussions are underway to coordinate distributed data systems across the IPCC working groups, including PCMDI, BADC, MPI, and TGICA. Incorporating data streams from non-climate models (e.g., impacts, mitigation, etc.) will require community-wide standards and a framework for these groups. In addition, there will need to be coordination across the climate and IAM communities regarding land use/land cover and emissions data.

IV.3 Integrated assessment modeling coordination

To help coordinate this work across the IAM teams and between them and other communities involved in global change research, an Integrated Assessment Modeling Consortium (IAMC) has been formed. So far, 37 groups have joined the consortium (see Table IV.1), and a number of others are considering joining. The mission of the consortium is scientific leadership and coordination rather than representation, and it is envisioned that its decisions will be made democratically by individuals with the appropriate expertise.

It is anticipated that the IAMC will be the main vehicle for coordinating the work of the IAM community on RCPs and subsequent IAM variants of them. This will involve coordinating work among relevant subgroups of the IAM community as well as between them and the CM, IAV, and EMIC communities. Specifically, as additional resources are sought for these activities, the three leaders of the consortium (see Table IV.1) will use existing funding to initiate work on the preparatory phase of the plan, in coordination with the other communities in subsequent phases of the work. For example, a joint meeting of modeling community and consortium members coordinating the development of the RCP scenarios was held 7–8 February 2008, in Washington, DC, immediately following a major Energy Modeling Forum (EMF) meeting, and subsequent opportunities will be created at the International Institute for Applied Systems Analysis (IIASA), the National Institute for Environmental Studies (NIES), and other venues as desired. The IAMC will also coordinate with and help organize any complementary IPCC workshops that are deemed appropriate.

IV.4 Impacts, adaptation, and vulnerability coordination and institution building

In mobilizing to connect effectively with new climate change scenarios, the IAV (vulnerability, impacts, mitigation, and adaptation) research community faces at least three significant challenges: (1) its research base is relatively small, because investments in IAV research over the past decade and a half have been only a small fraction of the investments in climate science; (2) at least partly for that reason, the IAV community is a very loose collection of researchers and research centers, most of them relatively small in scale, which lacks coherence and structure; and (3) most IAV research, both past and current, is not strongly scenario-linked—it is generally analytical rather than model-based, emphasizing risks and vulnerabilities rather than projections of impacts. Moreover, the community is growing and evolving rapidly in response to a growing demand.

These challenges make advances in IAV coordination, including appropriate institution building, a high priority for the new scenario effort. Coordination priorities include: (a) adding maturity to IAV methods by improving the understanding of methods and their appropriate use, including the adoption of standards to enhance credibility with users; (b) improving the treatment of uncertainties in analyzing and reporting IAV findings; (c) improving climate impact and response data, especially consistent time series of observations, and data management; (d) improving the understanding of relationships among impacts, adaptation, and mitigation; (e) developing a rich family of regional storylines regarding possible IAV futures and issues, with strong bottom-up participation by regional experts and stakeholders, especially in developing regions; and (f) contributing to the development of socioeconomic scenarios as an essential tool for assessing impact risks and vulnerabilities, especially for human systems.

International Institute for Applied Systems Analysis (IIASA)

- *Asbjorn Aaheim*
CICERO University of Oslo
- *Keigo Akimoto*
Research Institute of Innovative Technology for the Earth (RITE)
- *Eduardo Calvo*
WG III Bureau IPCC
- *Patrick Criqui*
Institut d'Economie et de Politique de l'Energie, IEPE-CNRS
- *Francisco de la Chesnaye*
US Environmental Protection Agency
- *Jae Edmonds*
Pacific Northwest National Laboratory
- *Allen Fawcett*
US Environmental Protection Agency
- *Brian Fischer*
CRA International
- *Donald Hanson*
Argonne National Laboratory
- *Thomas Hertel*
Purdue University
- *Jean-Charles Hourcade*
CIRED/CNRS/EHESS
- *María E. Ibarrarán Viniegra*
Universidad Iberoamericana Puebla
- *Kejun Jiang*
Energy Research Institute

Energy Modeling Forum (EMF) Stanford University

- *Mikiko Kainuma*
National Institute for Environment Studies
- *Claudia Kemfert*
DIW Berlin
- *Atsushi Kurosawa*
The Institute of Applied Energy
- *Emilio Lèbre La Rovere*
Programa de Planejamento Energético PPE/COPPE/UFRJ
- *Robert Lempert*
RAND
- *Bruce McCarl*
Texas A&M University
- *Nebojsa Nakicenovic*
International Institute for Applied Systems Analysis
- *Hom Pant*
Australian Bureau of Agricultural and Resource Economics (ABARE)
- *Hugh Pitcher*
Pacific Northwest National Laboratory
- *Keywan Riahi*
International Institute for Applied Systems Analysis (IIASA)
- *Richard Richels*
Electric Power Research Institute (EPRI)
- *Steven Rose*
US Environmental Protection Agency

National Institute for Environmental Studies (NIES)

- *Thomas Rutherford*
Economist
- *Ronald Sands*
Joint Global Change Research Institute
- *Priyadarshi Shukla*
Indian Institute of Management
- *Steve Smith*
Pacific Northwest National Laboratory
- *Brent Sohngen*
Ohio State University
- *Richard Tol*
University of Hamburg and Economic and Social Research Institute (ESRI)
- *Jose Eddy Torres*
Universidad de Los Andes / Universidad Nacional de Colombia
- *Detlef van Vuuren*
The Netherlands Environmental Assessment Agency (MNP)
- *Marc Vielle*
CEA-LERNA
- *Virginia Vilariño*
Business Council for Sustainable Development – Argentina
- *Robert Watson*
Tyndall Center for Climate Change Research
- *John Weyant*
Energy Modeling Forum, Stanford University

None of this coordination is likely to be possible, beyond small case-by-case problem solving, unless the IAV community becomes better organized and structured. At present, aside from such occasional foci as an IPCC assessment report, no one is responsible for communicating, coordinating, or otherwise making IAV community activities happen. There are no contact points, gatekeepers, or designated leaders. The top institutional coordination priority for IAV is to establish a structure, created by the community itself, linked with regional nodes, to bring coherence to the community's involvement in new climate change scenarios and to represent IAV interests in this process.

Discussions are under way within the IAV community about institution building to meet this need. During this expert meeting, the IAV participants proposed an IPCC workshop on IAV institution building early in 2008, and this idea is being pursued. This workshop would consider processes for institution building, participation in new scenario-related coordination activities in the near future, and possibly the creation of some documents for discussion by the community that address issues with relating CMs and IAMs and their findings to IAV research.

In addition, efforts are being made to convert informal networking into an appropriate consortium-type structure, recognizing the highly diverse and distributed nature of IAV research, practice, and user interactions. One challenge, however, is that such a structure is likely to have legitimacy with this particular community only if it arises from the grassroots rather than appearing to be imposed from above. Strong reasons for accelerating IAV coordination must be balanced against a potentially counterproductive backlash from colleagues who feel that they are being marginalized by a few individuals asserting leadership and control.

IV.5 Inter-group coordination issues

Developing a new international climate change scenario infrastructure, built on full collaboration among the CM, IAM, and IAV communities, is clearly essential for supporting climate change response decisions in the future. It requires, however, connecting three research communities that in most regards lack a tradition of working together and in some cases may not automatically see such close coordination as a high priority for their time and resources. Overcoming obstacles to inter-group coordination is therefore a key part of the process.

High-priority issues that need attention include the following:

- Coordination between the IAM and CM communities, as IAM emissions scenarios are communicated as bases of the new ESM scenarios;
- Coordination among the CM, IAM, and IAV communities in preparing integrated scenarios, including climate change downscaling methods and approaches and data management by the respective communities, so that data integration potentials are facilitated rather than compromised;
- Active collaboration between the IAM and IAV communities in building the scenario library;
- Coordination among the CM, IAM, and IAV communities regarding bottom-up regional and local storyline development and its linkages with new scenario development and implementation, particularly coordination between the IAM and IAV communities regarding regional initiatives; and
- Coordination among the three communities in their interactions with DC partners to be sensitive to possible human and financial resource constraints on advancements in a variety of types of expertise in the same general time frame.

In most cases, progress with these kinds of coordination needs will depend on a sincere commitment by leaders of all three communities to work together, recognizing that coordination will consume some time and resources that could otherwise be invested in the community's own agendas. In some cases, it will require resources not currently available to any of the communities.

IV.6 Next steps for coordination and institution building

In support of the new international climate change scenario infrastructure, the following four specific steps are proposed for action by the middle of 2008:

(1) An IAM/IAV community meeting to develop a joint strategy for storyline development, including plans for regional participation, encouraging especially more participation by DC/EIT researchers;
(2) An IAV community expert workshop to propose steps to build structure and add coherence to the work of that community, especially as it relates to new scenario development, and facilitating in particular the participation of DC/EIT researchers;
(3) An IAM/IAV community meeting to develop plans for the scenario library; and
(4) A joint IAM/IAV/CM discussion that provides shared insights into model assumptions and requirements within and across modeling groups.

Several other steps are also needed over the coming two years in order to address a variety of challenges in moving toward new integrated scenarios of broad value to the climate change research, policy, and stakeholder communities:

(1) A CM/IAM/IAV community expert workshop to pursue a collaborative approach to climate change downscaling and its relationships with bottom-up regional and local storyline development, with the participation of DC/EIT researchers encouraged. In addition, challenges regarding nonlinearities and lags related to pattern scaling will need to be addressed;
(2) An IAM/IAV community meeting to develop strategies for improving the integration of mitigation into IAV analyses;
(3) A joint CM/IAM/IAV community meeting with selected stakeholder groups to assure sensitivity to stakeholder concerns and information needs, with a special focus on DC/EIT countries particularly prone to severe climate change impacts in the near term;
(4) A CM/IAM/IAV community meeting to exchange information about current data management assets and practices and to identify steps that would improve prospects for data integration, with active participation of DC/EIT country experts; and
(5) A CM/IAM/IAV community expert workshop on a topic of interest to all three communities, using that topic both to advance understanding of the subject and to enhance communication among the communities (e.g., sea ice/sea level rise/coastal impacts and adaptation).

V. Increasing Developing Country Participation

The IPCC's April 2006 decision (see Box I.1), issued after its 25th Session in Mauritius, called for the enhancement of DC participation in the scenario development process. The decision's recommendation underscored the ongoing problem of identifying and involving sufficient expertise from Africa, Asia, Latin America, island states, and from countries with an economy in transition, principally in Central Europe and the former Soviet Union.

Future efforts to increase and sustain DC/EIT participation in climate change assessments must address a series of challenges that have contributed to their under-representation to date. Among these is the need for the expansion of expert and institutional scientific capacity in developing regions. There is significant variance in current levels of scientific capacity within and among developing regions, resulting in a corresponding variance in capacity for participation in international scenario development efforts and climate change assessments. Likewise, there is an ongoing need for more funding and for new funding mechanisms to support the continued participation of DC/EIT representatives in international scientific activities related to climate change. Addressing capacity and funding limitations to enhanced DC/EIT participation will demand concerted outreach and integration initiatives on the part of the broader international research and policy communities. This section addresses each of these considerations and offers specific recommendations to promote the expansion of DC participation and representation in climate change scenarios and assessments.

V.1 Developing country/economies in transition (DC/EIT) modeling and scenario development

Developing countries and economies in transition often rely on modeling and scenario development, to the extent they are available, as domestic tools to inform policymakers' decisions related to economic and social development, energy and land use planning, and other near- to mid-term policy questions. In many DCs, including most of the sub-Saharan African countries, modeling and scenario development that incorporate climate change considerations are widely used in the preparation of National Communications under the UNFCCC.[34] In broader policy and planning modeling applications however, climate change considerations less often play a leading role. In the light of their primary intended uses as short- to mid-term decision support tools for national-level public and private sector decisionmakers, DC/EIT models and scenarios, whenever available, frequently have time horizons that are significantly shorter than those of global models designed principally for climate change assessment and scenario development. For example, while global IAMs or ESMs may have time horizons extending to 2100 and beyond, models most frequently used by policymakers in developing regions are narrower in their geographical scope and sectoral coverage and have time horizons that extend in most cases to approximately 2030. The fact that DC/EIT decisionmakers use models for national-level decisionmaking also helps to explain the relative lack of regional-scale modeling efforts in these areas.

The shorter time horizons found in current DC/EIT models also reflect the higher levels of uncertainty that surround scenario projections in those areas. Factors common to many DCs, such as rapid demographic change, volatile economic growth rates, and institutional instability, all increase the

[34] As stated in Decision 2 of the Second Conference of the Parties, Paragraph 33: "Non-Annex I Parties are encouraged to include a description of approaches, methodologies and tools used, including scenarios for the assessment of impacts of, and vulnerability and adaptation to, climate change, as well as any uncertainties inherent in these methodologies."

complexities associated with scenario development, making projections beyond the short- to mid-term more speculative than in industrialized regions exhibiting higher degrees of regularity in these and other key variables. The incumbent differences in time steps, data requirements, modeling detail, and policy objectives between national-level models in DC/EIT regions and the global models often used in climate assessments may constrain transfer of information between national/regional and global models, and limit the ability of DC/EIT modelers to participate in the global discourse on climate change. Limitations on data production and availability in DCs are major constraints in this regard.

At the same time, DC/EIT representation in global emissions models may be underspecified for several reasons, including limitations on human and financial resources for model development and on data availability. Partly as a result of these limitations, there are large variations across global models in their geographic aggregations of DC/EIT regions. Such aggregations, while often necessary, diminish the ability of global models to offer plausible assessments and reduce opportunities for inter-model comparison of developing region scenarios. In addition, these aggregations may alienate some DC/EIT scientists and policymakers, who see their respective national development pathways and unique characteristics subsumed in regional modeling aggregations that they view as bearing little resemblance to reality. Since some degree of regional aggregation will always be necessary in global modeling and scenario efforts, regional scenarios produced by DC/EIT experts for incorporation in global climate and emissions models could play an important role in improving the future representation of developing regions.

Following the IPCC's 24th plenary session in Montreal in November 2005, a paper prepared by the TGICA called attention to the broad DC/EIT data and scenario needs of each of the three principal IPCC research communities (IPCC/TGICA, 2005). The TGICA noted that climate and related socioeconomic data for DC/EIT regions are often not available at the temporal and spatial scales necessary for impacts and adaptation research in these regions. For example, GCM data are frequently available only in the form of monthly means for key variables, imposing obvious limitations on the extent to which resulting scenarios can be used in IAV assessments for developing regions.

V.2 Expert and Institutional Capacity Development

The challenges associated with the enhancement and improvement of DC/EIT scenarios are complicated by apparent limitations on modeling and scientific capacity in these geographic areas. While several DC/EIT countries (e.g., Brazil, Mexico, Argentina, India, China, South Africa, Russia) have well-developed, internationally recognized modeling groups, these centers are relatively few in the DC/EIT world as a whole. Moreover, the scarcity of modeling centers in developing regions places significant burdens on the established modeling groups, which must serve as the principal voice of their regions in global climate assessments and other international fora.

Existing modeling and climate change assessment capacity in DC/EIT countries may also reflect the resource limitations and policy priorities within those regions. For example, capacity for the assessment of IAV often exceeds capacity for emissions/IAM and ESM. Consequently, the DC/EIT contributions to climate science and emissions modeling may be constrained by underlying limitations on research funding and infrastructure, as well as by the need to address more urgent policy questions associated with climate impacts and vulnerability in DCs.

To some extent, DC capacity development may also be a question of enhancing participation in the international climate change assessment and scenario development communities. As individual scientists and modeling groups gain international reputations in climate change scientific and policy circles, these researchers become the established invitees and participants in international climate change assessment circles. While there are certainly other individuals and groups that could make important contributions to the scenario development and climate change assessment processes, the difficulties associated with identifying and establishing these scientists as regular members of the international community act as barriers to the expansion of DC/EIT participation and capacity development.

In 2005, the TGICA created an IPCC-endorsed framework to facilitate the development of research capacity in DC/EIT countries. The TGICA has proposed a framework for further development of appropriate data products and capacity development in DC/EIT countries, based on the development of a network of institutions and individual researchers in countries with well-developed, moderate, and underdeveloped scientific capacity and ability to produce necessary data and scenario products. The TGICA proposal outlines a 5- to 10-year training and network-building program under which researchers in high-capacity countries would engage with young scientists in moderate- and underdeveloped-capacity countries in a tiered mentoring relationship. Because the IPCC does not have a training mandate, the TGICA suggests that such a program be implemented by an institution like the System for Research, Analysis, and Training (START), which has an established history of assisting in the professional development of young scientists from developing countries. To date, however, there has not been any action on the TGICA proposal. This proposal may be considered in the future under the agenda items of the Conference of the Parties to the UNFCCC.

V.3 Funding DC/EIT participation and capacity development

As noted previously, financial limitations constitute one of the most evident barriers for experts from DC/EIT countries to participate actively in the scenario-building process. As a point of reference, authors from DC/EIT countries only accounted for about 17% of the list of authors (including lead authors and contributing authors) in the 2000 IPCC SRES.

Financial needs of DC/EIT countries in the scenario development process here refers specifically to funding constraints that limit the involvement of experts from these regions in the following activities:

- Participation in international workshops/seminars;
- Institutional capacity building; and
- Networking activities and multidisciplinary approaches.

Up to now, the IPCC, through a dedicated trust fund, has provided full travel and per diem funding for experts from DC/EIT countries to travel to the expert workshops and lead author meetings addressing the scenario process. While the IPCC trust fund has been a unique and indispensable source of support in this regard, its limited budget has also had the effect of limiting the number of DC/EIT experts who have participated in IPCC expert meetings.

While accepting that funding limitations present constraints to all scientific activities and not only to the participation of DC/EIT experts, both an increase in IPCC trust fund resources and the establishment of new DC/EIT financing mechanisms will be essential elements of a strategy to enhance and sustain ongoing participation of DC/EIT experts in the scenario development process. Other institutions that appear well-positioned to play a role in future support for DC/EIT expert participation include multilateral development banks (e.g., World Bank, African Development Bank, Asian Development Bank, and Inter-American Development Bank), and international development agencies such as UNDP and UNEP. Regional energy organizations in the developing world, such as the Organizacion Latinoamericana de Energia, may also consider future support.

As the financial capacity of existing DC/EIT institutions is constrained, frequently small expert teams or even individual experts make great efforts to combine their participation in various scenario initiatives/projects that involve multiple coordinating institutions. Because of their relative scarcity, these teams or individual experts tend to be overburdened and this situation may adversely affect the quality of their work, their innovation potential, and their availability for training young researchers. Moreover, the contending demands of the domestic and international policy communities pull these researchers in divergent directions, spreading their time and other resources very thinly.

In many cases, due to the limited financial capacity and the concomitant narrow technical capacity of DC/EIT institutions, modelers and scenario experts from these countries who participate in global exercises are involved in top-down processes with few options to shape or enrich the projects with a more detailed bottom-up approach based on their own direct experiences of the socioeconomic and environmental conditions in these regions/countries. This situation underscores the need for sustained efforts to enhance DC/EIT capacity and to involve researchers from these regions in scenario efforts from the earliest design stages.

Thus, in thinking about future efforts to finance DC/EIT institutional capacity building, it will be important to consider both the qualitative (i.e., narratives and storylines) and the quantitative (quantification and model results) components of scenarios and to involve DC/EIT experts in these discussions from the beginning. Incorporating both of these elements will help to integrate top-down and bottom-up perspectives in climate assessments, scenarios, and other international scientific activities.

Funding limitations on DC/EIT country participation also place constraints on the multidisciplinary approach required by the scenario development process. This approach refers to the integrated analysis of multiple drivers of change, including economic, social, demographic, and environmental factors. This approach also requires intensive international networking and interaction among researchers, and long-term linkages among collaborating institutions and experts. Since international interdisciplinary networks and relationships are the product of sustained interactions among researchers, deepening the presence of DC/EIT scientists in international research networks will require an ongoing commitment of resources for this purpose. The promotion of networking activities also implies the improvement of the research infrastructure and technologies for information and communications, particularly in the poorest countries.

Few formal mechanisms exist to support ongoing DC/EIT participation in international scientific activities. In the context of the IPCC, the main contribution to the support of DC/EIT institutions and experts involved in the scenario development projects has been oriented to finance travel needs of experts from these regions to ensure a certain geographical balance in the writing teams and expert meetings. Assistance from the IPCC has also included financing meetings and publications.

Other international institutions have provided limited support for scenario building by providing travel support, grants to expert participants, and defraying related administrative costs. For example, that was the case with the scenarios chapter of the Global Environment Outlook (GEO4) Project, coordinated by UNEP. That chapter was prepared using a networking process that included a core team, consisting of the chapter coordinators and representatives from key modeling groups and seven world regions, and the associated modeling groups and seven regional teams. The latter consisted of, among others, participants from the GEO Collaborating Centres and included people with experience in previous scenario exercises, including those of GEO3 and the IPCC

In this context, the TGICA proposal (see Section V.2) should be encouraged as a primary vehicle for the expansion of research capacity in DC/EIT countries. The strength of this proposal lies in its strong emphasis on a tiered system of inter- and intra-regional networking with a designated institution to coordinate the project implementation.

The idea (adopted from UNEP) of establishing a global network of representative “collaborating centers/institutions” within different regions could be particularly useful in the process of preparing new scenarios. These regional or subregional collaborating centers would administer the use of funds received for their operation in the region/subregion, and would facilitate the interaction among institutions and experts from specific regions/subregions. These institutions might also serve as regional hubs for data collection and for coordination with key global research consortia such as the PCMDI and the IAMC.

V.4 Coordination and outreach

Many of the institutional and coordination issues addressed in Section IV apply to DC/EIT regions, which are important stakeholders in the scenario production process. As contributors to the scenario production process and as scenario users, DC/EIT countries must be engaged through a series of coordination and outreach mechanisms suited to their particular needs and considerable potential to contribute data, information, and expertise relevant to the creation of new scenarios.

As contributors to and users of new scenarios, DC/EIT regions are likely to have particular interest in a subset of the different types of scenarios that are available for use. From a user perspective, short-term scenarios with a 20- to 30-year time horizon will be needed for policy planning and mitigation analysis as well as for vulnerability assessment and adaptation planning. Shorter-term scenarios will be especially important considering the likelihood that climate change impacts will affect low latitudes, where most developing countries are located, more seriously in the short- to mid-term than countries at higher latitudes.

The development of new qualitative regional storylines integrating national socioeconomic trends and emissions projections with IAV assessments in a consistent framework will also be important for subsequent regional and global modeling efforts to more accurately represent DC/EIT priorities concerning sustainable development and, thus, to meet the needs of policymakers and other user groups. An important step in the process of drafting storylines will be the identification and compilation of data on relevant regional/subregional indicators (socioeconomic, environmental, and climate change indicators) through regular consultations with local experts and stakeholders, including contributions by regional/subregional organizations. The learning process that these interactions will foster will be essential to the development of accurate and consistent storylines.

While efforts to create higher resolution intraregional models and scenarios within DC/EIT regions are now under way via institutions such as the Asian Energy Economic Modeling Forum and Argentina's Centro de Estudios en Optimizacion y Simulacion, such initiatives are at an early stage of development. Similarly, global IAMs and ESMs frequently have low resolution for DC/EIT regions due to data and other resource limitations, and by necessity aggregate these regions in ways that yield less than satisfactory results. Coordination with DC/EIT researchers and institutions will be essential to the production and collection of regionally and sectorally disaggregated data that will facilitate the improvement of DC/EIT representation in future modeling and scenario efforts.

Stronger coordination between DC/EIT researchers and user community members could begin with new outreach efforts on the part of key data and research institutions. For example, the PCMDI and the newly formed IAMC could be primary vehicles for outreach to DC/EIT regions by the CM and IAM communities, respectively.[35] For that matter, several DC/EIT institutions have already joined the IAMC and now may find an opportunity through the consortium to contribute to improved representation of their regions in the scenario creation process. While the IAV community does not yet have a similar coordinating body, storyline development exercises coordinated by the IAMC could offer near-term opportunities for the integration of IAV considerations and perspectives into DC/EIT regional storylines and scenarios.

Finally, there is a clear need for coordination on the part of the key DC/EIT research communities and user groups to organize themselves in order to specify their own respective needs, perceived strengths and weaknesses, data gaps, and opportunities for linkage with other institutions in the broader global research community. Such self-organization could be facilitated by third parties such as the IPCC Bureau, WCRP, TGICA, or other international bodies, and could help the DC/EIT research communities to determine their own strategic goals for enhanced coordination and linkage with the larger community. Capacity building, including the development of new research communities in areas with the fewest scientific and technical resources, will be particularly important.

The qualitative and quantitative improvement in the participation of DC/EIT experts in the global scenario exercise would imply that the priorities, concerns, and main socioeconomic and environmental challenges of these regions would be captured to a greater extent by the writing teams. Thus, the resulting report would be more attractive in the respective regions and subregions as a policy tool for informed actions in this field.

The success of the scenario exercise is based on its conception as a process (rather than an end in itself) that requires systematic interaction between the authors and the users through an ongoing system of consultations, diffusion of partial results, organization of meetings for stakeholders, and similar activities. As a continual learning enterprise, this process will be particularly important for DC/EIT institutions (research centers, universities, etc), as well as decisionmakers at different government levels, NGOs, and others. An important goal and likely result of deeper, more sustained involvement of DC/EIT researchers in international scenario development will be the integration of DC/EIT issues and

[35] DC/EIT member institutions of the IAMC currently include Universidad Iberoamericana Puebla (Mexico), Universidad Federal do Rio de Janeiro (Brazil), the Indian Institute of Management (India), the Energy Research Institute (China), the Business Council for Sustainable Development (Argentina), and the Universidad Nacional de Colombia (Colombia).

concerns in the analytical frameworks used by policymakers and analysts across the main global research communities.

V.5. Recommended actions

The following proposed actions constitute the elements of a plan to promote the accelerated development of DC/EIT capacity and enhance the participation of these regions in future scenario development and climate change assessment. The recommendations are grouped according to their relevance to each of the specific challenges discussed in Sections V.1 through V.4, although there is inevitably and necessarily overlap among recommendations in each area.

A principal recommendation is that the IPCC sponsor a workshop in 2008 dedicated to addressing the manifold challenges associated with efforts to expand DC/EIT scientific capacity and participation in international scenario development and climate assessment activities. Such a workshop would provide an opportunity for key members of the research community to begin discussing and prioritizing the actions listed below, to identify additional or alternative recommendations, and to initiate the development of new inter-/intra-regional networks for sustained DC/EIT capacity building and deeper participation in the international research community.

1. Modeling and Scenario Development

- Inventory and assess current intraregional modeling representation in DC/EIT countries and identify data and institutional needs, capacity limitations, and opportunities for/barriers to intraregional coordination and linkage among IAMs and ESMs.
- Inventory and assess current DC/EIT representation in key global IAMs and ESMs. Key issues to address include key variables, data sources and availability, scalability, and questions of intraregional aggregation.
- Foster collaboration among DC/EIT modelers for intraregional model integration and for collaborative efforts with global modelers for the improvement of DC/EIT representation, the development of new regional storylines and scenarios, and for scenario downscaling/upscaling in preparation for a possible AR5.

2. Expert and Institutional Capacity Development

- Establish and sustain DC/EIT scientific peer groups to identify key areas for capacity development and expansion, and for the nomination of peers as potential participants in future modeling and scenario development institutions.
- Promote intra- and trans-regional DC/EIT modeling and scenario development initiatives, modeled on existing programs such as those managed by START, the Hadley Center, and other institutions with training and capacity-building missions, to develop deeper and broader scientific capacity in DC/EIT regions and to expand data development and availability, as described in the 2005 TGICA framework proposal. Capacity building for downscaling and upscaling of model results should be a key area of emphasis.
- Establish an online network/clearinghouse of DC experts and institutions to familiarize the international scientific community with existing capacities, foster communication among individual researchers and modeling groups, and call attention to geographic and disciplinary areas in which additional capacity building is needed.

3. Funding DC/EIT participation and capacity development

- Identify potential donor institutions for sustained financial sponsorship of capacity building efforts. These might include multilateral institutions (e.g., World Bank, regional development banks), international organizations such as the UNDP, national governments, and private scientific and educational foundations such as the Gates Foundation.
- Identify potential collaborating centers and institutions to serve as lead agencies for the management of funding for future efforts to build DC/EIT capacity and participation and to serve as grantmaking and networking institutions.
- Establish a trust dedicated to funding fellowships for young scientists from DC/EIT regions to study and work abroad with leading modelers and scientific research groups.

4. Coordination and Outreach

- Identify key areas for capacity building, research, and storyline and scenario development; existing DC/EIT data limitations and needs; IAV assessment capacity needs; and potential avenues of inter-regional coordination and financial support for sustained efforts to address these problems.
- Promote stronger coordination between DC/EIT researchers and user community members beginning with new outreach efforts on the part of key data and research institutions. For example, the PCMDI and the IAMC could be primary vehicles for outreach to DC/EIT by the CM and IAM communities, respectively.
- Promote exchanges and collaborative efforts between DC/EIT regions and modeling groups in industrialized countries to develop capacity in regions and in areas currently receiving less attention in DC/EIT areas (e.g., IAM, ESM) and to establish institutional relationships among younger modelers and emerging groups in key DC/EIT countries and established groups in industrialized countries.

VI. Conclusion

This section summarizes the ways in which the parallel process for development of climate change scenarios described in this report relates to the six general questions introduced in Section I.

1. Can new integrated scenarios that meet user needs be produced with the available resources and completed in time for consideration in a possible future IPCC assessment?

Earlier approaches to the use of scenarios in climate change science have followed the sequence of development of a complete set of emissions scenarios, development of the corresponding complete set of climate change simulations, and finally development of a range of matching impact and adaptation analyses. This stepwise process involved delays of many years in transferring information between the relevant IAM, CM, and IAV communities. The parallel process now planned by these science communities will reduce the time required for such transfers through better coordination at all stages so that each community can start to work within the same overall framework as soon as possible.

In addition, the early agreement on RCPs and generation of the corresponding climate simulations using ESMs will open the way to using pattern scaling as a means to construct climate change scenarios corresponding to additional socioeconomic and emissions scenarios as those are subsequently developed, without requiring the very time-consuming ESM runs. While the full validity of pattern scaling in this context requires further research (see question 3 below) the parallel process will clearly be able to provide more consistent analyses across the different disciplines than have been available for an IPCC assessment at any stage in the past.

The timetable discussed in this report has been set following extensive interdisciplinary discussions. It will require strict limits on the number of scenarios to be considered by the CM community, which has indicated that there are only resources for comprehensive runs for two to four RCPs within the necessary time frame. However, the focus by the CM community on larger ensembles for fewer emissions scenarios will provide better information for subsequent IAV analyses, as it will allow probabilistic estimation of uncertainties in future climate change (e.g., due to uncertainties in climate parameters such as climate sensitivity), and in particular will enable more robust analyses of changes in extreme events that are critical to impacts.

Although the research community is confident that the parallel approach and the timetable given here will provide a better framework for future IPCC assessments, it is important to recognize that the approach now planned is untested and by its nature involves new types of interdisciplinary interactions. There remain significant underlying differences of approach in different areas of climate change science and the extent to which these may limit the effectiveness of the parallel process remains to be seen. Given this exploratory nature of what is now being planned in the science community, it should be understood that interdisciplinary consistency and synthesis is more likely to be available for a comprehensive IPCC assessment in 2014 or later, than in 2013.

2. To what extent can concentration pathways be usefully abstracted from underlying emissions and socioeconomic changes?

Although a very large number of emissions scenarios now exist, from a physical climate perspective these can be spanned by a much smaller number of radiative forcing pathways. This suggests that many different socioeconomic and technological pathways may map to climate change scenarios that are indistinguishable within natural climate variability and ESM uncertainties. However, as noted earlier, only a relatively small number of emissions scenarios provide details for all the species now required in ESMs. In addition, the prescription of regional-scale evolution of land use/land cover, aerosol emissions, tropospheric ozone precursors, and other factors influencing climate now introduces potentially tighter linkages to socioeconomic and technological factors than has been the case when only global-scale long-lived GHG emissions were used for climate modeling.

The emergence of new dependencies between what is required by ESM simulations and the underlying socioeconomic assumptions means that we cannot assume that significantly different socioeconomic pathways could produce effectively equal climate scenarios, particularly at the regional scale that is important for IAV studies. As a result, the range of socioeconomic pathways that may be consistent with a particular pathway for radiative forcing or global and regional climate change can only be identified through further research. The parallel modeling and integration phases of the parallel process described in Section II of this report will provide an initial basis for such research.

3. To what extent can climate changes be interpolated between forcing levels?

As noted earlier, the later stages of the parallel process envisaged here will use pattern scaling between climate change scenarios developed for the RCPs to generate climate change scenarios corresponding to new emissions scenarios that fall between the high and low RCPs. The robustness of this pattern-scaling approach has been tested to some extent for AOGCMs (e.g., Mitchell et al., 1999), but is likely to be reconsidered in light of new results from the more complex ESMs. Major tools for such work are simple and regional CMs and models of intermediate complexity (e.g., Mitchell, 2003; Ruosteenoja et al., 2007) and further research will be needed to ensure that these can be calibrated or matched to ESMs. To date, pattern scaling techniques have employed linear assumptions about the scaler (e.g., annual global mean temperature) and the pattern of response at the regional scale (see above references). At this stage, it is generally expected that pattern scaling will be more reliable for climate variables such as average temperature than for variables such as precipitation or for identifying extreme or rare events. Although the AR4 model runs suggest that broad patterns of precipitation change are common to different scenarios used in AOGCMs, these generally reflect the effect of atmospheric water vapor increases. Higher spatial resolution in future simulations may introduce greater local dependence on orography and regional-scale feedbacks, (e.g., soil moisture loss, frost days, and land cover change), which are less likely to scale linearly with the applied radiative forcing (Ruosteenoja et al., 2007).

Regions where significant feedbacks occur, such as on the margins of snow and ice cover or where significant land cover change occurs, may also show temperature changes that do not scale with radiative forcing. In addition, there are potential thresholds in the physical climate system, such as the transition from positive to negative surface mass balance of the Greenland Ice Sheet, whose effects are unlikely to be captured by a simple linear scaling approach. Finally, the introduction of an overshoot scenario for the low RCP raises the prospect of physical and biological systems switching their responses from a warming world to a cooling world over a range of quite different time scales. The applicability of linear scaling in such circumstances is untested but appears likely to be less robust than scaling between climates in which the responses are all occurring in the same direction.

Thus, although there is an expectation that some climate variables will scale linearly in some regions, the overall robustness of the pattern-scaling approach will need to be re-evaluated when new model results are available. This can be performed to some extent using an RCP intermediate between the high and low cases, and can be done by specific research projects in the CM and IAV communities.

4. What information can be provided in the form of downscaled climate and socioeconomic information for use by the IAV community?

The physical climate variables to be diagnosed by ESMs are well defined and the issues involved in downscaling these from the resolution of global ESMs to regional and local scales more appropriate for IAV studies are generally understood. In some respects such downscaling raises similar issues to those of scaling with radiative forcing as discussed above and many of the same caveats occur. Downscaling the magnitude and frequency of extreme events is particularly important for determining impacts and this merits further research, for example, working from the existing archive of AOGCM results for the AR4. Downscaling of physical climate variables may be advanced by further reviews of the techniques, agreement on best practice, and improving the accessibility of archived products for IAV analyses.

Issues that are more difficult are raised in relation to downscaling the major socioeconomic and technological assumptions that determine the RCPs from the macro scale, where they are prescribed or diagnosed in the IAM community, to the regional and local scales where they influence adaptive capacity. In this regard, a merging of bottom-up and top-down perspectives as discussed below for question 5 will be helpful. For example, consistency across different scales can be improved by the development of regional storylines that are compatible with one another and with the global scenario underlying the RCPs.

Further work on downscaling for physical variables will require collaboration between the CM and IAV communities, and for socioeconomic factors will require collaboration between the IAV and IAM communities. In both cases, primary responsibility rests with the IAV community, which is in the best position to judge the type of results required and the value and robustness of what can be produced. The TGICA and the DDC are well placed to provide the necessary organizational and archival infrastructure to support such collaborations.

5. How can disaggregated analyses of mitigation opportunities at the scales of large countries (e.g., China, India, and the United States) or regions (e.g., European Union) be undertaken in a way that can be related to more highly aggregated global scenario studies using IAMs?

The rapidly growing interest of governments in determining strategic plans for emissions within their jurisdiction, and the many studies already being undertaken for regional initiatives that would reduce carbon intensity or increase energy efficiency, signal a clear need to keep such developments in mind when considering future emissions scenarios. Regional considerations can have significant implications for investment strategies (in relation to both adaptation and mitigation), the nature and scale of new infrastructure, the rate at which new technologies penetrate markets, and the governance structure that affects the balance between individual and communal decisions. One technique for ensuring consistency between the regional and global levels is through use of storylines that carry sufficient contextual detail to allow the matching of compatible changes across different regions and ultimately with a world view of each scenario considered.

New institutional interactions may be needed to ensure that regional policy options are promptly and effectively considered in relation to emissions scenarios used for research purposes. Several international organizations are already involved in such work and could contribute their perspectives and knowledge base. However, it may be necessary to demonstrate more clearly to such organizations that their interests can be advanced through analyses of climate change impacts and vulnerability, or of regional- to global-scale economic interactions, by the international research communities.

This is an area in which experts from DC/EIT countries should clearly play major roles. Such local experts provide the best means of linking their government strategies to international research, and provide the local credibility that one would expect international funding agencies to be looking for when considering new research initiatives.

6. How can the proposed scenario process be strengthened to evaluate key dimensions of uncertainty (e.g., in our understanding of key natural processes or socioeconomic futures)?

Scenario analyses are themselves a primary tool for exploring uncertainties in future climate change. The parallel process envisaged here, through its early agreement on RCPs followed by its development of new scenarios, will extend the work undertaken for the SRES scenarios and provide new insights into the factors in socioeconomic development that are most influential in determining future climate change, its impacts, and human and natural vulnerabilities.

The growing regional disaggregation of factors that underlie scenarios and the increasing sophistication and spatial resolution of ESMs should be used to provide additional information on those uncertainties that are common to all regions and those that are of more importance within particular areas or sectors. The strategy of covering the full range of plausible scenarios should also allow identification of the widest possible range of thresholds in the physical climate system as well as consideration of the key aspects and timing of socioeconomic and technological change that may act as bifurcation points in determining world futures. The introduction of an overshoot scenario for the low RCP will raise, for the first time, important issues of recovery of physical and biological systems.

The focus on two or four RCPs that are well spaced in terms of radiative forcing, and the generation of large ensembles of simulations for these cases, should provide a better focus for future IAV studies in terms of reducing uncertainties in determining the impacts of extremes. It will also support new intercomparisons and assessments of the methodological and sectoral modeling uncertainties in IAV analyses. This focus on fewer and more clearly separated future climate scenarios should also enable better estimates of avoided impacts.

The summary above indicates many areas in which future research is clearly needed to ensure that the parallel process is effective in bringing together a truly cross-disciplinary synthesis of research on climate change. By its nature, research can uncover new sources of uncertainty, however, through accelerating the transfer of information between disciplines, the parallel process described in this report should address currently known uncertainties more rapidly and comprehensively than would be possible otherwise.

References

Clarke, L., J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, and R. Richels, 2007. *Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations*. Sub-report 2.1A of Synthesis and Assessment Product 2.1 by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Department of Energy, Office of Biological & Environmental Research, Washington, DC, 154 pp.

Denman, K.L., G. Brasseur, A. Chidthaisong, P. Ciais, P.M. Cox, R.E. Dickinson, D. Hauglustaine, C. Heinze, E. Holland, D. Jacob, U. Lohmann, S. Ramachandran, P.L. da Silva Dias, S.C. Wofsy, and X. Zhang, 2007. Couplings between changes in the climate system and biogeochemistry. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, pp. 499–587.

Fisher, B.S., N. Nakicenovic, K. Alfsen, J. Corfee Morlot, F. de la Chesnaye, J.-Ch. Hourcade, K. Jiang, M. Kainuma, E. La Rovere, A. Matysek, A. Rana, K. Riahi, R. Richels, S. Rose, D. van Vuuren, and R. Warren, 2007. Issues related to mitigation in the long term context. In: *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Metz, B., O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer (eds.)]. Cambridge University Press, Cambridge, pp. 169–250.

Friedlingstein, P., P. Cox , R. Betts, W. von Bloh, V. Brovkin, S. Doney, M. Eby, I. Fung, B. Govindasamy, J. John, C. Jones, F. Joos, M. Kawamiya, W. Knorr, K. Lindsay, H.D. Matthews, T. Raddatz, P. Rayner, C. Reick, E. Roeckner, K.-G. Schnitzler, R. Schnur, K. Strassmann, S. Thompson, A.J. Weaver, and N. Zeng, 2006. Climate-carbon cycle feedback analysis, results from the C^4MIP model intercomparison. *Journal of Climate*, **19**:3337–3353.

Fujino, J., R. Nair, M. Kainuma, T. Masui, and Y. Matsuoka, 2006. Multigas mitigation analysis on stabilization scenarios using AIM global model. *Multigas Mitigation and Climate Policy. The Energy Journal Special Issue*. pp. 343–354.

Govindasamy, B., P.B. Duffy, and J. Coquard, 2003: High-resolution simulations of global climate, part 2: Effects of increased greenhouse gases. *Climate Dynamics*, **21**:391-404.

Hibbard, K.A., G. Meehl, P. Cox, and P. Friedlingstein, 2007. A strategy for climate change stabilization experiments. *Eos*, **88**(20):217,219,221, doi:10.1029/2007EO200002.

Hijioka, Y., Y. Matsuoka, H. Nishimoto, M. Masui, and M. Kainuma, 2008. Global GHG emissions scenarios under GHG concentration stabilization targets. *Journal of Global Environmental Engineering*, **13**:97-108.

IPCC, 2007a. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.)]. Cambridge University Press, 976 pp.

IPCC, 2007b. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Metz, B., O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds.)]. Cambridge University Press, 851 pp.

IPCC/TGICA (Intergovernmental Panel on Climate Change, Task Group on Data and Scenario Support for Impact and Climate Analysis), 2005. *Framework to Facilitate Development of Appropriate Data Products and Research Capacity in Developing and Transition-Economy Countries*, 12 December,http://www.ipcc-data.org/guidelines/TGICA_Data_and_Capacity_Building_Proposal.pdf

IPCC/TGICA, 2007: *General Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment*. Version 2. Prepared by T.R. Carter on behalf of the Intergovernmental Panel on Climate Change, Task Group on Data and Scenario Support for Impact and Climate Assessment, 66 pp, http://www.ipcc-data.org/guidelines/TGICA_guidance_sdciaa_v2_final.pdf.

Jiang, K., X. Hu, and Z. Songli, 2006. Multi-gas mitigation analysis by IPAC. *Multigas Mitigation and Climate Policy. The Energy Journal Special Issue.*

Kurosawa, A., 2006. Multigas mitigation: an economic analysis using GRAPE model. *Multigas Mitigation and Climate Policy. The Energy Journal Special Issue.*

Meehl, G.A., K. Hibbard, and meeting participants, 2007a. *A Strategy for Climate Change Stabilization Experiments with AOGCMs and ESMs*. Report of the Aspen Global Change Institute 2006 Session: Earth System Models: The Next Generation, 30 July – 5 August 2006, Aspen, Colorado. WCRP Report No. 3/2007, ICPO Publication No. 112, IGBP Report No. 57, 37 pp., http://www.aimes.ucar.edu/activities/WCRP/Aspen_WhitePaper_final.pdf.

Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver, and Z.-C. Zhao, 2007b. Global climate projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, pp. 747–843.

Meinshausen, M., B. Hare, T.M.L. Wigley, D. van Vuuren, M.G.J. den Elzen, and R. Swart, 2006. Multi-gas Emissions Pathways to Meet Climate Targets. *Climatic Change*, **75**:151.

Mitchell, J.F.B., T.C. Johns, M. Eagles, W.J. Ingram, and R.A. Davis, 1999: Towards the construction of climate change scenarios. *Climatic Change*, **41**, 547–581.

Mitchell, T.D., 2003: Pattern scaling: an examination of the accuracy of the technique for describing future climates. *Climatic Change*, **60**, 217–242.

Plattner, G.-K., F. Joos, T.F. Stocker, and O. Marchal, 2001. Feedback mechanisms and sensitivities of ocean carbon uptake under global warming. *Tellus*, **53B**:564–592.

Rao, S., and K. Riahi, 2006. The role of non-CO_2 greenhouse gases in climate change mitigation: long-term scenarios for the 21st century. *Multigas Mitigation and Climate Policy. The Energy Journal Special Issue.*

Reilly, J., M. Sarofim, S. Paltsev, and R. Prinn, 2006. The role of non-CO_2 GHGs in climate policy: analysis using the MIT IGSM. *Multigas Mitigation and Climate Policy. The Energy Journal Special Issue*.

Riahi, K., A. Gruebler, and N. Nakicenovic, 2007. Scenarios of long-term socioeconomic and environmental development under climate stabilization. *Greenhouse Gases - Integrated Assessment. Special Issue of Technological Forecasting and Social Change*, **74**(7):887–935, doi:10.1016/j.techfore.2006.05.026.

Ruosteenoja, K., H. Tuomenvirta, and K. Jylhä, 2007. GCM-based regional temperature and precipitation change estimates for Europe under four SRES scenarios applying a super-ensemble pattern-scaling method. Climatic Change, **80**:193–208, doi:10.1007/s10584-006-9222-3.

Smith, S.J., and T.M.L. Wigley, 2006. Multi-gas forcing stabilization with the MiniCAM. *Multigas Mitigation and Climate Policy. The Energy Journal Special Issue.*

van Vuuren, D.P., B. Eickhout, P.L. Lucas, and M.G.J. den Elzen, 2006. Long-term multi-gas scenarios to stabilise radiative forcing - Exploring costs and benefits within an integrated assessment framework. *Multigas Mitigation and Climate Policy. The Energy Journal Special Issue.*

van Vuuren, D.P., M.G.J. den Elzen, P.L. Lucas, B. Eickhout, B.J. Strengers, B. van Ruijven, S. Wonink, and R. van Houdt, 2007. Stabilizing greenhouse gas concentrations at low levels: an assessment of reduction strategies and costs. *Climatic Change*, **81**:119–159.

van Vuuren, D.P., M. Meinshausen, G.-K. Plattner, F. Joos, K.M. Strassmann, S.J. Smith, T.M.L. Wigley, S.C.B. Raper, K. Riahi, F. de la Chesnaye, M. den Elzen, J. Fujino, K. Jiang, N. Nakicenovic, S. Paltsev, and J.M. Reilly. Temperature increase of 21st century stabilization scenarios (submitted).

Wigley, T.M.L., and S.C.B. Raper, 2001. Interpretation of high projections for global-mean warming. *Science*, **293**:451–454.

Appendix 1: Data Requirements for RCPs

This appendix defines the RCP data requirements of the climate and atmospheric chemistry modeling communities, and therefore the data that the IAM community needs to produce for each RCP. As discussed in Section III, in general terms these requirements include data on emissions and concentrations of GHGs, emissions of aerosols and chemically active gases, and land use and land cover. Additional issues are the need for spatially explicit emissions and land use data, and extensions of pathways to 2300.

Table A1.1 summarizes the CM data requirements for serving both near- and long-term CM community needs (whether data needs will differ significantly for the two types of simulations is a question that will be resolved through continuing discussion among relevant communities). The remainder of this appendix discusses the following issues in more detail: (1) the process of producing the required data; (2) harmonization of model output and base year data; (3) downscaling; (4) extension to 2300; (5) chemically active gases; and (6) land use and land cover data.

A.1 Process

The IAMs responsible for the RCPs will need to do additional work to finalize the data for transfer to the ESM and atmospheric chemistry modelers. This includes extending data to 2300, downscaling land use and emissions data, potential standardization of historic data representations, and potential standardization of methods used to finalize the data. This process takes time for proper development and implementation of methods and rigorous evaluation. For example, some modeling teams will need to implement spatial downscaling techniques in order to provide gridded results. As this will lead to information that will be attached to the originally published scenario, a review is needed that will be organized by IAM community. It has been proposed that the IAM teams review one another's results. It should be noted that, while not anticipated, the evaluation process could lead to changes in the eligibility of a scenario for an RCP.

The data are to be reviewed across the IAM teams during the summer of 2008, and are to be provided to the CM community no later than fall 2008.

It is proposed that the different IAM teams involved in providing data for the RCPs work together with representatives of the CM community. The cooperation between the teams could ensure consistency between the different tools that are applied, including possible decisions on standardizing techniques. Standardizing techniques across models would eliminate one source of heterogeneity in the results, but possibly at the expense of benefiting from specialized tools developed by the different teams for their specific model characteristics.

Working groups will be set up for the different steps with regard to 1) concentrations and emissions (standardization of output; harmonization and extension beyond 2100) and 2) land use. In the period until early spring 2008, these working groups will explore differences among the modeling teams, and propose activities to perform each of the steps mentioned above. A meeting was held 7–8 February 2008 (see Section IV.3) in which the two working groups, IAM teams, and climate modelers reconvened and decided on methodologies that will be applied.

Table A1.1. *Information needed by CM groups.*

Variable	Units	Spatial scale	
		Concentrations	**Emissions**
Greenhouse gases			
CO_2 (fossil fuel, industrial, land use change)	ppm and Pg/yr	Global average	Sum
CH_4	ppb and Tg/yr	Global average	Grid[1]
N_2O	ppb and Tg/yr	Global average	Sum
HFCs[2]	ppb and Tg/yr	Global average	Sum
PFCs[2]	ppb and Tg/yr	Global average	Sum
CFCs[2]	ppb and Tg/yr	Global average	Sum
SF_6	ppb and Tg/yr	Global average	Sum
Aerosols[2]			
Sulfur (SO_2)	Tg/yr	Generated by CM community[3]	Grid
Black Carbon (BC)	Tg/yr	Generated by CM community[3]	Grid
Organic Carbon (OC)	Tg/yr	Generated by CM community[3]	Grid
Chemically active gases			
CO	Tg/yr	Generated by CM community[3]	Grid
NO_x	Tg/yr	Generated by CM community[3]	Grid
VOCs[2]	Tg/yr	Generated by CM community[3]	Grid
NH_3	Tg/yr	Generated by CM community[3]	Grid
Land use & land cover			
CO_2 flux (land use change)	Tg/yr	n/a	≤ 1° x 1°
Land use & land cover	Fraction of types[4]	Regional results (grid)	

Notes:
[1] The CM community has expressed an interest in specifying all RCPs at the same grid, for both the near- and long-term, e.g., 0.5° x 0.5° or 1.0° x 1.0°. The exact grid chosen will be specified further in discussion between the CM and IAM communities.
[2] Additional information by species and/or sector is required. This will be specified further in discussion between the CM and IAM communities. For volatile organic compounds (VOCs), for example, a preferred distinction for VOC emissions could be 1) transport, 2) fossil fuel production, 3) biomass burning, and 4) other. For hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and chlorofluorocarbons (CFCs), specification of particular species can be important given their different lifetimes. Nevertheless, in ESMs aggregated numbers are sometimes used. Exact specification will be determined in discussion between the two communities.
[3] The CM community will be generating this information from IAM emissions data. Ozone (O_3) concentrations are not included in the table as IAMs calculate these concentrations at a scale too coarse to be meaningful for the CM community. Emissions of O_3 precursors are provided instead. ESMs and/or chemistry-transport models will provide O_3 distributions. For several other gases, a comparable approach will need to be used, since the coarse scale of IAMs does not provide meaningful information for the CM community.
[4] The specification of land use classes is elaborated further in Section A.6.

In addition to finalizing the data transfer elements, the IAM and CM communities need to review the overall modeling approaches and evaluate differences across RCPs and CMs in the following areas: 1) the level and spatial distribution of aerosols and chemically active gases, and 2) land use patterns, in order to estimate the potential sensitivity of CM runs to these differences. An additional issue to consider for future research is differences in terrestrial carbon cycle modeling, where regional climate feedbacks have significant implications for land use.

The selection of RCPs is based on their differences in radiative forcing. In subsequent use, it is proposed that the climate results of the RCPs can be used to cover a range of radiative forcing levels by scaling procedures. This assumes that the climate response of the RCPs can indeed primarily be explained by their radiative forcing differences. For well-mixed GHGs, initial calculations using simple CMs suggest that this condition is indeed met—and that differences in for instance the composition of GHG emissions under the selected target have only a minor influence (van Vuuren et al., submitted). However, interpretation of the climate scenarios, especially regional and geographic patterns of change, could be complicated by aerosols, ozone, and land use change. These factors have been shown to be important for climate signals in ESMs. The complications that these factors may pose for scaling are particularly important if differences among the different RCPs are large and not correlated in a logical way to radiative forcing.

The peer review process may also propose additional requirements for the RCPs of ESM runs, including standardization requirements (e.g., the same downscaling procedures used for each RCP) and/or CM community runs that explore the influence of these variables.

A.2 Harmonization of model output and base year data

The IAM community is already undertaking activities to compare: 1) regional definitions, 2) sectoral definitions (for emissions), and 3) definitions for land use and land cover categories. Based on these comparisons, decisions can be made on a useful common definition of categories across the different teams.

Earth system models need a smooth transition between historic trends (taken from different inventories) and scenarios. Unfortunately, the different IAMs use different base years and are calibrated against different data sources. In this context, it is proposed that the data be harmonized for a single (base) year. The IA and climate modelers agreed in Noordwijkerhout that a 2005 base year (possibly based on 2004 data) would be a logical choice.

Activities have been initiated to identify potentially useful data for base year harmonization of emissions and land use. For emissions, different inventories exist, but the Emissions Database for Global Atmospheric Research (EDGAR) database has the advantage of consistent regional and grid-level data.[53] The use of EDGAR is therefore preferred at this stage—possibly harmonized at the global scale to the data of other inventories. The method applied in harmonization of SRES data is likely to be applied here as well (a scaling factor for each single gas that is used to multiply the model outcome in such a way that it is equal to harmonization value in the base year and which declines linearly over time from the base year to a value of 1 in 2100). For land use, data might best be harmonized at the regional level (data could possibly be based on FAO data; but interaction with institutes involved in the Global Carbon Project will also be considered).

[53] See http://edgar.jrc.it and http://www.mnp.nl/edgar/.

A.3 Downscaling

Different methods have been proposed for downscaling IAM information from the regional level to grid level. In most cases, such methods can be applied as post-processing of regional data, although in other cases model calculations are performed at the grid scale (e.g., land use in some of the models). Modeling teams will discuss the different available methods for downscaling emission data and decide whether to harmonize methods or to apply model-specific methodologies.

Again, details were discussed at the February 2008 workshop. For land use, a possible option is that downscaling of regional data could be left to CM community teams (since CM community modeling teams might be using very different land cover maps in the base year).

A.4 Extending IAM published data to 2300

The integrated assessment scenarios presented in the literature generally run through 2100. In climate modeling, extending to 2300 is necessary to take into account the large inertia in the response of some components (particularly the deep oceans and the ice sheets), and because most stabilization scenarios can only achieve full stabilization after 2100. Therefore, the RCP IAM teams need to extend their pathways to 2300 to satisfy the full data request. In extending the scenarios, these purposes need to be considered (for instance, socioeconomic data will not be needed for climate modeling per se).

There are several implications of extending the data to 2300, including the methodology used to extend the scenarios and the amount of detail needed beyond 2100. Methods for extending the RCPs to 2300 may differ given the specific characteristics of the underlying RCP scenario. Stabilization concentrations (or radiative forcing) need to, by definition, stay constant beyond the point of stabilization, which typically occurs in the published scenarios in the timeframe 2100 to 2150. In contrast, both the high and low RCP cases lack a concentration target that could guide the extrapolation of emissions to 2300. Estimation of emissions and concentrations in these cases might therefore be more challenging. For the highest scenario, some additional constraints to growth may need to be considered for this extended time horizon, particularly regarding hydrocarbon reserves. The Aspen protocol on the CM community runs of the RCPs does specify how the extension may be performed, which will be discussed further between the IAM and CM communities.

It should be noted that one reason for considering this longer time horizon is to evaluate impacts of changes such as sea level rise that will continue well after the emissions that caused them. While such impacts are also strongly dependent on socioeconomic parameters, such as the spatial distribution of population, it remains doubtful whether any meaningful socioeconomic information can be provided beyond 2100. This issue will be considered further by the IAM community.

A.5 Chemically active gases and aerosols

For the short-term experiment, emissions of chemically active gases are needed by CMs for both climate change and air pollution calculations. Non-CO_2 emissions will provide atmospheric chemistry models with the information needed to calculate the four-dimensional (space and time) distributions (concentrations) of gases and aerosols relevant to (1) climate and (2) air quality. Depending on the ESM and on the scientific purpose, this calculation will be performed online (interactively in the ESM) or offline (using global three-dimensional chemistry models, the results being then fed into the CM with a 10- to 20-year time frequency). For modeling groups without the capability of simulating atmospheric chemistry, one possibility is the use of averaged or selected results from models that have this capability (for an example, see the Atmospheric Composition Change—The European Network of Excellence (ACCENT) protocol).

Given that air quality is a local to regional phenomenon, its simulation requires the use of fairly high-resolution models (global or regional) with high-resolution input data. Because full interactive chemistry is computationally very intensive, only short-term simulations (to 2035) are likely at high resolution. Emissions from only one RCP would be used in these simulations.

Owing to strong nonlinearities in chemistry, it is important to have gridded emissions at the highest resolution available (of the order of 0.5° to 1°); it is always possible for the ESM groups to average these emissions over a coarser grid if necessary.

Additional specific requirements:

- As information on the specific volatile organic compounds (VOCs) can be derived from the sectoral breakdown of emissions, a common set of VOC emissions sources needs to be agreed upon. A similar issue might hold for aerosol emissions (e.g., black carbon (BC) emissions from industrial processes versus biomass burning).
- While most global chemistry models use time-varying emissions on a monthly timescale, IAM emissions will be provided as annual means. The actual redistribution to monthly emissions will be performed by the CM community with careful consideration of the implications of the methods for the results.
- If available it would also be useful to provide specific information (certainly for the near-term simulations) about:
    - Ship emissions, considering their expected increase and their role in coastal regions, including the projected opening of the polar routes; and
    - Aviation emissions, considering their inducement of cirrus cloud formation as well as linear contrails, and effect on upper tropospheric ozone and methane.

    The comparability/consistency with the RCPs might be improved if IAMs could report any relevant information they already contain, such as relative changes in inter-regional trade flows.
- Changes in land use/land cover need to provide sufficient information to enable the CM community to evaluate changes in biogenic emissions (mostly isoprene) over the simulation period. In particular, some specific plants (such as oil palm and poplar) are very strong isoprene emitters and knowledge of their use would be useful.
- Discussion might be needed on how to treat the emissions from forest fires (natural and anthropogenic) and other (natural and anthropogenic) biomass burning.
- Attention may also be needed in considering and handling of the aviation influence on cirrus cloud formation.

A.6 Land use and land cover data request

Among the current generation of CMs, several include the ability to respond to prescribed changes in area associated with different vegetation types, or with mixtures of plant functional types, and more CMs are actively developing this capability. The models typically represent the biophysical and mass flux consequences of transitions from natural vegetation (forest or grassland) to agriculture, and from agriculture back to natural vegetation. Some models also are equipped to represent multiple transitions between natural vegetation, agriculture, and pasture. The level of detail in these representations varies significantly between CMs, but the trend within the CM community is toward models including more detail in both cropping systems and natural ecosystems.

Given differences in the handling of land cover, land use, and land use change across CMs and differences in the modeling of land use dynamics across IAMs, a standardization protocol for providing data at a sufficient level of detail—both spatially and temporally—will need to be considered (the alternative is for each ESM to develop model-specific transformation rules for each RCP). Several factors contribute to the difficulty of developing a single protocol at this time. In addition to both ESMs and IAMs having different schemes to represent vegetation within each group, neither of the groups have a consistent representation of present day or historical land cover distributions (e.g., different ESMs are using different historic land use maps). Differences depend on the sources of information used to create present day global land cover distributions (e.g., different satellite systems) and different methods for estimating the extent of human land uses. One major consideration in the transfer of information is the need to ensure that IAM future and ESM present day and historical land cover classification schemes are consistent in the present as well as future scenarios.

One possible protocol would be to have IAMs provide information on land use change at the level of regions—while downscaling to grids is performed by individual ESMs. The decision on the procedure that will be used, the land use definitions, and the detail of the grid used will be discussed in early 2008 between the IAM and CM communities. One possible minimum distinction for land use could be a) crop area (including relative partitioning of crops by major types either by specifying specific crop types (e.g., wheat, maize, rice, beans etc.) or distinguishing between C3 and C4 crops at a minimum), b) grazing area (to be defined), c) irrigated area, and d) plantation areas (indicating tree type). Both the resolution and the definition of land use types need to be discussed further (preferably coupled to the categorizations ESM and IAM teams are currently using).

As not all CMs endogenously calculate carbon fluxes, how to provide these fluxes to other models needs to be considered. Such information may come either from IAM output or from selected CMs with an endogenous representation.

Integrated assessment model output could include gridded carbon fluxes. The level of detail in terms of the flux sources will need to be determined. Flux data is additional information that will further help with ESM calibration to the IAM land dataset. Some CMs may use these fluxes directly, or draw flux information from CMs that endogenously calculate fluxes. While CMs that include their own representation of fluxes will not ingest the IAM fluxes directly, the information will be valuable for comparing IAM and ESM results.

The usual protocol for an ESM experiment with prognostic carbon fluxes is to perform a pre-industrial spin-up followed by a historical transient that passes through the present before moving into a future scenario. Therefore, it is important to have (a) consistency, to the extent possible, in the historical trajectories across IAMs, and (b) smooth transitions from the historical period into the future. It is also important to ensure some consistency with constraints on net regional CO_2 fluxes derived from atmospheric isotope analysis (*inter alia*). This implies that standardization and harmonization of IAM output with the CM community will be useful.

Appendix 2: RCP3-PD Review Correspondence

International Institute for Applied Systems Analysis (IIASA)
Schlossplatz 1
A-2361 Laxenburg, Austria

Energy Modeling Forum (EMF)
Stanford University
Stanford, CA, USA 94305-4026

National Institute for Environmental Studies
16-2, Onogawa, Tsukuba
305-8506 Japan

1 November 2007

Dr. Rajendra K. Pachauri
Chairman, Intergovernmental Panel on Climate Change (IPCC)
Director, The Energy and Resources Institute (TERI)
Darbari Seth Block, Habitat Place, Lodhi Road
New Delhi, 110 003
India
Email: <chairipcc@teri.res.in>, <pachauri@teri.res.in>

Subject: International consortium to facilitate the coordination of scenario development efforts

Dear Dr. Pachauri,

We want to start by thanking you, Dr. Elgizouli, Dr. Moss and the other members of the Steering Committee for organizing the expert meeting on new scenarios from September 19-21, 2007 in the Netherlands. It was a unique and productive opportunity for engaging researchers across all the climate research communities.

This letter responds to the expressed interest at the meeting in the published IMAGE 2.6 scenario (van Vuuren et al., 2006) for the lowest Representative Concentration Pathway (RCP3-PD), and outlines a planned process for evaluating the robustness and suitability of this scenario to serve as the basis for Earth system modeling (ESM) experiments.

Background

The IMAGE 2.6 scenario has emissions that peak and decline rapidly from the present and result in radiative forcing of 2.6 W/m^2 in 2100. This scenario requires very aggressive emissions reductions early in the century and deployment of negative emissions technologies later in the century.[1]

From the expert meeting, it is clear that this pathway is appealing scientifically to the ESM and IAV (impacts, adaptation, and vulnerability) communities. In particular, the pathway is appealing because of the following: (a) in combination with the high of 8.5 W/m^2 in 2100, it provides a broad span of potential future emissions and concentration pathways for future climate scaling between RCPs, (b) it follows a peak-and-decline shape, and (c) it exhibits net negative emissions towards the end of the century. The notion of net negative global carbon emissions is controversial. For this reason, low pathways are also of scientific interest to the integrated assessment modeling (IAM) community for exploring socio-economic implications, and to the carbon cycle and earth systems modeling (ESM) communities. Finally, the pathway is of interest to policy-makers seeking information on overshoot emissions, concentration, and climate change pathways.

[1] Specifically, bioenergy combined with carbon dioxide capture and storage that ceteris paribus has a net negative effect on atmospheric concentrations of GHGs.

While the IMAGE 2.6 scenario is appealing for many reasons given, the feasibility of reaching such a low radiative forcing level has not yet been evaluated by the IAM community. Specifically, the scenario has not yet been reproduced by other models in this class of IAMs.[2] This is important because scenario replication is used by the IAM community, as well as the climate modeling community, as a method for establishing robustness in results. Furthermore, given the substantial resource requirements associated with running ESMs, it is prudent that the scenarios selected for RCPs be scientifically robust, i.e., reproducible and technically sound.

The IMAGE 2.6 scenario represents important pioneering research, and the scenario is exploratory in character. Van Vuuren et al. (2006) presented the scenario in the literature in the context of a discussion of mitigation scenarios with higher forcing levels. During the expert meeting, the IMAGE modeling team cautioned that the scenario should not be used as the basis for the ensemble runs of ESMs until the IMAGE team has had sufficient time to revisit the scenario. In particular, given the importance of bio-energy to the 2.6 scenario, it is imperative that the IMAGE team evaluate the scenario in light of recent scientific literature on bio-energy greenhouse gas emissions and recent insights that greenhouse gas emissions growth in Asia is higher than anticipated. The technical re-examination of the scenario is a necessary first step for making the IMAGE 2.6 scenario available for consideration as the low RCP for the climate research community. The reexamination could potentially lead to quantitative changes in the scenario. The IMAGE team has noted that the quantification changes could mean that the radiative forcing levels in the scenario are no longer attainable under the assumptions made in the published 2.6 scenario.

Finally, it is worth noting that the IAM community, as represented by the IAMC, believes that the van Vuuren et al. (2006) IMAGE 2.9 scenario also satisfies many of the various interests based on the following points:

- Both IMAGE 2.6 and 2.9 are overshoot scenarios with peaking and declining radiative forcing. The peak and decline with IMAGE 2.6 is more pronounced.
- The ESM community has stated that the climate signals from the published IMAGE 2.6 and 2.9 pathways will be indistinguishable.[3]
- Both IMAGE 2.6 and 2.9 produce pathways with at least a 50% probability of achieving the target of 2 degrees Celsius, which was reinforced as the official climate protection goal of the European Community in 2005.

However, the IAM community recognizes the expressed preference of the expert meeting on new scenarios for the IMAGE 2.6, if it is determined to be robust.

Evaluating the robustness of the IMAGE 2.6 pathway

Given the level of interest in the IMAGE 2.6 scenario, as well as the scientific-technical questions raised, the Integrated Assessment Modeling Consortium (IAMC) believes that it is vital to evaluate the scientific question of whether the IMAGE 2.6 scenario is robust before substantial ESM community resources are applied in evaluating its climate and atmospheric chemistry implications. The intent is to provide the IMAGE 2.6 scenario if found to be robust. The scenario will be evaluated for technical soundness and replicability. Should the exercise be unable to establish the robustness of the IMAGE 2.6 scenario, the published (and replicated) IMAGE 2.9 overshoot scenario will be provided instead to the ESM community to serve as the low RCP.4

[2] This class of IAMs endogenously models radiative forcing and all its relevant components—the full suite of GHG and non-GHG emissions and concentrations, land-use and land cover, and climate, as well as the terrestrial and ocean carbon cycle.
[3] A difference of approximately 2.5 W/m^2 in 2100 is required to identify unique climate signals.
[4] An important criteria for a scenario to be considered as an RCP is that it must have been published in the peer reviewed literature.

To ensure the scientific credibility and transparency of the evaluation, the IAMC will appoint a six person panel that will be responsible for the final judgment of the robustness of the IMAGE 2.6 scenario and thus the determination of which published IMAGE scenario will be available for the low RCP.

The panel will ensure that the evaluation is conducted in a careful, scientific, and unbiased way; consult with the IAMC on technical criteria for assessing robustness; and, consult with the integrated assessment modeling teams and other experts in bioenergy and land-use in making its robustness determination. The panel is proposed to consist of the following six individuals: Mikiko Kainuma, Nebojsa Nakicenovic, John Weyant, Christian Azar, Gary Yohe, and Kejun Jiang. Please note that some of these individuals need to be contacted to confirm participation in the panel.

The conclusions of the evaluation panel will be provided to the IPCC in a letter report that will provide a detailed description of the full evaluation process and results. We strongly urge the IPCC to work with the IAMC to make this letter report openly available to all interested parties.

So as not to delay the hand-off of data to the ESM community, the IMAGE team will be preparing the required ESM input data from both the published IMAGE 2.6 and 2.9 scenarios.

It is important to keep in mind that each of the modeling teams has numerous analytical commitments, and this assessment will be in addition to other activities associated with coordinating, evaluating, and preparing the data for all the RCPs.

While we acknowledge the expressed preference of the expert meeting on new scenarios for the IMAGE 2.6, we feel strongly that an RCP scenario must be robust, and a determination of robustness of IA modeling results is a question of scientific merit that, for the legitimacy of the decision, must be judged by the experts most familiar with the models and results. We hope the Steering Committee will find that this plan satisfies its needs. The plan was designed to provide the Steering Committee with the input necessary for completing its meeting report by March 2008. The plan ensures delivery of one of the two pathways identified by the Steering Committee for the low RCP via an aggressive and scientifically rigorous process. We look forward to hearing from you and answering any questions you may have.

Yours sincerely,

甲斐沼 美紀子

Nebojsa Nakicenovic
International Institute for
Applied Systems Analysis
(IIASA)

John Weyant
Energy Modeling Forum
Stanford University

Mikiko Kainuma
National Institute for
Environment Studies (NIES)

Cc: "Ismail Elgizouli" <hcenr@sudanmail.net>, "Moss, Richard" <Richard.Moss@WWFUS.ORG>, "Renate Christ" <rchrist@wmo.int>, "Leo Meyer" <Leo.Meyer@mnp.nl>, "Sander Brinkman" <sander.brinkman@zonnet.nl>, Members of the Steering Committee

WMO *Intergovernmental Panel on Climate Change*
Steering Committee, Expert Meeting on New Scenarios UNEP

6 November 2007

Dr. Mikiko Kainuma, NIES
Dr. Nebojsa Nakicenovic, IIASA
Dr. John Weyant, EMF/Stanford

Dear Drs. Kainuma, Nakicenovic, and Weyant,

On behalf of the IPCC Chair, Dr. Rajendra K. Pachauri, the Steering Committee for the Expert Meeting on New Scenarios welcomes your letter of 1 November 2007 on behalf of the Integrated Assessment Modeling Consortium (IAMC).

We welcome your proposal to resolve the issue of choosing of the lowest Representative Concentration Pathway (RCP) through evaluation of the robustness of the IMAGE 2.6 scenario. We fully agree that the choice of the RCP involves technical issues that should be evaluated by experts in integrated assessment modeling, bio-fuels, and other related areas. We believe we are now very close to a solution to this issue. Your proposal is consistent with our reading of the outcome of the discussions in Noordwijkerhout. These discussions indicated a preference for the IMAGE 2.6 scenario if it is judged to be scientifically robust and reproducible by other scenario modeling groups. In the event that the IMAGE 2.6 scenario is not evaluated as robust and reproducible, then the IMAGE 2.9 scenario will be used as the lowest RCP.

Given the decision of the Panel at IPCC-26, the Steering Committee for the Expert Meeting on New Scenarios is mandated to identify the Representative Concentration Pathways, previously referred to as Benchmark Concentration Scenarios, through the Expert Meeting. We are happy leave the evaluation of the robustness and reproducibility of the IMAGE 2.6 scenario to an ad hoc expert group.

We would like to raise a few points intended to clarify and strengthen your proposal and hope that you will be able to agree to these requests:

- The Steering Committee agrees that the individuals you have recommended in your letter would constitute a strong ad hoc panel for evaluation of the robustness of the IMAGE 2.6 scenario, assuming that they are willing to take on this responsibility. Your letter indicates the need to include expertise in the area of bioenergy and land use. We believe that this would be a good opportunity to augment participation from developing countries. Thus we suggest that another expert from a developing country be included as an official member of the ad hoc panel. Potential candidates include Emilio La Rovere or Jose Roberto Moreira.

- The criteria the ad hoc evaluation panel will use in their judgment of scenario robustness are not yet specified. These criteria could include a variety of technical factors, for instance: physical/technical feasibility of the mitigation options; scientific correctness of the emission calculations; a reasonable high-end cut-off carbon price; or no use of geo-engineering options. We believe it is essential that the criteria be specified ex ante, not after the evaluation is under way. In order for the evaluation to be transparent and credible, we thus request that the ad hoc panel develop the set of criteria for the evaluation and provide these to the Steering Committee by early December, so that they can be included in the draft report of the expert meeting that will be circulated for wide review. The final draft of this report will be submitted to the 28th session of IPCC in April 2008.
- We believe that participants of the Noordwijkerhout meeting in September agreed that the IMAGE 2.6 scenario should be reproducible by other scenario groups. We concur with this view and request that the ad hoc panel explicitly considers the issue of reproducibility. We also request that the ad hoc panel specifies in advance how it will evaluate this issue (including an indication of how other IAM groups attempting to reproduce the scenario can submit results for consideration) given that it is unlikely that new scenarios can be published in the time available (to approximately mid-2008).
- The Steering Committee will accept the judgment of the ad hoc panel regarding the robustness and reproducibility of the IMAGE 2.6 scenario as long there is agreement within this group, a full and transparent explanation is given based on the specified criteria, and the evaluation is communicated before early September 2008.
- The steering committee will recommend to the IPCC plenary that the steering committee goes into "hibernation" once its New Scenarios expert meeting report is completed in the first quarter of 2008. The steering committee will be formally dismissed once the evaluation panel completes its work and agreement is reached on IMAGE 2.6. If and only if the ad hoc panel is unable to come to consensus, however, the steering committee would be reconvened to resolve the lack of an agreed low RCP.
- The Steering Committee recognizes that preparation of the RCPs, including evaluation and reproduction of the IMAGE 2.6 scenario, entails significant new work on the part of the IAM community. We encourage funding agencies to consider the adequacy of resources available to support this work, and we invite interested institutes to participate in the reproduction of the IMAGE 2.6 scenario.

We hope that these points are agreeable to you. We request that you reply with final information about whether the individuals you have recommended are willing to serve on the ad hoc panel, and whether the requests outlined above are acceptable to you. Given the schedule of the Panel, it would be most helpful if we could receive your reply by 12 November 2007. Furthermore, we suggest convening a teleconference of the chairs of the steering committee and the ad hoc group to further discuss the timeline and reporting.

Sincerely,

Ismail Elgizouli Richard Moss
Co-Chairs, Steering Committee for the Expert Meeting on New Scenarios

International Institute for Applied Systems Analysis (IIASA)
Schlossplatz 1
A-2361 Laxenburg, Austria

Energy Modeling Forum (EMF)
Stanford University
Stanford, CA, USA 94305-4026

National Institute for Environmental Studies
16-2, Onogawa, Tsukuba
305-8506 Japan

30 November 2007

Dr. Richard Moss
World Wildlife Fund
1250 Twenty-Fourth Street, N.W.
P.O. Box 97180
Washington, DC 20090-7180
<richard.moss@wwfus.org>

Ismail A.R.Elgizouli
Energy & Environment Consultant
PO Box 10488,
Khartoum
Sudan
<hcenr@sudanmail.net>,<elgizouli@yahoo.com>

Subject: Review Panel for the 2.6 W/m^2 stabilization scenarios

Dear Ismail and Richard,

Thank you for your letter of 6 November 2007. The Integrated Assessment Modeling Consortium (IAMC), is pleased that the Steering Committee was amenable to our overall plan for assessing the robustness of the IMAGE 2.6 scenario as described in our letter of 1 November 2007. Your letter requested clarification on a number of points. Specifically, your letter requested a reply on whether the individuals we have recommended for the review panel are willing to serve, and whether the suggestions and requests you outlined in your letter are acceptable to us.

On the review panel, there are three items on which we would like to reply. First, we are happy to report that, we have received confirmation from all six of the individuals that we proposed regarding their willingness to participate. Second, your letter proposed augmenting developing country participation on the panel. We support your suggestion and propose two additions to the panel: Prof. P.R. Shukla and Prof. Emilio La Rovere. Together with Jiang Kejun, Profs. Shukla and La Rovere will provide developing country representation with intimate expertise in the class of models relevant to this exercise, as well as important expertise and perspectives on regional participation in global stabilization and bio-energy supplies.

Finally, your letter suggests that the panel must “come to consensus.” We will require that the panel provide a consensus recommendation, based on their IMAGE 2.6 robustness assessment, on whether the IMAGE 2.6 or IMAGE 2.9 scenario should be used for the lowest RCP. While panel members may not necessarily agree on all aspects of the robustness of the IMAGE 2.6 scenario, they will be required to provide a single recommendation to the IAMC as the convening body, which will then transmit the finding to the Steering Committee.

The robustness assessment of the IMAGE 2.6 scenario by the IAMC will be based on two criteria, both of which must be met: technical soundness and replicability.

> *1. Technical soundness:* The IAMC will ask the modeling teams to (a) review the published IMAGE 2.6 scenario for technical soundness, and (b) address any technical issues that arise from that review. The IMAGE team will be asked to lead the activity that will focus on technical components of the IMAGE 2.6 scenario. In particular, those that distinguish the scenario from the IMAGE 2.9 scenario, namely the representation of biomass combined with carbon dioxide capture and storage. If the team review reveals fundamental problems with the IMAGE 2.6

scenario, the scenario will not be made available for consideration as an RCP. The findings from this assessment will be made available for consideration by the Review Panel.

2. Replicability: The IAMC will ask all the IAM teams in this class of models[1] to participate in the design and development of low stabilization scenarios that limit radiative forcing to around ~3 W/m^2 during the 21st century, achieve radiative forcing as low as 2.6 W/m^2 by 2100 (with a tolerance of ±5%, for 2100), and declining thereafter. The IMAGE modeling team will also be asked to produce a scenario with these characteristics using the most recent version of the IMAGE model. Overall, the modeling teams will be asked to employ their standard assumptions and include biomass and CCS, but avoid non-traditional assumptions like geo-engineering, and dramatic dietary changes or severe economic collapse. Replication will be deemed successful if both of the following two conditions are met:

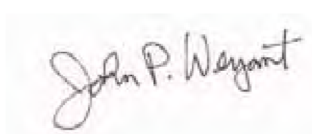
A. IMAGE replication: after addressing any modest technical issues identified in Step 1, the IMAGE modeling team must be able to generate the scenario using the latest version of the IMAGE model.
B. Replication by other modeling teams: at least two of the other IAM modeling teams in this class must be able to generate a technically sound scenario.

The review panel will be asked to develop and apply a set of broad criteria, which will be considered in the evaluation of the technical soundness of the replication scenarios. The panel is invited to communicate the initial set of criteria to the Steering Committee, together with a draft plan of action, prior to the start of the work. The panel is invited to consider, among other things, technical soundness of the representation of key technologies, internal plausibility and consistency of the technology portfolio, GHG and carbon cycle accounting, land-use implications and economic viability relative to the 2.9 W/m^2 path way. It is important to acknowledge that the scenario analysis of the modeling teams might yield the identification of important new criteria. In such a case, these would be clearly communicated by the panel in its report.

In general, the scenario assumptions and implications will be fully documented to ensure proper interpretation and handling by the relevant scientific communities and policy users. All modeling teams with models in this class, i.e., able to satisfy the requirements for candidate RCPs, will be invited to participate in replication.

We hope our reply serves your needs. We are enthusiastic about this opportunity for beginning our exploration of low stabilization scenarios, which we expect to continue well beyond this activity. The IAMC will be beginning the evaluation process that we have laid out in this letter and our 1 November 2007 letter soon. We recommend a teleconference to discuss timeline and reporting and to clarify any remaining ambiguities.

Yours sincerely,


Nebojsa Nakicenovic
International Institute for Applied Systems Analysis (IIASA)

John Weyant
Energy Modeling Forum
Stanford University

Mikiko Kainuma
National Institute for Environment Studies (NIES)

Cc: "Renate Christ" <rchrist@wmo.int>, "Leo Meyer" <Leo.Meyer@mnp.nl>, "Sander Brinkman" <sander.brinkman@zonnet.nl>, Members of the Steering Committee

[1] This class of IAMs model radiative forcing and all its relevant components—the full suite of GHG and non-GHG emissions and concentrations, land-use and land cover, and climate, as well as the terrestrial and ocean carbon cycle (see Appendix 1 of the background paper to the IPCC New Scenarios Meeting held 19–21 September, 2007 in 19 Noordwijkerhout, The Netherlands).

WMO *Intergovernmental Panel on Climate Change*
Steering Committee, Expert Meeting on New Scenarios
UNEP

21 December 2007

Dr. Mikiko Kainuma, NIES
Dr. Nebojsa Nakicenovic, IIASA
Dr. John Weyant, EMF/Stanford

Dear Drs. Kainuma, Nakicenovic, and Weyant,

We wish to thank you for your letter of 30 November 2007. We agree with your proposals and we feel that you have very constructively addressed all important questions coming from our side. Your reply enables us now to get started resolving the outstanding issue of the low-end scenarios raised during the meeting in Noordwijkerhout.

We hope the expert review panel can start their work soon. We would very much like to include a short description of the evaluation process and considerations that will be important in determining the robustness of the 2.6 scenario in the draft meeting report, which is in review now. If the Secretariat to the Steering Committee could be of any help in supporting the review panel (for instance arranging phone conferences, drafting minutes), let us know.

We would be happy to hold a teleconference with you as soon as possible to discuss timeline, reporting, and any other issues that may come up.

Again, please accept our appreciation for the cooperative spirit with which you have dealt with this issue.

Yours sincerely,

Richard Moss and Ismail Elgizouli
Co-Chairs, Steering Committee for the Expert Meeting on New Scenarios

Appendix 3: Expert Meeting Agenda

Program IPCC Expert Meeting on New Scenarios
19-21 September 2007, Noordwijkerhout, the Netherlands

Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies

Objective:
The objective of this meeting is to identify requirements and plans for the development of new scenarios of emissions, climate change, and adaptation and mitigation (including underlying socio-economic conditions that shape emissions and vulnerability). The scenarios will be of interest to the research and user communities, and will assist in the coordination of research assessed in a possible IPCC Fifth Assessment Report (AR5).

Deliverables:

- A proposed set of "benchmark concentration pathways" that will be used in initial Earth system model runs. These pathways will be selected from the existing scientific literature and will cover a representative range of stabilization, mitigation, and reference scenarios. They will be used in Earth system models to provide simulated climate outputs;
- Plans for the relevant research communities to coordinate, organize and communicate further actions towards the development of new integrated scenarios, including institutional arrangements for coordination and scheduling of activities;
- A plan for increasing involvement of experts from developing countries and economies in transition in the development of new scenarios, including funding and organizational aspects;
- A meeting report that describes the benchmark concentration pathways and the plans of the research community to coordinate and develop new integrated scenarios, including plans for increasing involvement of experts from developing countries and economies in transition.

Tuesday 18 September

Lobby	**18.00 – 20.00**	**Registration**
Dali	**18.00 – 20.00**	**Dinner (at own expense)**
Boston 9	**20.00 – 22.00**	**Welcome drinks (offered by IPCC TSU WG III)**

Wednesday 19 September

Dali	**7.30 – 9.00**	**Breakfast**
Lobby	**7.30 – 9.00**	**Registration**
Sorbonne 2 **Plenary**	**9.00 – 9.30**	**Opening Session (Chair: Ismail Elgizouli)** *1. A Policymaker's Perspectives on Scenarios* **Hans Bolscher,** Director Climate Change and Industry, Netherlands Ministry of Environment *2. Welcome and Overview* **Rajendra Pachauri**, Chair of the IPCC
Sorbonne 2 *Plenary*	**9.30 – 10.30**	**Introduction: Scenarios Past and Future** *1. Previous IPCC scenarios and decisions; purposes of the expert meeting* **Leo Meyer** *2. Overview of process for scenario development and application* **Richard Moss** **Discussion**

Sorbonne Lounge, 10.30– 11.00 Coffee break

Sorbonne 2 **Plenary**	**11.00 – 13.00**	**Process Overview and Preliminary Scenario Requirements (Chair: Seita Emori)** *1. Phases of scenario development and application* **Jae Edmonds** *2. Earth system modeling: preliminary scenario requirements* **Kathy Hibbard** *3. Criteria and review of available scenarios for Benchmark Concentration Pathways.* **Nebojsa Nakicenovic** *4. Available scenarios and options for benchmarks* **Jean Pascal van Ypersele** **Discussion**

Dali **13.00 – 14.30** **Lunch**

Sorbonne 2 Plenary **14.30 – 16.00** **Long-Term Scenarios (Chair: Shuzo Nishioka)**

1. *ESM approach to long-term scenarios (2100 and beyond): Coupled climate-carbon cycle experiments*
John Mitchell
2. *IAV approach to long-term scenarios: impacts, vulnerability, and long-term adaptation needs*
Tim Carter
3. *Mitigation policy and IAM approach to long-term scenarios: policy analysis and mitigation requirements*
John Weyant

Discussion

Sorbonne Lounge **16.00 – 16.30 Break**

Sorbonne 2 Plenary **16.30 – 18.30** **Near-Term Scenarios (Chair: Eduardo Calvo)**

1. *ESM approach to near-term scenarios (~2030): High-resolution modeling focusing on extreme events, regional climate, and interactive chemistry*
Masa Kimoto
2. *IAV approach to near-term scenarios: adaptation planning and management*
Roger Jones
3. *Mitigation policy and IAM approach to near-term scenarios: baselines, air pollutants, transitions, and developing country dynamics*
Fatih Birol
4. *Regional modeling and applications: relationship to global scenarios*
Emilio La Rovere

Discussion

18.30 **Conclude for the day**

Lobby **19.00** **Departure to dinner**

Departure by buses to a restaurant at the sea front in a small village called Katwijk. The dinner will be offered by the Technical Support Unit of IPCC WG III. All participants and their partners are cordially invited to join.

Thursday 20 September

Sorbonne 2 Plenary **8.45 – 10.15** **Recap and Panel/General Discussion:** *Benchmark Pathways and Coordination Requirements and Plans*
Chair: Tom Kram, Panelists: Jae Edmonds, John Mitchell, Jean Pascal van Ypersele

Sorbonne 2 Plenary **10.15 – 10.45** **Introduction to breakout groups on disciplinary and user perspectives: agendas and key meeting deliverables (by Bert Metz)**

Sorbonne Lounge **10.45 – 11.00 Coffee break**

11.00 – 12.30 **Breakout groups on disciplinary and user perspectives**

Four groups will discuss the scenario process from the perspectives of:

Sorbonne 2	**ESM** (Co-Chairs: Martin Manning and Murari Lal)
Cambridge 30	**IAM** (Co-Chairs: Leo Meyer and PR Shukla)
Boston 11	**IAV** (Co-Chairs: Jean Palutikof and Leonard Nurse)
Boston 12	**Users**, for example the World Bank, FAO, OECD, IEA, WMO and UNEP (Co-Chairs: Ian Carruthers and Ismail Elgizouli)

Purposes/deliverables:

- Develop recommendations regarding benchmark scenarios
- Identify strengths and weaknesses of the current plans for scenario development, including issues that require further clarification
- Define “deliverables” needed from and to be supplied to other research communities
- Develop recommendations for strengthening the process, e.g. research questions, organizational needs, coordination with other research communities, etc.

Dali **12.30 – 14.00** **Lunch**

14.00 – 15.30 **Continuation of breakout groups on disciplinary and user perspectives**

Boston Lounge & Sorbonne Lounge		
	15.30 – 16.00	**Break**
Sorbonne 2 Plenary	**16.00 – 17.00**	**Report from breakout groups and discussion (Chair: Tom Kram)**
Sorbonne 2 Plenary	**17.00 – 18.30**	**Plenary Discussion:** *Initial Recommendations and Conclusions on the Benchmark Pathways* **Co-Chairs: Richard Moss** and **Ismail Elgizouli**
	18.30	**Conclude for the day**
Dali	**19.00 – 20.30**	**Dinner (own expense, at conference centre)**
Sorbonne 2 Plenary	**20.30 – 22.00**	**Breakout on benchmark emission pathways (Co-Chairs: Jean Pascal van Ypersele** and **Mustafa Babiker)**

Friday 21 September

Sorbonne 2 Plenary	**8.30 – 9.00**	**Plenary: Recap and introduction to interdisciplinary breakout groups (Chair: Jean Pascal van Ypersele)**
Sorbonne 2	**9.00 – 9.30**	**Introduction to breakout groups on <u>interdisciplinary</u> Plenary <u>perspectives</u>: agendas and key meeting deliverables (by Tim Carter)**
	9.30 – 11.00	**Interdisciplinary breakout groups**

Sorbonne 2 **Benchmark emission pathways**
(Co-Chairs: Jean Pascal van Ypersele and Mustafa Babiker)
Deliverable: Specific proposal for the benchmarks

Cambridge 30
Organizational framework for development of new integrated scenarios
(Co-Chairs: John Weyant and John Mitchell)
deliverables:

- Identify needed coordination across disciplines and sub-disciplines (e.g., handoff of data from one "community" to another)
- Assess compatibility of different modeling approaches;
- For unresolved issues, develop problem statements/descriptions and identify meetings or institutions where these issues can be pursued
- Identify opportunities and barriers for DC & EIT countries

Boston 11 **Approaches for providing downscaled climate and socio-economic information for IAV assessment** (Co-Chairs: Linda Mearns and Xianfu Lu)
Deliverables:

- Identify what are the needs, uses and limits of available techniques, and the priorities for downscaling given currently limited resources?

Boston 12 **Regional/national assessment of mitigation opportunities in the context of global scenarios** (Co-Chairs: Hugh Pitcher and P.R. Shukla)
Deliverables:

- Identify how disaggregated analyses of mitigation opportunities (at the scales of large countries (e.g., China, India, and the United States) or regions (e.g., European Union) can be undertaken in a way that can be related to more highly aggregated global scenario studies developed with integrated assessment models?

Boston Lounge & Sorbonne Lounge		
	11.00 –11.30	**Coffee break**
	11.30 –13.00	**Continuation of interdisciplinary breakouts**
Dali	**13.00 – 14.30**	**Lunch**
(Boston 13	***13.00 – 14.30***	***Steering committee members finalize synthesis of break-out group results; rapporteurs prepare reports; meet to discuss integration)***
Sorbonne 2 Plenary	**14.30 – 16.00**	**Report from Breakout groups and discussions (Chair: Monika Zurek)**
Sorbonne 2 Plenary	**16.00 – 16.30**	**Plenary reporting, discussion, wrap-up (Co-chairs: Richard Moss** and **Ismail Elgizouli)**
Sorbonne Lounge	**16.30**	**Closure and coffee**

Appendix 4: Position Papers Distributed During the Expert Meeting As Reactions to the Background Paper

These papers were prepared in response to the background paper for the meeting.

- DISCUSSION NOTE, 18 SEPTEMBER 2007 -

IPCC Expert Meeting on New Scenarios
"Towards new scenarios for analysis of emissions, climate change, impacts, and response strategies"
19-21 September 2007, Noordwijkerhout, the Netherlands

Discussion Note[1]

Benchmark concentration scenarios to span the full range of plausible concentration profiles.

An informal response to the Background note distributed to participants on 11th September 2007.

Summary

The proposed range of new scenarios for analysis of emissions, climate change, impacts and response strategies ranges from a stabilization level of around 3W/m^2 (~500 ppmv CO_2 equivalence - CO_2e) up to around 8.5 W/m^2 (~1360ppm CO_2e). This range, however, neither characterizes the full range of published emission scenarios, nor the full forcing range relevant to climate change and its impacts.

Here a case is made for a definition of the low end Benchmark Concentration Pathway (BCP) that has characteristics that would enable the complete set of BCPs to: 1. Span the full range of contemporary mitigation policy discussions and nonmitigation scenarios so that ESM scenarios output is available for impact studies consistent with the lowest mitigation pathways. It is vital that the BCP scenarios provide a sufficient foundation to fully inform decision making, irrespective of whether policy makers decide to follow a very high or a very low emission pathway.

2. Enable assessment of the climate system response to scenarios where radiative forcing declines significantly from peak levels, as implied by the lower emission scenarios in the literature.

1 Prepared by Malte Meinshausen and Bill Hare and supported by (alphabetical order): Joe Alcamo, Myles Allen, Martin Claussen, Jan Corfee Morlot, Ottmar Edenhofer, Hans-Martin Füssel, Andreas Fischlin, Marco Giorgetta, Saleemul Huq, Daniela Jacob, Roger Jones, Stefan Lechtenböhmer, Anders Levermann, Jason Lowe, Jochem Marotzke, Ben Matthews, Michael Oppenheimer, Hermann Ott, Stefan Rahmstorf, Sarah Raper, John Schellnhuber, Michiel Schaeffer, Thomas Schneider von Deimling, Dennis Tirpak, Harald Winkler, Gary Yohe.

Examining peaking profiles (point 2) is of particular importance for the low emission scenarios, because this is likely to be the only appropriate way to assess avoidable and potentially unavoidable climate impacts. More knowledge on potentially unavoidable climate impacts even under maximum feasible reduction strategies in the literature at present would be vital information for any adaptation policies.

The lowest BCP proposed (BCP3) is currently defined as a "*Low stabilization (overshoot) with ~3W/m^2 in 2100"* path and implies either a stabilized forcing at this level or a pathway that temporarily overshoots and then stabilizes at 3W/m^2. Such a 3W/m^2 stabilization pathway would not be representative of the lower emission scenario categories I & II presented in IPCC AR4 WG3 (and shown in Figure III.2 of the background note).

From an IPCC assessment perspective, procedurally a 3W/m^2 stabilization pathway is not consistent with the decision at the 25th IPCC session, which states that the benchmark concentration pathways "should be compatible with the full range of stabilization, mitigation and baseline emission scenarios available in the current scientific literature". The IPCC is mandated to provide policy-relevant, not policy-prescriptive information and by excluding the lowest categories of the mitigation scenarios assessed in AR4 it could be argued that is in effect being prescriptive.

From a scientific point of view it would appear to be of vital importance that low mitigation pathways (that are present in both the scientific literature and actively discussed in international policy fora) are not intentionally excluded from the scientific debate.

We therefore propose that the present proposed low end member scenario of the BCP set be replaced by one that meets the needs described above. One possible option for this could be defined as "*Low stabilization (peaking) scenario with a maximum forcing of 3W/m^2 in the mid 21st century with a subsequent decline towards ~2.5W/m^2 by 2100 and continuing decreases to approach a lower stabilization level thereafter.*" This is similar to the "IM26" scenario (instead of the apparently envisaged "IM29" scenario cp. Figure III.2 in the background note).

On the following pages, we detail the main two reasons for this proposed new definition of BCP3, the low end member of the Benchmark Concentration Pathway set.

1. Full range needs to be spanned

3W/m² stabilization not representative of the lower categories of available emission scenarios.

The IPCC decision at the 25th session states explicitly that the new benchmark concentration pathways "should be compatible with the full range of stabilization, mitigation and baseline emission scenarios available in the current scientific literature". As figure III.2 in the background document (reproduced below) shows, the currently envisaged IMAGE 2.9 W/m² (IM29) scenario for BCP3 is more representative of the lower end of category III scenarios, as presented in IPCC WG3 AR4 (see table SPM5 in Appendix I below). IM29 is not representative of the emission scenario categories I or II, which are generally lower. Thus, IM29 is not a suitable candidate for BCP3, whose purpose is to represent the lower bound of scenarios currently in the literature. From the set of scenarios explicitly shown in figure III.2, the only appropriate mitigation scenario is IM26, which peaks at approximately 3W/m² (see right side of figure III.2 in the background paper and Figure 3 below) and is approximately representative of the lower two scenario groups I and II. Alternatively, if IM26 is not chosen, another mitigation pathway belonging to the IPCC WG3 category 'I' needs to be selected in order to obtain an appropriate representation of the low emission scenarios.

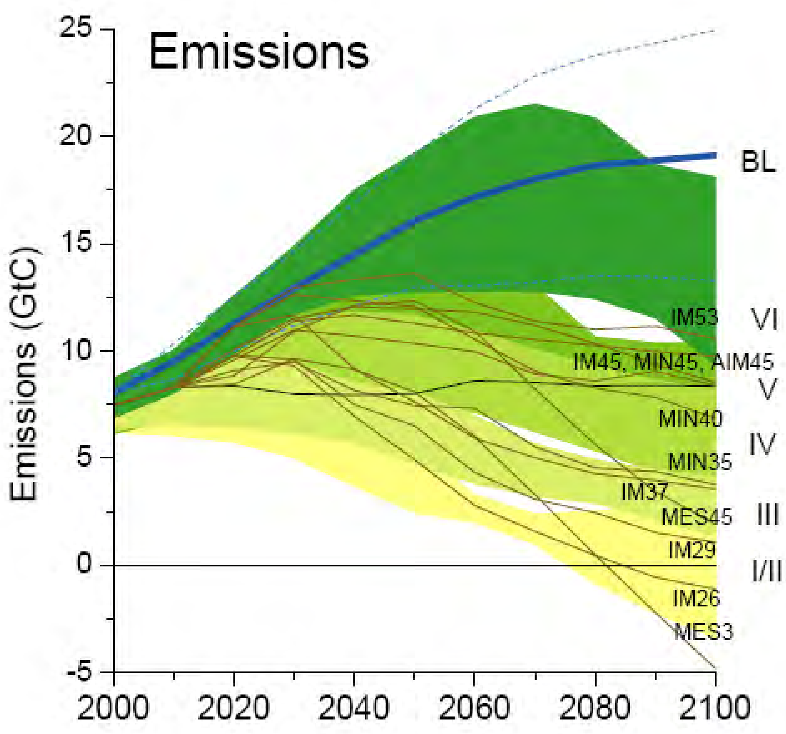


Figure 1 - Figure III.2 reproduced from the Background paper for participants**.**

Being policy-relevant, not policy-prescriptive: 3W/m2 stabilization to 8.5W/m2 does not span the policy-relevant range.

Even if the literature were not (yet) containing emission scenarios lower than a $3W/m^2$ stabilization, i.e. no emission scenarios that would lead to a $3W/m^2$ peaking with lower stabilization thereafter at e.g. $2W/m^2$, it would be inappropriate for the scientific community to neglect considering this lower range. (Clearly, the literature does in fact contain these lower emission scenarios, namely those of IPCC WG3 AR4 categories I and II as shown in figure III.2 of the background paper and reproduced here in Figure 1). The policy discussion has moved already beyond the scenarios like IM29, which is currently proposed for BCP3. For example, the reference in the G8 summit declaration from Heiligendamm with "at least globally halved emissions in 2050". The Club of Madrid tabled at the recent G8 Gleneagles process meeting a proposal for a new global framework that would be aimed at reducing emissions globally by 60% below 1990 by 2050[2]. In the UNFCCC/Kyoto Protocol context, the Ad Hoc Working Group On Further Commitments For Annex I Parties Under The Kyoto Protocol has recognized "global emissions of greenhouse gases need to peak in the next 10 to 15 years and be reduced to very low levels, well below half of levels in 2000 by the middle of the twenty-first century in order to stabilize their concentrations in the atmosphere at the lowest levels assessed by the IPCC to date in its scenarios"[3].

The IM29 scenario has only a global GHG reduction of 40% or 35% by 2050 relative to 2000 and 1990 levels, respectively. The lower IM26 scenario in contrast has a reduction of 55% or 50% below 2000 and 1990, respectively.

Often, an argument is raised that to analyze levels below the most prominent radiative forcing levels in the literature would be "policy-prescriptive". Quite the contrary is the case: Policy-makers require the best available information on the implications of any potential decision, no matter whether this decision is $8W/m^2$ or $2W/m^2$ stabilization. Not only is there the G8 reference to "at least halved global emission", but there is as well the 2°C temperature target adopted by the EU and many other stakeholders. Achieving the EU 2°C target with at least a likely chance would require a long-term stabilization below 400ppm CO_2 equivalence or $2W/m^2$ (although an intermediate peaking level at maximally $3W/m^2$ might be consistent as well). Thus, not providing policy-relevant information on the implications of policies actively considered would run contrary to the core principles of the IPCC, namely to provide policy-relevant, not policy-prescriptive information. Supporting informed decision making is a core role of IPCC, by analyzing the scientific knowledge in respect to both mitigation efforts and climate impacts of various considered non-mitigation and mitigation policies. An intentional act by IPCC or the scientific community to constrain the provided information to selective emission pathways or policies only, not including the lower range of mitigation scenarios, pathways or policies considered in international policy and in the literature, could be considered policy-prescriptive in itself. It is dubious whether scientists, rather than politicians, should make decisions about what are feasible mitigation pathways and what aren't. Policy-makers need to make these decisions based on sound scientific information. By not analyzing the lower end of the available scenario literature, scientists would by implication be making this decision in lieu of policy-makers.

[2] http://www.clubmadrid.org/cmadrid/index.php?id=1030

[3] FCCC/KP/AWG/2007/L.4, http://unfccc.int/resource/docs/2007/awg4/eng/l04.pdf

2. Assessment of climate response to decreasing forcing

A number of issues have been identified or have risen to higher levels of prominence in the course of the IPCC AR4 which policy makers and the scientific community will either wish or need to examine in the context of the next main global scientific assessments (see Table 1 below). Examination of the full range of options for policy makers will need or require that AOGCM experiments are conducted that span a wide range of future forcing scenarios, including scenarios with peaking and declining radiative forcing to low levels.

Selecting the IM29 scenario for BCP3 would not allow the study of the effects of decreasing concentrations/radiative forcing, as the concentration decreases are too small.

The background paper hints already at a scientifically interesting research area, which has so far not been subject to thorough analysis: the climatic response to decreasing concentrations. There have been initial idealized studies done on idealized “overshoot” scenarios at medium to high radiative forcing levels. However, fully coupled carbon cycle climate models will be needed to estimate the climate and carbon cycle responses to decreasing concentrations. Will the carbon cycle feedback, the ocean heat uptake and the response by ice sheets be symmetric to increases and decreases of radiative forcing? Most likely not. Examining the responses to decreasing concentrations would furthermore allow more in-depth studies on the irreversibility of various climate impacts.

Additionally, combining decreasing concentrations with the low forcing scenarios will enable the gathering of highly policy-relevant insights on potentially unavoidable longterm climate impacts, and the corresponding adaptation needs. Many areas of this both scientifically interesting and highly policy-relevant research would not be enabled by a BCP3 scenario which has only slightly decreasing concentrations, as temperatures would, at best, stabilize under the IM29 scenarios. Only in the IM26 scenario with decreasing forcing beyond 2100, slight decreases in temperatures can be expected. The BCP3 scenario as proposed in the background paper is envisaged to illustrate a “low overshoot” case, stabilization at 3W/m2 and seems to imply that this is illustrated by the IM29 scenario. The IM29 scenario has, however, a rather flat concentration trajectory after 2050, so studying an overshoot case will hardly be possible or meaningful (see Figure 2 and Figure 3 below). Only the IM26 scenario would enable to study the effects of peaking/overshoot[4] and potentially decreasing temperatures.

[4] The IM26 scenario could be described as an “overshoot” scenario in respect to an ultimate 400ppm (2.0W/m^2) or 450ppm (2.5W/m^2) stabilization level, depending on the assumed continuation trajectory of emissions beyond 2100 or 2150 (see Figure 3 below).

Table 1 - Examples of issues that require scenarios with decreasing radiative forcing in order to be assessed

Issue	Scaling of climate system
Responses to emission scenarios	Pattern scaling of response of climate models to different emission scenarios is reasonably satisfactory for standard radiative forcing scenarios. For scenarios where radiative forcing is declining from a peak, as implicit in some scenarios and policy debates, the scaling with patterns derived from standard scenarios may not work.
Assessment of avoidable impacts	The timing and scale of impacts have not been assessed for scenarios where radiative forcing is declining. This is relevant to the assessment of mitigation and adaptation responses in the context of avoided impacts. For certain ecosystems and species, and for elements of the cryosphere (mountain glaciers, ice sheets, sea ice cover, snow cover) such assessments could be informative for policy.
Steric sea level rise	Assessment of the long term commitment to steric sea level rise at present lacks climate responses from ESMs.

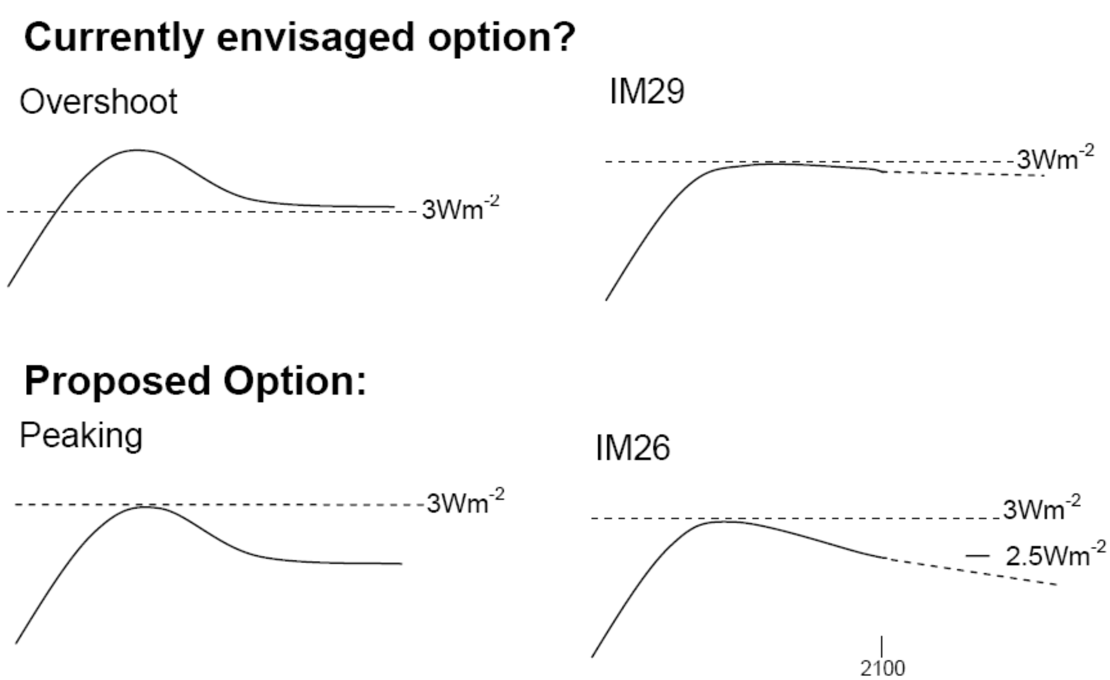


Figure 2 - Schematic illustration of peaking and overshooting pathways and the envisaged IM29 and IM26 options. Note that IM29 would neither allow studying effects to decreasing forcing, nor cover the lower forcing levels beyond 2050 representative for the emission categories I and II. In regard to the radiative forcing trajectories of the IM scenarios, compare figure III.2 (right) in the Background note to participants and Figure 3 below**.**

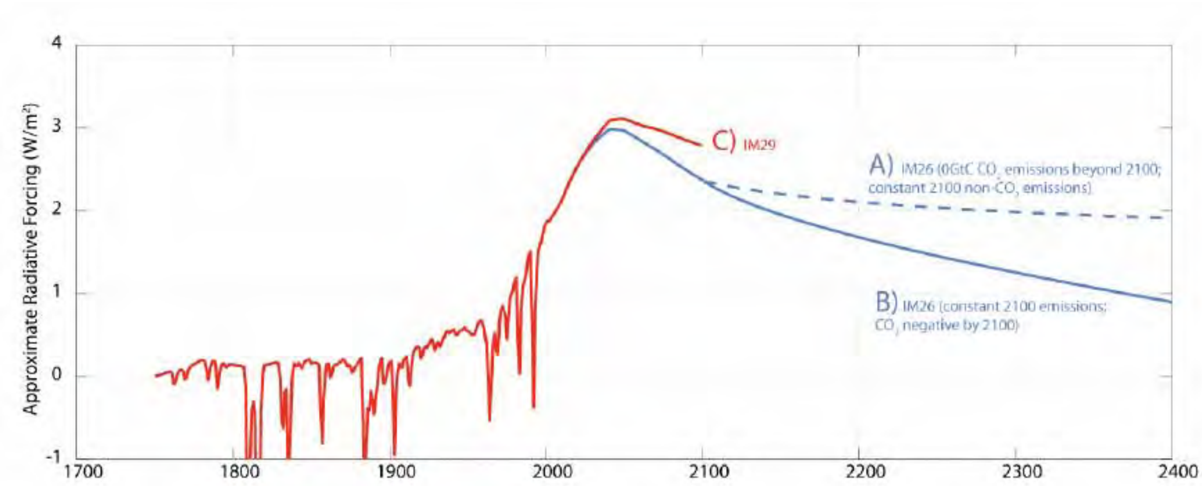


Figure 3 Stylized illustration of proposed possible low end BCP concentration pathway from IM26. A) illustrates the forcing pathway for a return to zero CO_2 emissions after 2100 (year 2100 CO_2 emission in IM26 are ca -1.3GtC/year) and constant other emissions at 2100 levels. B) maintains IM26 2100 emissions to 2400. C) seems to be the currently envisaged option for BCP3 with stabilization around 3W/m^2 after 2100. Compare with Figure III.2 (right) in the Background paper.

3. Additional issues

The current terminology "high stabilization", which is used to describe the 6.0W/m^2 scenario in table III.2, is misleading and needs to be changed into "medium reference"[5].

6.0W/m^2 by 2100 corresponds to approximately the SRES A1B scenario, which is the medium non-mitigation scenario analyzed in the last IPCC Assessment report AR4. (BTW: 4.5W/m^2 approximately corresponds to the SRES B1 scenario, analyzed in IPCC AR4 as low reference scenario). A terminology of one 'reference' and three 'stabilization' scenarios would mislead other parts of the scientific community into believing that all three stabilization scenarios 3.0, 4.5 and 6.0 W/m^2 would represent scenarios that imply mitigation, i.e. emission reduction policies. Clearly, some medium scenarios could represent both non-mitigation or mitigation scenarios, depending on the assumed hypothetical "baseline". However, labeling a scenario a "stabilization" scenario, which is equivalent to the medium SRES non-mitigation scenario A1B, implies that recent research regards only A1FI, A2 or similarly high scenarios as credible baselines.

Irrespective of recent short-term emission developments, such a statement would represent a major scientific development, if true. As well, the recent literature does not seem to justify this assumption that A1B is closer to a plausible mitigation than nonmitigation futures. In fact, even in the recent EMF-21 modelling intercomparison that has substantially higher baselines than SRES, the 6W/m^2 level in 2100 was encompassed by the range of baseline scenarios, but not by any mitigation cases (see right side of figure III.2 in the Background note for participants reproduced below in Figure 4).

[5] PS (after sign-on by many supporters): W e would like to emphasize an even more general point with regard to terminology: Encouragement to use value-neutral descriptions, like "lower", "higher" or "lowest assessed" for the scenarios instead of "low", "medium" or "high".

4. Conclusion

To deal with the issues outlined above and to establish a low end member scenario of the BCP set consistent with the literature, scientific considerations and that is policy relevant we propose that the present BCP3 be replaced. One option which we put forward is to define BCP3 as a *"Low stabilization (peaking) scenario with a maximum forcing of 3W/m2 in the mid 21st century with a subsequent decline towards ~2.5W/m^2 by 2100 and continuing decreases to approach a lower stabilization level thereafter.*" This is similar to the "IM26" scenario (instead of the apparently envisaged "IM29" scenario cp. Figure III.2 in the background note). If the background paper and its Annex are to be used as the basis for a decision on the BCP set the following necessary language edits are provided to give effect to the proposal we make here. Corresponding changes would need to be made throughout the text, where the language is either inconsistent or ambiguous.

Table III.2, page 23, Background paper currently states:

Table III.2: Proposed Benchmark Concentration Scenarios

Name	Type	Radiative Forcing in 2100
BCP8.5[a]	High reference	~ 8.5 W/m^2
BCP6[b]	High stabilization	~ 6 W/m^2
BCP4.5[b]	Medium stabilization	~ 4.5 W/m^2
BCP3[a]	Low stabilization (overshoot)	~ 3 W/m^2

[a]Radiative forcing refers to the 2100 radiative forcing.
[b]Radiative forcing refers to the stabilization level (often reached shortly after 2100).

And should read (edits in red):

Table III.2: Proposed Benchmark Concentration Scenarios

Name	Type	Radiative Forcing Level
BCP8.5[a]	High reference	~ 8.5 W/m^2
BCP6[b]	**Medium reference**	~ 6 W/m^2
BCP4.5[b]	Medium stabilization	~ 4.5 W/m^2
BCP3[c]	Low stabilization **(peaking)**	~ 3 W/m^2

[a]Radiative forcing refers to the 2100 radiative forcing.
[b]Radiative forcing refers to the stabilization level (often reached shortly after 2100).
[c] Radiative forcing refers to the maximal radiative forcing (peaking level) with 2100 levels ~2.5W/m^2 and subsequent decline to approach stabilization at lower levels.

5. Appendix I

Table 2 - Table SPM.5 reproduced from IPCC AR4 WG3

Table SPM.5: *Characteristics of post-TAR stabilization scenarios [Table TS 2, 3.10][a]*

Category	Radiative forcing (W/m²)	CO_2 concentration[c] (ppm)	CO_2-eq concentration[c] (ppm)	Global mean temperature increase above pre-industrial at equilibrium, using "best estimate" climate sensitivity[b), c)] (°C)	Peaking year for CO_2 emissions[d]	Change in global CO_2 emissions in 2050 (% of 2000 emissions)[d]	No. of assessed scenarios
I	2.5-3.0	350-400	445-490	2.0-2.4	2000-2015	-85 to -50	6
II	3.0-3.5	400-440	490-535	2.4-2.8	2000-2020	-60 to -30	18
III	3.5-4.0	440-485	535-590	2.8-3.2	2010-2030	-30 to +5	21
IV	4.0-5.0	485-570	590-710	3.2-4.0	2020-2060	+10 to +60	118
V	5.0-6.0	570-660	710-855	4.0-4.9	2050-2080	+25 to +85	9
VI	6.0-7.5	660-790	855-1130	4.9-6.1	2060-2090	+90 to +140	5
						Total	177

a) The understanding of the climate system response to radiative forcing as well as feedbacks is assessed in detail in the AR4 WGI Report. Feedbacks between the carbon cycle and climate change affect the required mitigation for a particular stabilization level of atmospheric carbon dioxide concentration. These feedbacks are expected to increase the fraction of anthropogenic emissions that remains in the atmosphere as the climate system warms. Therefore, the emission reductions to meet a particular stabilization level reported in the mitigation studies assessed here might be underestimated.

b) The best estimate of climate sensitivity is 3°C [WG 1 SPM].

c) Note that global mean temperature at equilibrium is different from expected global mean temperature at the time of stabilization of GHG concentrations due to the inertia of the climate system. For the majority of scenarios assessed, stabilisation of GHG concentrations occurs between 2100 and 2150.

d) Ranges correspond to the 15th to 85th percentile of the post-TAR scenario distribution. CO_2 emissions are shown so multi-gas scenarios can be compared with CO_2-only scenarios.

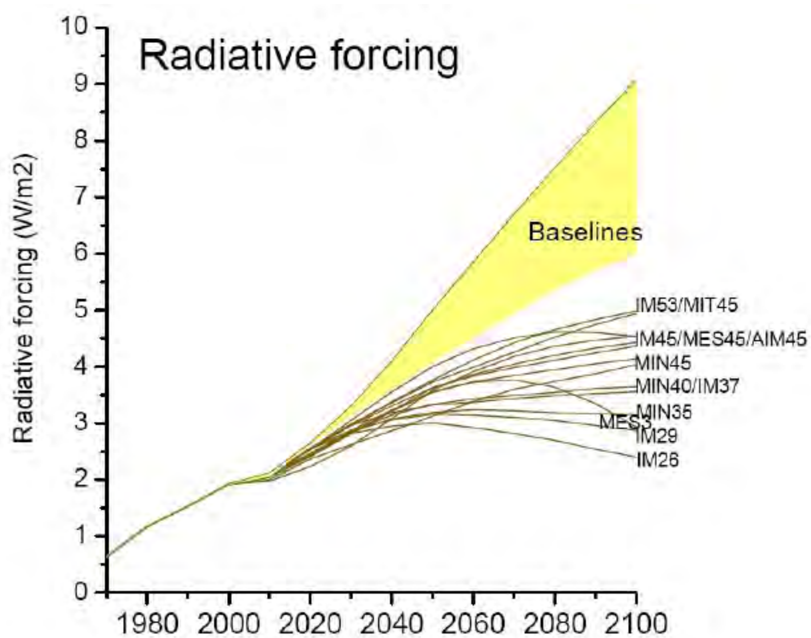


Figure 4- Figure III.2 (right) reproduced from "Background note for participants"

The IPCC new scenario must explore "concentration overshoot scenarios over centuries" – likely future

Taroh Matsuno* and Taishi Sugiyama**
Members of the Core Writing Team
For the Synthesis Report of the IPCC AR4
*WG1 **WG3

Abstract

It is time to depart from hypothetical "stabilization" pathways so that we can assess realistic consequences of alternative pathways over centuries. Our discussion in the AR4-SYR process led to the view that warning on "sea level rise after a thousand years of fixed concentration" based on hypothetical situation is difficult message for society to digest. IPCC should make more "analysis of alternatives" on likely future and the new scenarios should serve for the purpose.
As the global warming and climate change become a political agenda, scientific basis for identifying the optimum stabilization levels will become necessary. As to the impacts until the time of stabilization which is supposed to be soon after 2100, various studies are being conducted. After the stabilization climate will become stationary but the sea level continue to rise by thermal expansion of the sea water and melting of ice sheets for many centuries and millennia. The eventual sea level rise corresponding to the final equilibrium temperature may amount to a few meters or larger even for those moderate stabilization levels whose temperature rises until 2100 are supposed to be within acceptable limit of warming (until 2100), say less than 2.5°C. Thus it is very difficult to find a practically feasible stabilization level which does not require extremely stringent mitigation and compatible with the safety condition in the view point of long term sea level rise.
A cause of this difficulty lies in the assumption that a higher concentration and hence the higher temperature will continue for any long time which comes from the definition of "stabilization". Is this really needed? So far almost all CO_2 emission scenarios based on studies on the future outlook of economy/technology development cover only the 21st century and the emissions after 2100 are left indetermined or unpublished (e.g. SRES). On the other hand in some studies emission pathways leading to stabilizations of CO_2 concentration are investigated and the resultant CO_2 emissions are reported extending beyond 2100 typically until 2300 (e.g. WRE stabilization scenarios). In the present authors' understanding, in this latter case, first CO_2-concentrations approaching specified constant levels are determined and then the anthropogenic emissions are inversely calculated to be consistent with the concentrations under the action of natural uptakes. Therefore the latter emission pathways do not necessarily rest on economy/technology background.
Because of this situation the author would like to propose to explore possibility of "zero-emission" pathways in which emissions first follow those stabilization scenarios then approach zero sometime around 2200 or 2300. By doing so we may be able to get rid of the difficulty as mentioned previously.

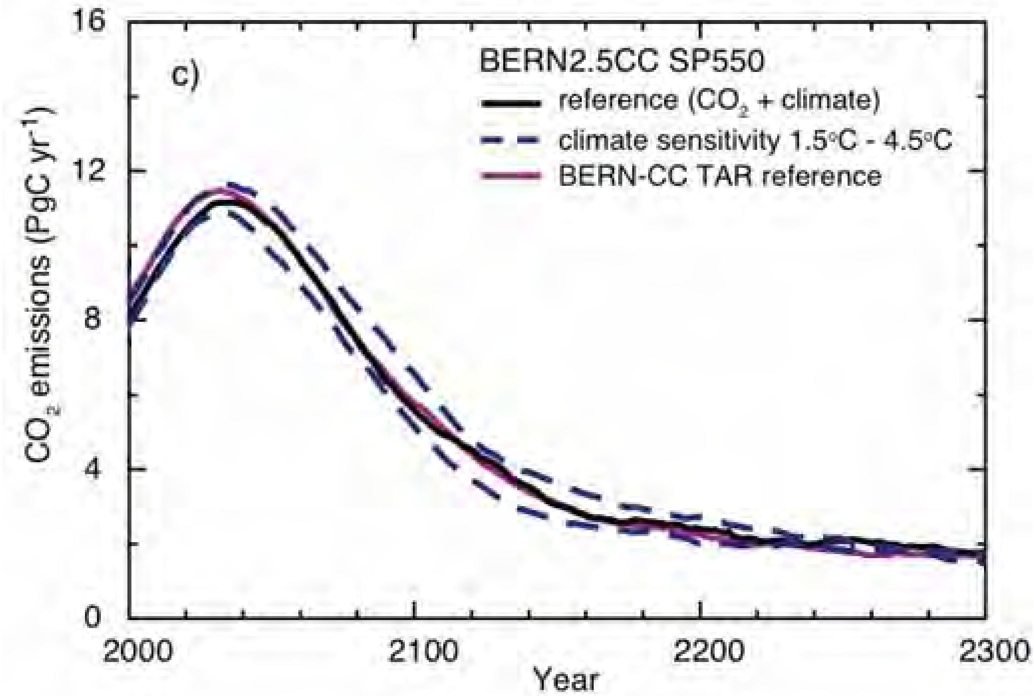


Fig.1 Emission profile corresponding to a stabilization at 550ppm (Adapted from Fig 10.22 of the IPCC WG1 AR4)

The situation can be understood from Fig.1 which shows the CO2 emission pathway leading to a stabilization at 550ppm, taken from the IPCC WG1 AR4 (Fig 10.22). As seen the emission decreases greatly from its peak at around 2040 to about 1/4 of the peak by 2150 when the concentration approaches the stabilization. (This emission profile is close to the SRES B1 scenario until 2100.) After this the emission does not decrease so markedly and a small but significant amount of emission continues. When we regard this as a mitigation scenario a question arises. Why does the emission reduction slow down after around 2100? Why one stops efforts of mitigation after the success of a remarkable reduction? Is the small but significant emission continuing until 2300 which is considered to be a consequence of the inverse calculation to maintain the constant concentration against the natural (ocean) uptake really needed? There may be no basis from the viewpoint of mitigation strategy. Let us assume that the above considerations are correct. Then by continuing efforts to reduce emission further going down below the amount of natural uptake, we can make the concentration turn to decrease to go down significantly below the originally targeted concentration of stabilization. This is an "overshoot scenario over centuries" approaching the equilibrium stabilization whose concentration is determined by the cumulative total of CO2 emission.

So far most of discussion on emission scenarios covers only the 21st century or until stabilization. If we extend emission scenario beyond the stabilization for one more
century or two as described above possibly approaching "zero-emission" we may be able to find a solution to the first raised problem.
Mentioning zero emission may sound unrealistic. But there are a few reasons to show that this is not the case as noted subsequently in the Appendix.

Appendix: Notes on zero emission

1. Practically-0 emission is meant. The zero-emission in the above discussion means emissions being sufficiently smaller than the natural uptake under an initially targeted stabilization level. For example, in the case of Fig.1, emissions less than 0.5 GtC/year or so may be taken practically 0. If the emission at this rate continues for 5 centuries, for example, the total cumulative emission amounts to 250 GtC and whose 20%, 50GtC, will remain in the atmosphere resulting in 25ppm above the true zero-emission which might be negligible.

2. All stabilization scenarios must end up with emission 0. As seen in Fig.1, a small amount of emission continues for a very long time under a stabilization condition. However, the amount gradually decreases finally to reach 0 when the whole atmosphere-ocean system attains the equilibrium for the specified (stabilization) CO_2 concentration. The time for equilibration is around 1,000 years the overturning time of the ocean. Thus exceeding several centuries there may be not so large difference between stabilization scenario and zero-emission scenario because the allowed emission under the stabilization becomes rather small.

3. Zero or even negative emission is already discussed in the post-SRES mitigation/stabilization scenarios. In the WG3 report the band of emission pathways which meet the lowest stabilization level, 350-440 ppm CO_2 (Category I) crosses the zero line before 2100 and the mid-line of the band appears to be in the negative side at 2100. For the next lowest one (Category II) also reaches the zero line around 2100. Thus “zero emission” is no longer an exceptional situation in the mitigation strategy. By the way, in the case of the Category I the emission must become positive again sometime after 2100 because the total emission amount by 2100 appears to be smaller than the total CO_2 to be added to the atmosphere-ocean system for the system to become equilibrium state with 375 (middle of 350-400) ppm CO_2.

Proposal for the Next Vintage of Long Run Scenarios in a Changing Scientific and Policy Context

Jean-Charles Hourcade, Emilio La Rovere, P.R. Shukla, Jiang Kejun

1 Objective: eliciting the development-climate Gordian Knot

The shared diagnosis underlying this proposal is that the development of economic scenarios under the IPCC impulsion should internalize, in addition to delivering GHGs emissions scenarios for climate modellers, the objective of better informing policy debates about how various visions of future long term development pathways affects the content, the efficacy and the social costs and benefits of adaptation and mitigation policies.

This paper provides a proposal for the production of new scenarios that stems from the following four policy-oriented concerns:

- To clarify ***catching – up (or differentiation) dynamics***, not only in terms of per capita GDP growth but also in terms of physical development patterns – this would allow to solve the difficulties of the PPP vs. MER controversy;

- To delineate ***the interplay between climate policies and sustainable development***, including energy security and poverty alleviation, in a context of long-term changes such as ageing, migrations, higher capital mobility and evolving world trade organization;

- To investigate ***the relative role of energy and non-energy parameters and policies*** in the achievement of high or low emission stabilization targets;

- To detect the ***long-standing implications of short term development options*** both for climate change and for overall development sustainability – this applies primarily to the dynamics of infrastructures and land-use, with a strong concern for technological and structural lock-in.

Progress in those directions will demand to address several methodological challenges, which were not equally underlined in the past four IPCC assessment reports, even if they have been mentioned earlier in the literature.

2 Methodological challenges

2.1 Scenarios meaningful for two scientific communities

A first difficulty comes from the fact that new scenarios catalyzed by the IPCC are expected first to be useful for mitigation and adaptation studies, second to be consistent with emissions scenarios used for next runs of heavy climate models. Indeed it would be increasingly blurring to disconnect the emissions scenarios from those used for analysing how to orient the world economy towards one of them. But policy analysis requires much more scenario variants than climate modelling itself, and it would be of no interest to try and feed climate models with all alternative scenarios developed for mitigation and adaptation assessment, since many of them indeed result in second order differences in terms of climate forcing.

Following the clear statement from the IPCC Working Group on New Emission Scenarios to limit the total number of new scenarios, we would suggest to concentrate on ***twelve basic scenarios*** which are meaningful both for climate simulations – because each of them will induce a different pace of climate forcing – and for economic analysis – because they can cover the range of economic mechanisms likely to impact on the efficacy of climate policies. Eventually, the following twelve scenarios should suffice in providing the information necessary to run climate models and provide various detailed climate change scenarios for detailed analysis and to be used in integrated mitigation and adaptation studies:

- A ***high*** no-policy emission scenarios in which the drivers of net GHGs emissions (including high carbon release from land cover changes) are set at their maximum plausible level, plus a ***low variant*** of this scenario for land cover changes[1];

- A ***medium*** no-policy emissions scenario in which these drivers are fixed at their average plausible value (including slowing down of carbon release from land cover change), plus a ***high variant*** of this scenario for land cover changes[1];

- ***Eight stabilisation*** scenarios, for 550 ppm and 450 ppm GHGs concentration targets, derived from an early policy action all over the world from each BAU emissions scenarios. This will allow to test the extent to which scenarios respecting identical stabilisation targets may lead to a different pace of global warming because of significant differences in emissions over the first part of the century. Obviously, how the *when and where* issue is likely to be resolved will generate a far more complex set of scenarios; they will simply be defined as variants of these eight scenarios which should be analysed only by economic modellers.

2.2 Short, medium and long run: linkages and path dependencies

The disconnection between very long run scenarios and scenarios examining short term policy issues should be reduced as far as possible and this for many strong reasons. First, negotiations will be conducted mostly on medium term objectives and the "passing points" between today and the end of the century are critical. Second the analysis of costs (or double-dividends) of early action cannot be separated from the impact of these decisions on the carbon content of growth over the medium and long run and of the differentiation and the sequencing of decarbonisation efforts amongst countries and sectors. Third, short and medium term emission trends will determine the pace of global warming and the magnitude of the environmental irreversibility effect.

The main challenge is the question of the path dependencies of development patterns and emissions trends, in particular those created by the building and transportation infrastructures in developing countries, the investments in electrical sector, the orientation of R&D, the dynamics of land uses.

2.3 Endogeneization of scenario variables, to avoid the combinatory trap

The determinants of GHG emissions can be grouped into three categories:

---

[1] Indeed a 'upper bound' high growth scenario may include a deepening of current trends of converting forests into cattle breading areas or croplands; on the contrary upper-bound high non agricultural emissions can also be associated to a slowing down of deforestation, in case of high productivity growth in agriculture and/or slowing down of the increase of the meat content of diet. Symmetric options can be defined for the 'medium scenarios'.

- The ***economic growth engine*** (demography, productivity growth and catch-up assumptions, savings, capital flows, fragmentation or integration of the world economy).

- The content of the ***development patterns*** (consumption patterns, technological styles, land cover and localization of activities, patterns of income distribution).

- The dynamics of the ***energy systems*** (energy efficiency, technological options on the supply and demand sides, fossil fuel resources) and the final price of fossil based energies.

Scenarios reported in the IPCC SAR showed the trap of combining the assumptions that can be made in each group of parameters as if they were totally independent. This practice resulted in an unrealistic large spectrum of emissions projections that the consideration of feedbacks mechanisms may narrow in the real world. For policy analysis, it did not help to understand the linkages between policies affecting the development patterns (in major part adopted for reasons independent from energy or climate) and climate centric policies.

Then a common ambition for energy-economy modellers should be to further endogenize the interdependences between these parameters, making for example GDP growth and structural change result from the interplay between the growth engine, the characteristics of development patterns and the energy markets (Figure 1). In particular this implies to consider a comprehensive endogenous growth engine – not only endogenous technical change, but also endogenous structural change and growth – when it is possible to get robust estimations of real mechanisms.

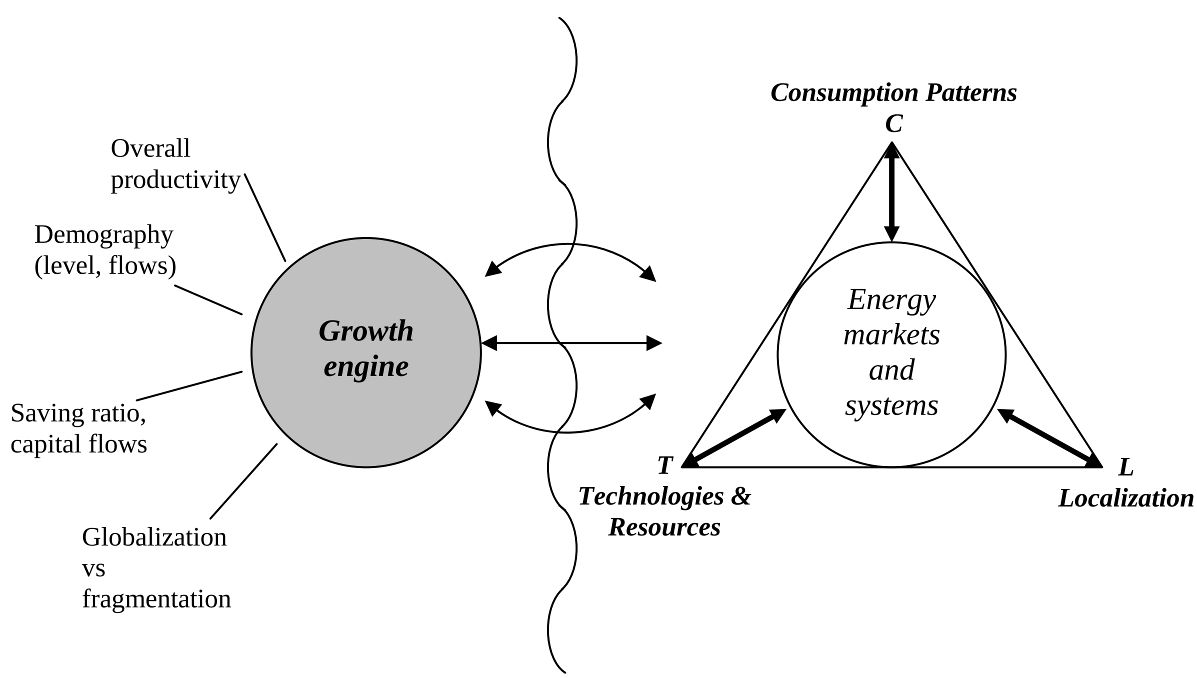


Figure 1: Interlinked mechanisms driving endogenous growth and structural dynamics

2.4 Non optimal baselines

The common practice is to use compact macroeconomic models or multi sector computable general equilibrium models for projecting equilibrated growth pathways (often optimistic for reasons of political correctness) and to represent environment policies in the form of new constraints altering these trends. This constitutes an intellectual obstacle to detect the possible leverage effects between climate policies and development since real sustainability challenges come primarily from:

- ***imperfections in the economic machinery***, the hallmarks of which are the existence of incomplete and fragmented markets (multiple discount rates, unequal marginal costs across sectors & regions), weak policy regime, poor governance, under protected property rights and dual economy in perpetual reformation;

- ***fuzziness of economic signals and non economic information*** and delays in perceiving ultimate consequences of current decisions. This inhibits timely actions and trigger higher transition costs to adapt to changes of the economic context (energy shocks, sudden moves in capital flows, over or under estimation of long term demand in rigid sectors);

- ***feedbacks from climate change and degradation of local environments*** : it is indeed increasingly misleading to project baseline 'at constant natural environment' since the coupled feedbacks from changes in environment and climate will generate stresses on natural resources (e.g. water, ecosystems) and degradation of land and labor productivity.

In this project we aim at delineating real baselines that incorporate barriers to the achievement of the growth potential of each country or region. In other words, it means to develop scenarios with ***economic disequilibrium*** generated by the interplay between inertia of social and technical systems, imperfect foresights and 'routine' policy behaviors, in order to detect the many sources of sub-optimality (structural debt, unemployment, informal economy and unfulfilled basic needs, capacity shortages, missing markets). The sub-optimality involved in these scenarios is not likely to be determinant for giving inputs to climate modelers; it will be for costs assessments.

3 Scenario development: generic scenarios and variants

The generic scenarios that could be developed in a first step would assume smooth growth pathways due to the progressive resolution of market imperfections (for example debt extinguishment) and to the absence of surprises in energy markets. In a second step, variants of these scenarios could incorporate assumptions likely to alter the social cost of meeting the concentration targets (with a second order impact on the pace of climate forcing).

3.1 Generic scenarios: balanced growth and globalisation of world markets

Combining high and low assumptions about the three sets of determinants of reference scenarios would lead to 8 reference and 16 stabilisation pathways. This number can be reduced to twelve by selecting the high and low bounds of plausible values for each determinant. We should not try and define two 'more plausible' scenarios in order to avoid harsh controversies and the accusation of political arbitrariness. If we manage to endogenize enough feedback mechanisms (cf. 0), it will lead to prevent that combining the lowest bounds of plausible parameters values results in an implausible scenario.

3.1.1 Key parameters of the potential of the 'growth engine'

We propose to generate two alternative growth patterns (H and L) using two contrasted sets of assumptions:

- ***Labour productivity, income distribution and catch-up***: new scenarios will greatly be improved with the lessons from the PPP vs. MER debate[2], especially the need to carefully consider initial productivity gaps and partial vs. full catch-up at the sector level. Then equations driving this parameter should take into account the sum of cumulated investments in each sector in each region, so that the effective catch-up rate (high or low) would depend on endogenous economic growth (assuming that 'leader economies' will follow mean productivity growth rates between 1.6% and 2% per year). The high and low catch up rates could ultimately be combined with assumptions about the ***income distribution patterns*** and the level of ***informal economies*** prevailing in each growth pathways;

- ***Saving rates and ageing***: in all regions, the secular evolution of the saving rates is correlated with the pyramid of age and, especially in developing countries, with migration flows and money flows from migrants. Scenarios could benefit from an overlapping generation analysis, in which the evolution of regional saving rates hangs on assumptions about risk aversion, pure time preference and long run interest rates.

- ***Capital deepening*** trends have to be checked (around central values) to fit with realistic ICOR values.

In complement to these sets of assumptions about the very growth engine, the 'balanced' character of growth pathways will be secured by assuming a) explicit foresight of technological evolutions and of the efficiency of equipments b) no strategic behaviours regarding parameters such as oil prices or regional relative prices c) no protectionist policies to mitigate transitory costs of the economic globalisation.

3.1.2 Development patterns, technical and structural changes

Assumptions about consumption styles, technology and localisation patterns may be combined into two contrasted visions of development over the 21th century:

(I) ***deepening and generalization of post-war II development patterns*** that basically continue on existing trends with a progressive convergence of all societies towards high levels of material consumption (with due adaptation to local conditions), standardization, economies of scale, 'just in time' stock management;

(II) ***re-switching and tunnelling towards an alternative pattern*** in which some of current trends are altered, for reasons unrelated with climate concerns, to achieve a less material intensive development ('service and information society'). In this hypothesis, developed countries progressively change their development styles whereas developing countries bypass the most material intensive phases of development.

[2] e.g. Nakićenović et al., 2003 ; McKibbin et al., 2004; Dixon et Rimmer, 2005 ; Nordhaus, 2007.

These two visions will be declined for following three sets of assumptions:

- ***Consumption styles**:* the (I) and (II) patterns incorporate respectively high and low assumptions regarding a) saturation asymptotes for demands of energy consuming services such as housing space or electric devices b) preference for mobility (short and long distance);

- ***Technological patterns**:* the (I) and (II) patterns are separated by different assumptions about a) the material content coefficients b) the substitutability potential between metals, fossil based feedstocks and bioproducts (bioenergy, biomaterials) c) the infrastructure choices in construction and transportation d) the transport input in production,

- ***Localization patterns*:** the (I) and (II) patterns will be characterised by high and low levels of households mobility demand (in consistency with assumptions about individual preferences and infrastructure policies) and territorial distribution of populations and activities (strength of the ocean coastal drift). The latter distinction is critical to elaborate consistent land cover scenarios and their implications for the carbon cycle (deforestation)

Efforts will be undertaken to incorporate as far as possible medium and long run feedbacks of climate change on the economic systems, which is a relatively new methodological challenge in scenario generation, and would raise the opportunity to gather work from WG II and III of the IPCC.

3.1.3 Energy Systems – Energy markets

On the demand-side, the (I) and (II) patterns would induce different demand profiles for energy services, first because of their differences in material intensity, second because of the resulting impact on the time profile of fossil fuel prices. These differences can be accentuated by assumptions about the efficiency of end-use equipments: pessimistic vs optimistic assumptions about the asymptotes of efficiency gains in end-use equipments.

On the supply-side, the (I) pattern would be associated with rather optimistic assumptions about fossil based energies and a slow relaxation of resistances to nuclear energy. The (II) pattern would be associated with more pessimistic assumptions on fossil energies, higher social acceptance of nuclear and more optimistic assumptions about bio-energies.

3.1.4 Policy mixes to achieve GHGs stabilization scenarios

The emissions profiles retained for the stabilization scenarios can be adjusted to some exogenous cost-minimizing profiles (in aggregate GDP terms) for each region under a fully idealized when and where flexibility assumption with full participation of all countries to a climate regime beyond 2012.

Not to enter the complex issues involved in the precise definition of such a climate regime and since a fully-fledged emissions trading system amongst all economic agents is unrealistic given the asperities of the real world, stabilization scenarios could:

- assume the existence of a single world carbon price applied to all gases;

- interpret this price as resulting from a carbon trading system amongst Parties (in the Kyoto sense) to which emissions allowance have been given in such a way that no import or export is economical for none of the regions or countries,

- let governments convert this world price domestically at their convenience (carbon taxes, emissions quotas at the sector level, pricing differentiation in function of income levels etc …) to account for the specifics of their economies or any social constraints;

- assume that governments take any complementary measures helping to reach the final target at a minimal social cost (efficiency standards, modal choices in transportation, urban infrastructures)

- assume that countries experiencing more significant transitory or permanent GDP losses than others will remain in the system and that international community will assist them (loans, assistance to dedicated investments) in minimizing these net losses.

3.1.5 Multi gas data

To be useful to the climate modelers, emission scenarios have to include improved multigas output. This raise methodological issues concerning aggregation, since the source of multigas emissions are often at a less aggregated level then fossil fuel consumptions. The use of aggregated activity indicators as proxies of the multigas emissions may appear very rough in the future.

3.2 Variant scenarios: frictions, disequilibria, timetables

Variants of the ‘stable growth’ scenarios should be carried out not only in the form of sensitivity tests but also to bring additional material for policy analysis.

- Three types of variants of ***baseline scenarios*** could be conducted:
  - (i) Test of the impact of technical, economical and political ***frictions*** slowing down the pace of penetration *of* ***alternative techniques to conventional oil and gas*** (nuclear, coal to liquids, biofuels);
  - (ii) Check how the baselines are altered by ***non energy-related parameters*** such as capital flows, a fragmentation of world markets, stickiness of the terms of trade, domestic wage policies;
  - (iii) Introduce endogenous or exogenous ***chocks*** triggered by sudden changes in oil prices or in exchange rates.

- The variants of ***stabilization scenarios*** could basically concentrate on three dimensions (in addition to sensitivity tests on the influence of frictions on the deployment of certain techniques):

(i) Make explicit ***economic signals that may swamp carbon price signals*** as a major component of climate policies – this concerns in particular the prices of land and real estates, wage adjustments, the heterogeneity of capital costs (risk premium included) amongst countries and sectors;

(ii) Capture the impact of ***regulatory uncertainty*** and ***price volatility*** on the efficacy of deployment of climate policies and alternative technologies, in view of examining what combination of policy tools would minimize the perverse effects of these parameters and enhance the incentive to innovate on both the demand and supply side.

(iii) Examine the ***time tables of policies*** (binding emissions targets, carbon markets and/or carbon taxes, other pricing policies, non price measures, compensating transfers) capable to minimize the transition costs towards a stabilized fully-fledged climate regime governed by a single carbon price

The basic assumptions behind these policy variants is that, even though the assumption of a unique world carbon price applied from now on and without complementary policies is a very useful benchmark for policy analysis, it does not correspond to an optimal policy in a 'second best' economy with sharp political constraints. Variant scenarios should thus relax this assumption, accept the ***transitory existence of disparities in levels of carbon pricing*** and examine the following policy issues:

- *Timing of various forms of commitments* and pledges by countries for a fragmented and progressively converging regime;

- Content and timing of policies *on non-CO2 gases and carbon sequestration*;

- Content and timing of *infrastructure policies*;

- *Differentiation of policy signals* across sectors (energy, industry, land transports, aviation and shipping, agriculture);

- Design and timing of policy tools to alleviate transitory tensions generated by the emergence of a carbon price: international transfers to mitigate *the adverse effects on low income populations* and/or to launch early policy signals to reorient investments in infrastructure sectors, sectoral approaches for exposed energy intensive industry)

4 Some perspectives for scenario development with Imaclim

The four teams signatories of this proposal co-develop the Imaclim-R framework which is designed to meet at least part of the above challenges. This framework is an hybrid model which a) organizes in a consistent way technological and economical expertise b) extend the endogenous technical change assumption to consumption, localization patterns and structural change c) describes an economic growth engine which allows for transitory disequilibrium d) allows for imperfect foresight and market imperfections which determine the duration of various disequilibria including those related to labor market, capital and trade balances.

The four teams have been and will be jointly embarked in various projects for example for the World Bank and for the World Energy Outlook of the International Energy Agency. They are prepared to build on this experience to develop jointly scenarios in the new IPCC context in harmony with the guidelines which will emerge from IPCC Expert Meeting “Toward New Emission Scenarios for Analysis of Greenhouse Gas Emissions Climate Change, Impacts and Response Strategies” of WG III, 19-21 September 2007, at Noordwijkerhout, The Netherlands.

Their specific priority will be on line with the above analysis, to generate scenarios (baselines and variants) helping to explore more in depth the relations between climate change and development - *sustainability* (preservation of' separate or aggregate values of capital stocks like manufactured, human, social and natural capital; dematerialization and its implications for growth). They will more specifically emphasize issues related to *irreversibility* (social costs of lock-ins and values of lost options), *discontinuity* (extreme events, oil shocks, abrupt changes in capital flows), *uncertainty* ' (including regulatory uncertainty due to global agreements and national policies), *equity* (intra and international).

Our scenario development work will not be exclusive or limited by the interactions among the four teams. We plan to gain benefits from the interfaces different partners have with several prominent global modeling teams such as MiniCAM and SGM at Pacific Northwest National Laboratory (USA), Asia Pacific Integrated Model (AIM) team at National Institute of Environment Studies (Japan) and MESSAGE model team at IIASA (Austria). We are obviously open to collaboration with any other teams pursuing the same priorities. Such interactions, we expect, would enhance our scenarios in specialized areas like forestry and land-use, the viability of various technology strategies (biofuels, nuclear) and multi-gas assessment; It would also allow for a better understanding of differences in results between Imaclim and their own modeling approaches.

References :

Dixon, P. B., Rimmer, M. T., 2005, ‘Analysing convergence with a multi-country computable general equilibrium model: PPP Versus MER’, *Energy & Environment*, vol. 16 (6), pp. 901-921.

McKibbin W., Pearce D., Stegman A., 2004, ‘Long run projections for climate change scenarios’, Working Paper in International Economics, The Lowy Institute for International Policy.

Nakićenović, N., Grübler, A., Gaffin, S., Jung, T. T., Kram, T., Morita, T., Pitcher, H., Riahi, K., Schlesinger, M., Shukla, P. R., van Vuuren, D., Davis, G., Michaelis, L., Swart, R. and Victor, N.: 2003, IPCC SRES revisited: a response, *Energy & Environment*, 1 May 2003, vol. 14, no. 2-3, pp. 187-214(28)

Nordhaus, W., 2007, ‘Alternative measures of output in global economic-environmental models: Purchasing power parity or market exchange rates?’, *Energy Economics*, 29(3), pp. 349-372.

Appendix 5: Expert Meeting Participants

John van Aardenne, JRC, European Commission, Italy
Keigo Akimoto, Research Institute of Innovative Technology for the Earth, Japan
Joe Alcamo, University of Kassel, Germany
Michail Antonovskyi, Institute for Global Climate and Ecology, Russia
Nigel Arnell, Walker Institute, University of Reading, UK
Mustafa Babiker, ARAMCO, Saudi Arabia
Philip Bagnoli, OECD, France
Brad Bass, TGICA, Canada
Gerardo Bazan Navarette, National Autonomous University of Mexico, Mexico
Yevgen Berezhniy, Ministry of Environmental Protection, Ukraine
Fatih Birol, IEA, France
Prithiviraj Booneeady, Mauritius Meteorological Service, Mauritius
Hans Bolscher, Ministry for the Environment, The Netherlands
Peter Bosch, IPCC TSU WG III, The Netherlands
Olivier Boucher, Met Office Hadley Centre, UK
Bram Bregman, TNO, The Netherlands
Thelma van den Brink, IPCC TSU WG III, The Netherlands
Sander Brinkman, IPCC TSU WG III, The Netherlands
Jos Bruggink, ECN, The Netherlands
Eduardo Calvo, Universidad Nacional de San Marcos, Peru
Ian Carruthers, Australian Greenhouse Office, Australia
Pasha Carruthers, National Environment Service, Cook Islands
Tim Carter, Finnish Environment Institute, Finland
Wenying Chen, Tsinghua University, Beijing, P.R. China
Robert Steven Chen, Columbia University, USA
Renate Christ, IPCC Secretary, Switzerland
Luis Cifuentes, Universidad Catolica de Chile, Chile
Ogunlade Davidson, IPCC WG III, Sierra Leone
Phil DeCola, NASA/Office of Science and Technology Policy, USA
Jae Edmonds, Joint Global Change Research Institute, USA
Simon Eggleston, NGGIP, Japan
Ismail Elgizouli, Higher Council for Environment and Natural Resources, Sudan
Seita Emori, National Institute for Environmental Studies, Japan
Johannes Feddema, University of Kansas, USA
Guenther Fischer, IIASA, Austria
Brian Flannery, Exxon Mobil Corporation, USA
Ronald Flipphi, VROM Ministry Netherlands, The Netherlands
Joos Fortunat, EMIC, Switzerland
Pierre Friedlingstein, IPSL, LSCE, France
Ursula Fuentes, Ministry of Environment, Germany
Xuejie Gao, National Climate Center, P.R. China
Amit Garg, UNEP Risoe Centre on Energy, Environment and Sustainable Development, Denmark
Amadou Thierno Gaye, Laboratory of Atmospheric Physics, Senegal
Marc Gillet, Ministère de l'Écologie et du Développement Durable, France

Philip Glyde, Australian Bureau of Agricultural and Resource Economics, Australia
A.K. Gosain, Indian Institute of Technology, India
Kirsten Halsnaes, UNEP Risoe Centre on Energy, Environment and Sustainable Development, Denmark
William Hare, Greenpeace International, Germany
Jochen Harnisch, Ecofys, Germany
Wilco Hazeleger, KNMI, The Netherlands
Kathy Hibbard, NCAR, USA
Jean-Charles, Hourcade, CIRED-CNRS, France
Maria Eugenia Ibarraran, Universidad Iberoamericana Puebla, Mexico
Roger Jones, CSIRO, Australia
Mikiko Kainuma, National Institute for Environmental Studies, Japan
Lucka KajfezBogataj, University of Ljubljana, Biotechnical Faculty, Slovenia
Jessica Kelleher, UN Foundation, USA
Haroon Kheshgi, ExxonMobil Research and Engineering Co, USA
Masahide Kimoto, CCSR, Japan
Tom Kram, Netherlands Environmental Assessment Agency (MNP), The Netherlands
Thelma Krug, NGGIP, Brazil
Won-Tae Kwon, Meteorological Research Institute, Korea
Emilio La Rovere, Federal University of Rio de Janeiro, Brazil
Murari Lal, Indian Institute of Technology, India
Jean-Francois Lamarque, UCAR, USA
Rodel Lasco, University of the Philippines, Philippines
Robert Lempert, RAND, USA
Herve Letreut, LMD, France
Erda Lin, Chinese Academy of Agricultural Sciences, P.R. China
Richard Loulou, HALOA and ETSAP, Canada
Jason Lowe, Met Office Hadley Centre, UK
Martin Manning, IPCC TSU WG I, USA
Luis Mata, Universität Bonn, Germany
Ben Matthews, Universite Catholique de Louvain, Belgium
Linda Mearns, NCAR, USA
Anita Meier, IPCC TSU WG III, The Netherlands
Malte Meinshausen, Potsdam Institute of Climate Impact Research, Germany
Dominique van der Mensbrugghe, The World Bank, USA
Bert Metz, IPCC WG III, The Netherlands
Leo Meyer, IPCC TSU WG III, The Netherlands
Pauline Midgley, German IPCC Coordination Office, Germany
John Mitchell, Met Office Hadley Centre, UK
Richard Moss, University of Maryland, USA
Lars Muller, EU Commission,
James Murphy, Met Office Hadley Centre, UK
Nebojsa Nakicenovic, IIASA, Austria
Raholijao Nirivololona, Direction Generale de la Meteorologie, Madagascar
Shuzo Nishioka, National Institute for Environmental Studies, Japan
Leonard Nurse, CERMES, UWI, Barbados
Richard Odingo, University of Nairobi, Kenya

Brian O'Neill, IIASA, Austria
Raul O'Ryan, Universidad de Chile, Chile
Rajendra Pachauri, IPCC Chair, India
Jean Palutikof, IPCC TSU WG II, UK
Jiahua Pan, Chinese Academy of Social Science CASS, P.R. China
William Pepper, ICF Consulting, USA
Stelios Pesmajoglou, UNFCCC, Germany
Ramon Pichs, CIEM, Cuba
Hugh Pitcher, JGCRI, USA
R Ramaswamy, GFDL, USA
Sarah Raper, Manchester University, UK
Phil Rasch, NCAR, USA
N.H. Ravindranath, Indian Institute of Science, India
Keywan Riahi, IIASA, Austria
Richard Richels, EPRI, USA
Steven Rose, U.S. Environmental Protection Agency, USA
Cynthia Rosenzweig, NASA, USA
Dale Rothman, International Institute for Sustainable Development, Canada
Paul Runci, Pacific Northwest National Laboratory, USA
Peter Russ, European Commission, Spain
Hannah Ryder, Defra, UK
El Amin Sanjak, University of Khartoum, Sudan
Earl Saxon, IUCN-World Conservation Union, Switzerland
Roberto Schaeffer, Federal University of Rio de Janeiro, Brazil
Sergei Semenov, Inst. Of Global Climate and Ecology, Russia
Peter James Sheehan, University of Melbourne, Australia
Drew Shindell, NASA, USA
Ram Shresta, Asian Institute of Technology, Thailand
P.R. Shukla, Indian Institute of Management, Ahmedabad, India
Steve Smith, Pacific Northwest National Laboratory, USA
Anond Snidvongs, SEA START RC, Thailand
Thomas Stocker, EMIC, Switzerland
Ronald Stouffer, NOAA, USA
Taishi Sugiyama, Socio-economic Research Center, Japan
Kiyoshi Takahashi, National Institute for Environmental Studies, Japan
Karl Taylor, PCMDI, USA
Jean Pascal van Ypersele, Universite Catholique de Louvain, Belgium
María Virginia Vilariño, BCSD - Argentina, Argentina
Detlef van Vuuren, Netherlands Environmental Assessment Agency (MNP), The Netherlands
John Weyant, Stanford University, USA
Tom Wilbanks, Oak Ridge National Laboratory, USA
Harald Winkler, University of Cape Town, South Africa
Lu Xianfu, UNDP, P.R. China
Monica Zurek, AO, Italy

Appendix 6: Meeting Report Reviewers

Keigo Akimoto, Japan
Australian Government, Australia
Brad Bass, Canada
Prithiviraj Booneeady, Mauritius
Jens Borken, Germany
Olivier Boucher, France
Robert Chen, USA
Arthur Collins, Canada
Philip Duffy, USA
Seita Emori, Japan
Johannes Feddema, USA
Ursula Fuentes, Germany
Donald Hanson, USA
Bill Hare, Australia
Maria Ibarrarán, Mexico
Kejun Jiang, China
Jinhe Jiang, China
Martin Juckes, UK
Karin Kartschall, Germany
Claudia Kemfert, Germany
Atsushi Kurosawa, Japan
Robert Lempert, USA
Erda Lin, China
Xianfu Lu, China
Luis Jose Mata, Venezuela
Malte Meinshausen, Germany
Lars Müller, EU
Shuzo Nishioka, Japan
Attilio Pigneri, Italia
Nirivololona Raholijaho, Madagascar
Richard Richels, USA
José Romero, Switzerland
Fabien Roques, France
Steven Rose, USA
Richard Rosen, USA
Dale Rothman, USA
Earl Saxon, USA
Roberto Schaeffer, Brazil
Robert Schock, USA
Vanessa Schweizer, USA
Bernard Seguin, France
Ronald Stouffer, USA
Roger B Street, Canada
Rob Swart, Netherlands

Kiyoshi Takahashi, Japan
Karl Taylor, USA
Peter Verburg, Netherlands
María Virginia Vilariño, Argentina
Rachel Warren, UK

Appendix 7: Acronyms and Abbreviations

ACCENT	Atmospheric Composition Change—The European Network of Excellence
AGCI	Aspen Global Change Institute
AIM	Asia-Pacific Integrated Model
AIMES	Analysis, Integration and Modeling of the Earth System
AOGCM	atmosphere–ocean general circulation model
AR4	Fourth Assessment Report
AR5	Fifth Assessment Report
BADC	British Atmospheric Data Centre
BC	black carbon
C^4MIP	Coupled Carbon Cycle-Climate Model Intercomparison Project
CCS	CO_2 capture and storage
CFC	chlorofluorocarbon
CH_4	methane
CLIVAR	CLImate VARiability and Predictability
CM	climate modeling or model
CMIP	Coupled Model Intercomparison Project
CO	carbon monoxide
CO_2	carbon dioxide
CSO	civil society organizations
DC	developing country
DDC	Data Distribution Centre
EDGAR	Emissions Database for Global Atmospheric Research
EIT	economy in transition
EMF	Energy Modeling Forum
EMIC	Earth system model of intermediate complexity
ERI	Energy Resource Institute
ESM	Earth system model
EU	European Union
FAO	Food and Agriculture Organization
GAIM	Global Analysis, Interpretation and Modelling
GCM	general circulation model
GEO4	Global Environment Outlook
GFDL	Geophysical Fluid Dynamics Laboratory
GHG	greenhouse gas
GRAPE	Global Relationship to Protect the Environment
HFC	hydrofluorocarbon
IAE	Institute of Applied Energy
IAM	integrated assessment modeling or model
IAMC	Integrated Assessment Modeling Consortium
IAV	impacts, adaptation, and vulnerability
IEA	International Energy Agency
IGBP	International Geosphere-Biosphere Programme
IGSM	Integrated Global System Model

IIASA	International Institute for Applied Systems Analysis
IMAGE	Integrated Model to Assess the Global Environment
IPAC	Integrated Policy Assessment Model for China
IPCC	Intergovernmental Panel on Climate Change
MAGICC	Model for the Assessment of Greenhouse-gas Induced Climate Change
MESSAGE	Model for Energy Supply Strategy Alternatives and their General Environmental Impact
MiniCAM	Mini-Climate Assessment Model
MIT	Massachusetts Institute of Technology
MNP	Netherlands Environmental Assessment Agency
MPI	Max Planck Institute
N_2O	nitrous oxide
NCAR	National Center for Atmospheric Research
NGO	nongovernmental organization
NH_3	ammonia
NIES	National Institute for Environmental Studies
NO_x	nitrogen oxides
O_3	ozone
OC	organic carbon
OECD	Organisation for Economic Cooperation and Development
PCMDI	Program for Climate Model Diagnosis and Intercomparison
PFC	perfluorocarbon
PNNL	Pacific Northwest National Laboratory
RCM	regional climate model
RCP	representative concentration pathway
SF_6	sulfur hexafluoride
SGGCM	Steering Group on Global Coupled Models
SLS	short-lived species
SRES	Special Report on Emissions Scenarios
START	System for Research, Analysis, and Training
TAR	Third Assessment Report
TGICA	IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis
TGNES	IPCC Task Group on New Emissions Scenarios
UN	United Nations
UNDP	United Nations Development Programme
UNEP	UN Environment Programme
UNFCCC	UN Framework Convention on Climate Change
VIMA	vulnerabilities, impacts, mitigation, and adaptation
VOC	volatile organic compound
WCRP	World Climate Research Programme
WGCM	Working Group on Coupled Models
WGI	Working Group I
WGIII	Working Group III
WHO	World Health Organization
WMO	World Meteorological Organization

Supporting material prepared for consideration by the Intergovernmental Panel on Climate Change. This material has not been subjected to formal IPCC review processes. This expert meeting was agreed in advance as part of the IPCC work plan, but this does not imply working group or panel endorsement or approval of this report or any recommendations or conclusions contained herein.

The report has been subjected to an expert peer review process and revised accordingly. A collation of the comments received is available on the IPCC website (http://www.ipcc.ch/ipccreports/supporting-material.htm).