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

# IPCC EXPERT MEETING REPORT

19–21 September, 2007
Noordwijkerhout, The Netherlands

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## IPCC EXPERT MEETING REPORT

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# Executive 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 would now be coordinated by the research community. Under the new arrangement, the immediate objective of the IPCC's involvement would be to "catalyze" the timely production by others of new scenarios for a possible Fifth Assessment Report (AR5). The Panel decided to convene another IPCC expert meeting to consider the scientific community's plans for developing new scenarios, and to identify a set of "benchmark emissions scenarios" (referred to as "Representative Concentration Pathways—RCPs")[1] that 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.

The expert meeting was held on 19–22 September 2007 in Noordwijkerhout, The Netherlands. The meeting brought together over 130 participants, including a variety of users and representatives of the principal research communities involved in development and application of scenarios. The representatives of the scenario user community included officials from national governments, international organizations, multilateral lending institutions, and nongovernmental organizations (NGOs). The principal research communities represented at the expert meeting were

- the climate modeling (CM) community;
- the impacts, adaptation, and vulnerability (IAV) community; and
- the integrated assessment modeling (IAM) community.

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.

This summary provides an overview of the 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 economy in transition that would further strengthen the process. Further details are provided in the full report of the expert meeting.

[1] The name "representative concentration pathways" was chosen to emphasize the rationale behind their use. Each RCP is intended to be representative of range of multigas reference and stabilization radiative forcing, concentration, and emissions pathways in the literature, such as high reference scenarios, low mitigation scenarios, and intermediate scenarios The term "benchmark," used by the Panel, 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, associated concentrations, and radiative forcing, and their primary purpose is to provide these concentration pathways to the climate modeling community to produce new climate change projections.

*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. Abstracting from these discussions, the 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.

Near-term adaptation and mitigation management issues include identifying immediate risks, developing corresponding adaptive capacity, reducing vulnerability, and making efficient investments to cope with climate change. Initialization of climate models is a more significant issue for the near term than the longer term. It is anticipated that use of fixed initial conditions based on current climate may reduce the spread in ensembles of simulations over the next one or two decades. This is, however, an area of active of research within the climate modeling community. Thus, the effort to provide high-resolution scenarios for the near-term time scale must still be considered experimental.

The longer term policy focus shifts towards establishing targets for stabilizing anthropogenic influence on climate, improving the understanding of risks of major geophysical and biogeochemical change and feedback effects, and adopting strategies for mitigation and development that are robust to remaining uncertainties.

Another clear interest of the users of scenarios is development of regional- or national-scale 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 classes of response 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.

[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 DC)
http://www.mnp.nl/ipcc/pages_media/meeting_report_workshop_new_emission_scenarios.pdf (Laxenburg) and
http://www.ipcc.ch/meetings/session25/doc11.pdf (Spain). The latter contains important background to this report.

*I.2 Expected scenario products*

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

1. *Representative concentration pathways (RCPs)*. Four RCPs are to be produced from IAM pathways available in the published literature: one pathway without any climate policy for which radiative forcing reaches >8.5 W/m$^2$ by 2100 and is still rising; two intermediate "stabilization pathways" in which radiative forcing is stabilized at approximately 6 W/m$^2$ and 4.5 W/m$^2$; and one pathway that peaks at approximately 3 W/m$^2$ and declines thereafter. These scenarios include time paths for emissions and concentrations of the full suite of greenhouse gases (GHGs) and short-lived species, as well as land cover. The anticipated completion date is September 2008.
2. *Ensemble climate projections forced by the RCPs*. These are ensembles of gridded, time dependent projections of climate change produced by multiple climate models including general circulation models (GCMs), atmosphere–ocean GCMs (AOGCMs), Earth system models (ESMs), Earth system models of intermediate complexity (EMICs) and regional climate models (RCMs) for the four long-term RCPs and high-resolution, near-term projections to 2035 (4.5 W/m$^2$ stabilization only). The anticipated completion date is early to mid-2010.
3. *New socioeconomic and emissions scenarios developed by the IAM community*. A set of new scenario pathways will be developed by the IAM research community exploring a wide range of dimensions associated with anthropogenic climate forcing. Anticipated outputs include alternative socioeconomic driving forces, alternative technology development regimes, alternative realizations of Earth system science research, alternative stabilization scenario pathways including traditional, "not-to-exceed" scenario pathways, "overshoot" scenario pathways, and representations of regionally heterogeneous mitigation policies and measures, as well as regional socioeconomic trends and policies. These are anticipated to be available in the third quarter of 2010.
4. *Global narrative storylines*. These detailed descriptions are to be associated with the pathways developed as part of Product 3, as well as the four RCPs produced in the preparatory phase, as selected by the IAM and IAV communities. These global and large region storylines should be able to inform IAV and other researchers, including those who wish to develop national- to local-scale storylines that take account of local conditions but are broadly consistent with the global scenarios. 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. This product is anticipated to be available in the third quarter of 2010.
5. *Integrated ensembles of new IAM scenarios with associated scaled climate scenarios*. Ensemble climate change scenarios (Product 2) will be associated with combinations of new IAM scenarios (Product 3) to create combinations of ensembles. These scenarios will be applied 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 of the production of these five products is depicted in Figure 1.

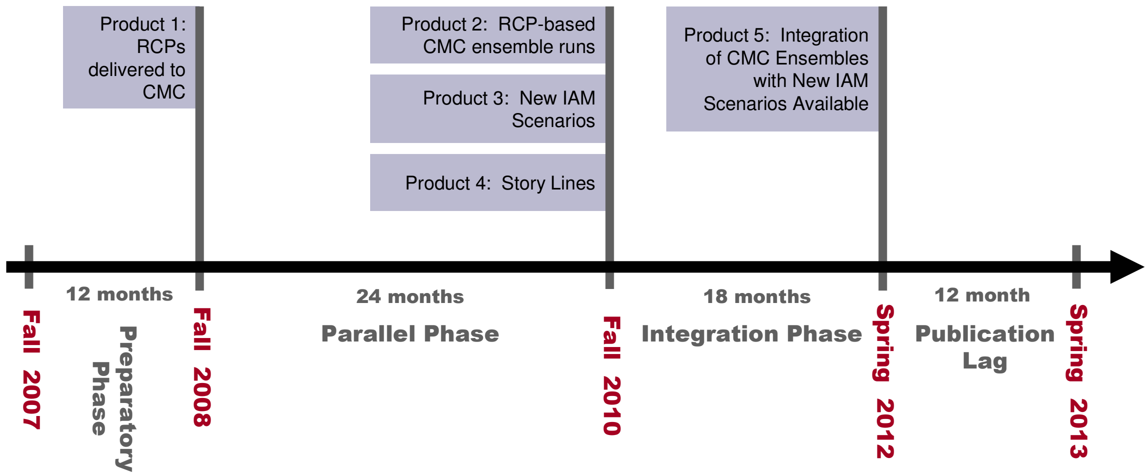


**Figure 1.** Timeline of key scenario development products (CMC = climate modeling community).

## *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. In contrast with the previous linear process, this parallel approach should provide better integration and consideration of feedbacks and more time to assess impacts and responses. This process has been developed by the research community in a series of meetings and workshops.[3]

### *II.1 Preparatory phase*

The preparatory phase is the first of three phases in which scenarios are developed. 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. Development of the RCPs entails a number of challenges that are the focus of current research across the IAM community. The set of data

[3] These meetings include a "summer institute" held under the auspices of the Aspen Global Change Institute in July 2006 (see Meehl et al. (2007b) and Hibbard et al. (2007)); 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.

provided with each RCP will need to be spatially downscaled for short-lived species, gaseous and aerosol emissions, and land use and land cover. Much of those data need to be provided at a fine spatial resolution. 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. 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.

### *II.2 Parallel modeling phase*

As illustrated in Figure 2, 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. While there are advantages and disadvantages to both the traditional sequential approach and the new parallel approach, as discussed in the full report, the parallel approach accelerates the scenario development process.

The RCPs are a prelude to more extensive, independent work across the research communities that will provide a richer and more consistent characterization of the many facets of climate change. 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.

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). 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 impacts models that can be used by IAV researchers in conjunction with the new scenarios including the RCPs.

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 column b of Figure 2). 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, limited only by their plausibility. 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 different stabilization levels can be attained.

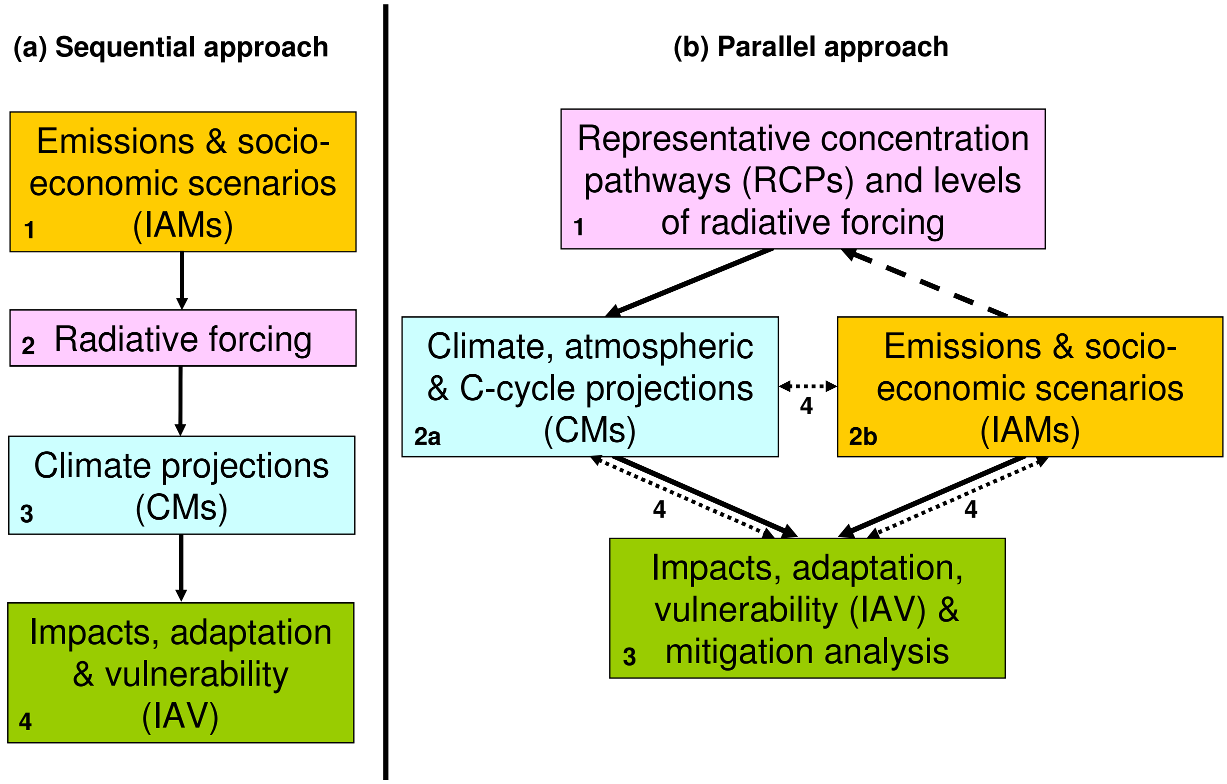


**Figure 2.** Approaches to the development of global scenarios: (a) previous *sequential* approach; (b) proposed *parallel* approach. Numbers indicate analytical steps (2a and 2b proceed concurrently). Arrows indicate transfers of information (solid), selection of RCPs (dashed), and integration of information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

The parallel process is as 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 Working Group I (WGI), as these no longer need to be rerun each time the emission scenarios are changed. A parallel approach will also decouple climate science from the issues of socioeconomic projections. This link is only made when the climate scenario is constructed from an RCP. In the future, updated CMs can be run against the same scenarios, allowing modelers to isolate the effects of changes in the CMs themselves. New forcing scenarios can be used to interpolate the existing CM simulations using simple models that have been calibrated to give comparable results to the full three-dimensional climate models (this approach has already been used in WGI assessments for 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 for 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.

### *II.3 Integration phase*

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 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 new IAM and IAV tools 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.

**Time Line & Critical Path of Scenario Development**

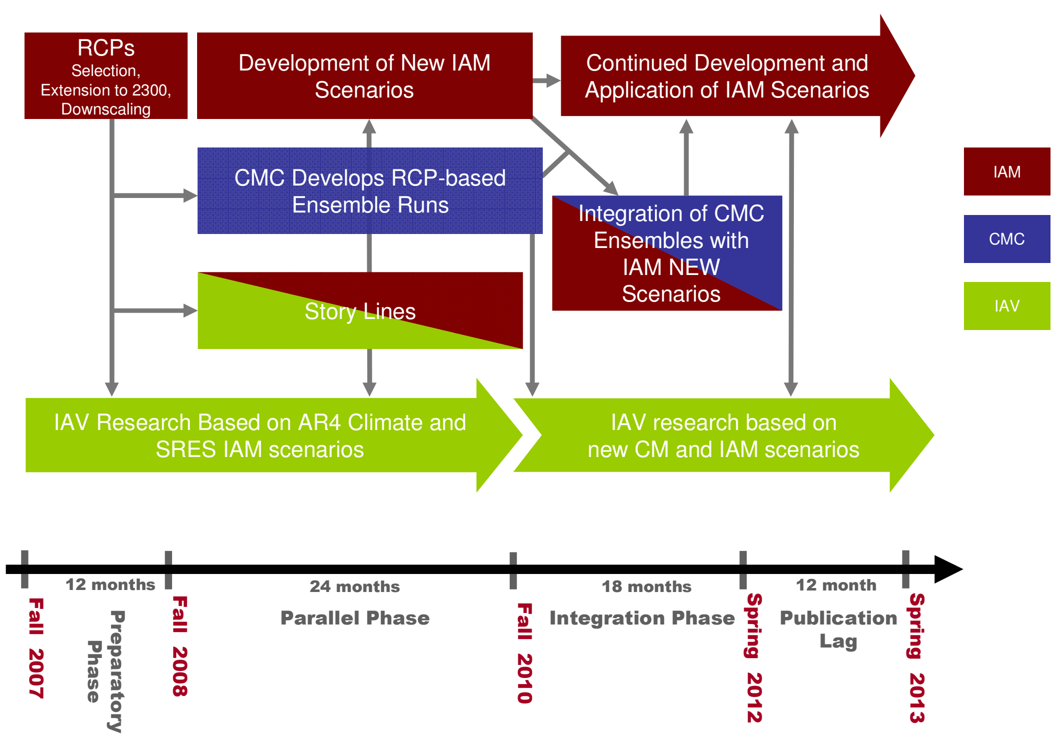


**Figure 3:** Relationship of scenario-related activities in three climate research communities. **S**ome of the major scenario-related activities across the IAV, IAM, and CM research communities. The boundaries between these phases are not precisely defined, although near-term deadlines, such as the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

### *II.4 Interactions among the research communities*

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

## *III. "Representative Concentration Pathways" (RCPs)*

Coordination of new integrated socioeconomic, emissions, and climate scenarios depends critically on the early identification of a set of "Representative Concentration Pathways" (RCPs). The main rationale behind the identification of RCPs is as a means to expedite the development of integrated scenarios by enabling climate modeling to proceed in parallel to emissions scenario development (see Figure 2).

The IPCC requested that the RCPs ("benchmarks") should be "compatible with" the full range of emissions scenarios in the peer reviewed 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. 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 greenhouse gases and aerosols, the RCPs have been selected based primarily on their emissions, associated concentration outcomes, and net radiative forcing. Each RCP is intended to be representative of a class of multigas scenarios currently available, such as high reference scenarios, low mitigation scenarios, and intermediate scenarios. Each of the selected RCPs comes from a different IAM and includes the concentration pathway and corresponding emissions and land use pathways.

### *III.1 Uses and limits*

The core uses of RCPs and the climate model outcomes associated with them are foreseen as:

- *Input to climate models*. 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 needed by CMs.
- *To facilitate pattern scaling of climate model projections*. Climate change projections based on RCPs will cover a wide range of outcomes. These outcomes will be used to investigate the extent to which they can be interpolated, using a technique known as pattern scaling, to provide climate change outcomes for intermediate forcing levels without re-running the CMs.
- *To explore the range of socioeconomic conditions consistent with a given radiative forcing*. It is an open research question as to how wide a range of socioeconomic conditions could be consistent with a particular level of radiative forcing. RCPs will facilitate exploration of alternative development futures that may be consistent with, for example, different stabilization levels.
- *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. It is an open research question as to how wide a range of spatial patterns of forcing

could be consistent with a given climate change outcome. The RCPs will provide a new focus for work on this topic.

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" or most likely projection.
- *They should not be considered policy prescriptive*. While all but the highest RCP are intended to represent mitigation scenarios, they are not meant to imply desirable policy outcomes. Rather, they are only intended to represent the range of mitigation scenarios in the literature.
- *The socioeconomic scenarios underlying each RCP should not be considered unique*. Each RCP is based on a scenario in the literature that includes socioeconomic development pathways. However, the scenario underlying each RCP is just one of many possible such scenarios that could be consistent with the level of radiative forcing associated with the RCP.
- *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, RCPs as a group were selected on the basis of their emissions and associated concentration and forcing outcomes. There is no overarching logic to the socioeconomic assumptions or storylines associated with the set of RCPs. The set of underlying scenarios is not intended to span the range of plausible assumptions for any particular element of the scenario (population, Gross Domestic Product growth, rates of technological change, land use, etc.) other than concentration outcomes. The socioeconomic assumptions underlying a particular RCP cannot be freely used interchangeably with the assumptions underlying other RCPs.

The remainder of this section of the Summary describes the process by which the proposed RCPs were selected from the literature. The number, characteristics, and kind of RCPs described here reflect outcomes of the expert meeting while technical decisions, such as proposing which model runs will be used to realize the RCPs, are matters that have been decided by the Integrated Assessment Modeling Consortium (IAMC).[4]

*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, robustness, number, separation, 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 pathways that spans from a

[4] The Integrated Assessment Modeling Consortium (IAMC) was established in November 2006 to coordinate community activities among IAM teams, and between them and other communities involved in global change research. So far, 37 groups have joined the consortium. See Section IV of the report for further information.

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.

- *Robustness:* Given the substantial resource requirements associated with running climate models, it is prudent that the pathways and scenarios selected for RCPs are considered robust by the scientific community. In this context, robustness means that a scenario would be found to be technically sound after a detailed review of its assumptions, logic, and associated calculations, and that in addition it could be independently reproduced by other modeling teams.
- *Number:* The research and user communities concluded that four RCPs should be produced, although all CM groups are not expected to 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 the need to reduce demands on the CM community given high cost of model simulations).
- *Separation and shape*: Atmosphere–ocean GCM runs are most effective when the climate change signal to be detected is large compared to the noise of inherent climate variability. For the climate change outcomes of two pathways to be statistically distinguishable by models, they 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 benefits of avoided damages.
- *Comprehensiveness*: Anthropogenic climate change is driven by a number of factors, which all contribute to radiative forcing of the climate system. The RCPs need to include all of these sources, modeled so they are internally consistent. This includes the full suite of greenhouse gases, aerosols, chemically active gases, and land use and land cover. The CM community will require gridded emissions for aerosols, chemically active gases, methane, and land use/cover.
- *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 short- and long-term continuity.

### *III.3 Scenarios in the literature and desirable types of RCPs*

The Working Group III AR4 assessed the new literature for reference and stabilization scenarios published since the Special Report on Emissions Scenarios (SRES) and the Third Assessment Report (TAR). A total of more than 300 scenarios were identified in AR4, 147 and 177 of which were reference and stabilization scenarios, respectively. A significant development since the TAR is the extension of many IAM models 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.[5] For the purpose of this report, the radiative forcing trajectories of more than 30 of these scenarios were collected to facilitate the identification of candidate RCPs. The left panel of Figure 4 shows the range of global average radiative forcing from these scenarios, while the right panel provides a comparison of the $CO_2$ emissions ranges of these scenarios to the full range in the literature.

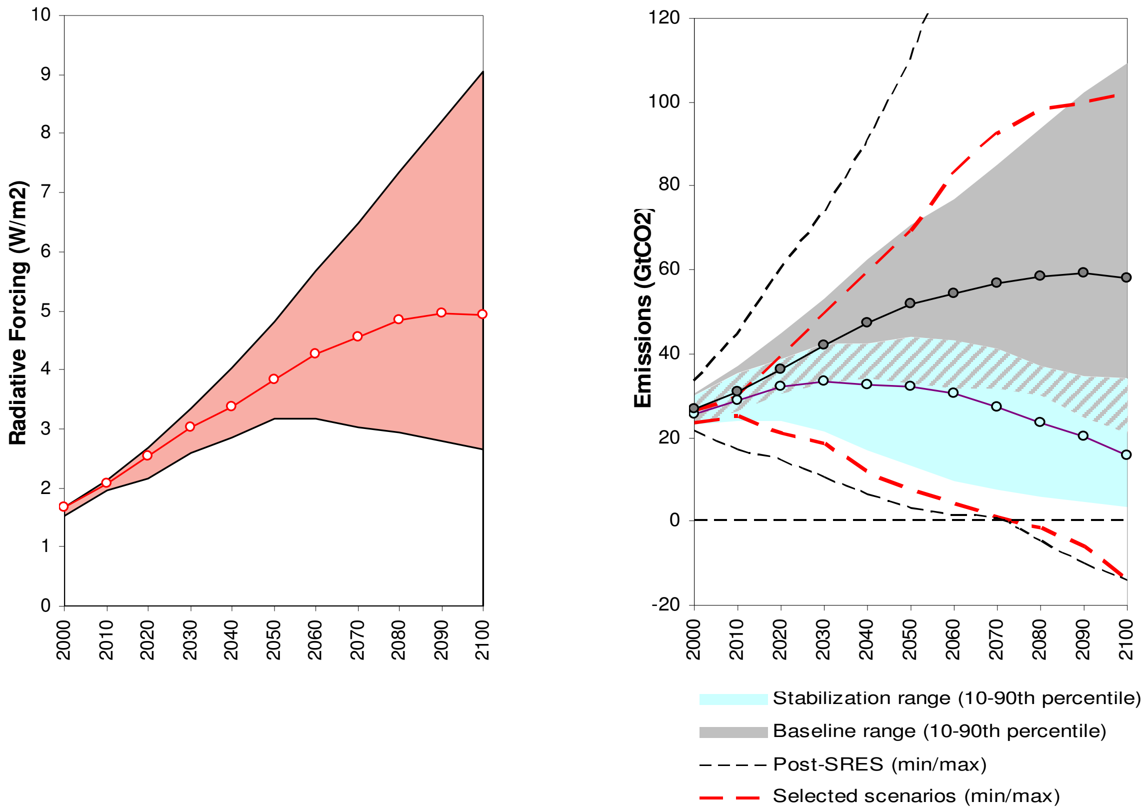


**Figure III.1.** Full range and median of the 30 radiative forcing pathways examined (left panel) and $CO_2$ emissions pathways for various ranges and medians (right panel). In the right panel, the lines connecting the filled and open circles are medians of the range of reference and stabilization scenarios, respectively. The red dashed lines correspond to the maximum and minimum of the range of $CO_2$ emissions pathways associated with the set of scenarios represented in the left panel. Data published for these scenarios extend only to 2100; RCPs will need to extend data to 2300.

The scenarios literature was reviewed with respect to the desirable characteristics of range, robustness, number, separation, and comprehensiveness in order to define desirable 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 1).

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[5] This class of IAMs compute internally consistent projections of radiative forcing and its major 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 Table A1.1 in Appendix 1). A comprehensive assessment of the radiative forcing pathways of all multigas scenarios in the literature is unfortunately not possible, since the forcing data for many multigas scenarios are not available.

***Table 1.*** *Desirable 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 exceeding target level |
| RCP4.5 | ~4.5 $W/m^2$ at stabilization after 2100 | ~650 $CO_2$-eq (at stabilization after 2100) | Stabilization without exceeding target level |
| RCP3-PD[3] | <3 $W/m^2$ in 2100 | < ~490 $CO_2$-eq in 2100 | Peak & decline stabilization |

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 $CO_2$-equivalent 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.

The set of pathways in Table 1 are representative of the range of reference 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. Furthermore, the stabilization RCPs from 3 to 6 $W/m^2$ are also representative of the stabilization portion of literature in terms of radiative forcing and $CO_2$ emissions pathways assessed in the AR4.

*III.4 Climate modeling community prioritization*

Given the scientific and computing limitations and different resource constraints across CM teams, some 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 climate model simulations is:

- The pair of the high and low RCPs (RCP8.5 and RCP3-PD);
- The intermediate range RCP with near-term resolution (RCP4.5); and
- RCP6.

*III.5 Criteria*

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

**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) Desirable 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 exceeding target)
    c. RCP4.5 (~4.5 W/$m^2$ at stabilization after 2100, stabilization without exceeding target)
    d. RCP3-PD (<3 W/$m^2$ in 2100, peak & decline stabilization)
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 and 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 ESM communities. These include harmonization of output and base year data, downscaling, and extending published data to 2300.
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, which includes (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.6 Candidates*

The IAM community identified 18 RCP candidates from the literature, which are listed in Table 2. 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 by consultation with the modeling teams.

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. The contents of the table are still under review to confirm that this is a complete listing of all candidates.*

| IAM (affiliation)[1] | RCP8.5 | RCP6 | RCP4.5 | RCP3-PD | Reference(s) |
|---|---|---|---|---|---|
| AIM (NIES) | | *[2] | * | *[2] | Fujino et al. (2006) |
| GRAPE (IAE) | | | * | | Kurosawa (2006) |
| IGSM (MIT) | * | * | * | | Reilly et al. (2006), Clarke et al. (2007) |
| IMAGE (MNP) | * | * | * | * | van Vuuren et al. (2006, 2007) |
| IPAC (ERM) | | *[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, 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, ERM = , 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 stabilization criteria.

### *III.7 Proposed RCPs*

Based on an assessment of the available scenarios to meet the identified data requirements, and the 'strawman' recommendation presented to the expert's meeting, the IAMC is proposing the following RCPs:

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

This proposal is based on several considerations:

- Not all modeling groups whose scenarios were identified in the candidate list 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 in 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 2 who are willing to participate, MESSAGE and IMAGE can produce scenarios on the high and low end (RCP3 and RCP8.5). The IMAGE model was selected for the low pathway, due to the large 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); and

- Both the AIM or the MiniCAM model could provide the required data for the intermediate levels. MiniCAM was chosen for RCP4.5, while AIM was chosen for RCP6.

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

The expert meeting was unable to resolve one issue: the choice between two alternatives for the low RCP, either the IMAGE 2.6 scenario or the IMAGE 2.9 scenario from 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 radiative forcing of 2.6 $W/m^2$ in 2100 and stabilization at a lower level beyond 2100.[6] The IMAGE 2.9 scenario peaks at over 3 $W/ m^2$ and declines to radiative forcing of 2.9 $W/m^2$ in 2100 and stabilization at 2.6 $W/m^2$ around 2150.

The meeting 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. In that context, both the IMAGE 2.6 and IMAGE 2.9 scenarios are appealing: (a) in combination with the high RCP of more than 8.5 $W/m^2$ in 2100, both provide a broad span of potential future emissions and concentration pathways, and (b) both follow peak-and-decline pathways to low stabilization levels beyond 2100.[7] The IMAGE 2.6 scenario was considered more appealing because of its more dramatic peak and decline and lower stabilization level. However, the IMAGE 2.6 scenario was exploratory in nature (as presented in the literature). The scenario requires very aggressive investment for mitigation early in the century and deployment of negative emissions technologies later in the century.[8]

The technical feasibility of reaching such low radiative forcing levels 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.[9] Moreover, recent focus on the diverse consequences of widespread application of bioenergy (including associated nitrous oxide emissions) may have important implications for this scenario. It should be noted that the CM community would not expect the small difference in the projected climates in 2100 associated with two scenarios to be distinguishable above the climate model variability. However, this is a research question that

[6] Insights on results beyond 2100 obtained through consultation with the IMAGE modeling team.
[7] Both scenarios are included in the lowest class of stabilization scenarios assessed by the IPCC in AR4 (this class contains only three multigas scenarios).
[8] The negative emissions technology is bioenergy combined with carbon dioxide capture and storage (CCS) that ceteris paribus has a net negative effect on atmospheric concentrations of GHGs. While biomass sequestration is assumed in both the IMAGE 2.6 and 2.9 scenarios, it is the combination with CCS that is novel in IMAGE 2.6.
[9] 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.

could be explored with individual models, ensembles, and with respect to different climate variables.

Based on the considerations above, the IMAGE 2.6 scenario is tentatively recommended as the selection for the RCP3-PD pathway. However, the robustness of the scenario needs to be assessed. The IMAGE 2.9 pathway is considered robust in that other models have published similar results.

Based on the expert meeting discussion, the IAMC has offered to organize an IAM community exercise and assessment panel for evaluating the robustness of the IMAGE 2.6 scenario for selecting it as RCP. If the robustness of the scenario in this context is established by mid-2008, it will be used for the low pathway. Otherwise, the IMAGE 2.9 pathway will be chosen. Thus, the robustness evaluation will ensure delivery of one of the two pathways via a scientifically rigorous process.

To ensure the scientific credibility and transparency of the evaluation, the IAMC will appoint a panel that will be responsible for the final judgment of the robustness of the IMAGE 2.6 scenario, and an assessment process will be set up for this evaluation. The robustness assessment will be based on two general criteria, both of which must be met: the technical soundness and the replicability of the IMAGE 2.6 scenario. For the former, 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 modeling team will lead an evaluation of the technical components of the IMAGE 2.6 scenario. In particular, components will include those that distinguish the scenario from the IMAGE 2.9 scenario, namely the representation of biomass combined with carbon dioxide capture and storage (CCS). For replicability, the IAMC will ask all the IAM teams in this class of models to participate in the design and development of technically sound low stabilization scenarios that satisfy the RCP3-PD definition. The modeling teams will be asked to employ their standard assumptions and include biomass and CCS, but avoid non-traditional assumptions such as geo-engineering. This evaluation process is described more completely in the full report.

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

## *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.

### *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.

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 developing countries 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 developing countries in the scenario creation process (discussed in greater detail in Section V of the full report) 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.

A further issue to explore is whether there is value in bringing together like-minded international organizations to contribute towards 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 FAO, the World Bank, the United Nations Environment Programme, the World Health Organization, and major NGOs 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*

The goal of developing a new international climate change scenario infrastructure, built on a 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. Overcoming obstacles to inter-group coordination is therefore key.

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

(1) An IAM/IAV meeting to develop a joint strategy for story line 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; and
(3) An IAM/IAV meeting to develop plans for the scenario library.

Several other steps are also needed as well 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;
(2) 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;
(3) 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
(4) 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 also to enhance communication among the communities (for example, sea ice/sea level rise/coastal impacts and adaptation).

## *V. Increasing Developing Country Participation*

The IPCC's April 2006 decision, issued after its 26th Session in Mauritius, called for the enhancement of developing country 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 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 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 the System for Research, Analysis, and Training, 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 Task Group on Data and Scenario Support for Impact and Climate Analysis framework proposal. Capacity building for downscaling and upscaling of modeling 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 ESM 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 developing 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.

# 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. 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 25th session (Mauritius, 26–28 April 2006), the IPCC decided to change the process of preparing new scenarios for use in its assessments. 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).[10]

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:

- Comparability of scenarios to serve the various user communities;
- Consideration of the results of scenario activities undertaken by the World Bank, the United Nations (UN) 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) in the near future, 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.

[10] 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, DC), http://www.mnp.nl/ipcc/pages_media/meeting_report_workshop_new_emission_scenarios.pdf (Laxenburg), and http://www.ipcc.ch/meetings/session25/doc11.pdf (Spain).

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."

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.

**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 19–22 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.

### *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, international organizations, multilateral lending institutions, and nongovernmental organizations. The principal research communities represented at the expert meeting were

- the climate modeling (CM) community;[11]
- the impacts, adaptation, and vulnerability (IAV) community;[12] and
- the integrated assessment modeling (IAM) community.[13]

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

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

[12] 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.

[13] 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.

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 requires 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.

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 them; and
- Impacts, adaptation, and vulnerability are assessed in a way that uses consistent information about socioeconomic drivers, technology, and land use change.

**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 (see footnote 1), 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)[14] 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 the expert meeting.[15]

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 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

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

scenario development process, and their details are addressed throughout this report. Appendix 3 provides the detailed meeting agenda and Appendix 4 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 decision-making 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 decisionmaking 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:

- Global public organizations and international conventions (e.g., Convention on Biodiversity, FAO);
- 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.[16] User needs vary widely between different stakeholders, and even information requirements within a given group are not homogenous. The report of the IPCC TGNES[17] 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

[16] See http://www.mnp.nl/ipcc/pages_media/meeting_report_workshop_new_emission_scenarios.pdf.
[17] See http://www.ipcc.ch/meetings/session25/doc11.pdf.

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 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 classes of response 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[18] 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, and making efficient investments to cope with climate change. The longer term policy focus shifts towards establishing targets for stabilizing anthropogenic influence on climate, 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)*

It is generally accepted that a primary aim of near-term scenarios is to develop better projections of regional climate change and associated impacts. This includes issues such as co-benefits of mitigation (e.g., improvement in air quality), as well as synergies between adaptation, mitigation, and development strategies.

As CM costs are lower for shorter simulations, use of higher resolution CMs becomes more practical over the near term. 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. 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

[18] 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.

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 fixed initial conditions based on current climate may reduce the spread in ensembles of simulations over the next one or two decades. This is, however, an area of active of 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 the 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 failure to do so. 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 that achieve stabilization of anthropogenic influence on climate at different rates and magnitudes 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). 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. 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. There are also many remaining analytical questions in this area, such as how to represent technology performance and availability in IAMs.

The introduction of overshoot 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 long-term economic costs, the potential for irreversible change (e.g., in ecosystems or biodiversity) is also clearly a key consideration. 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. Climate simulations extending to 2300, based on simplified extensions of pre-2100 scenarios, provide important information on 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 climate modeling to proceed in parallel to emissions scenario development (see Figure I.1).

#### *I.4.1 A parallel process for scenario development*

Past scenario development has been carried out 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.

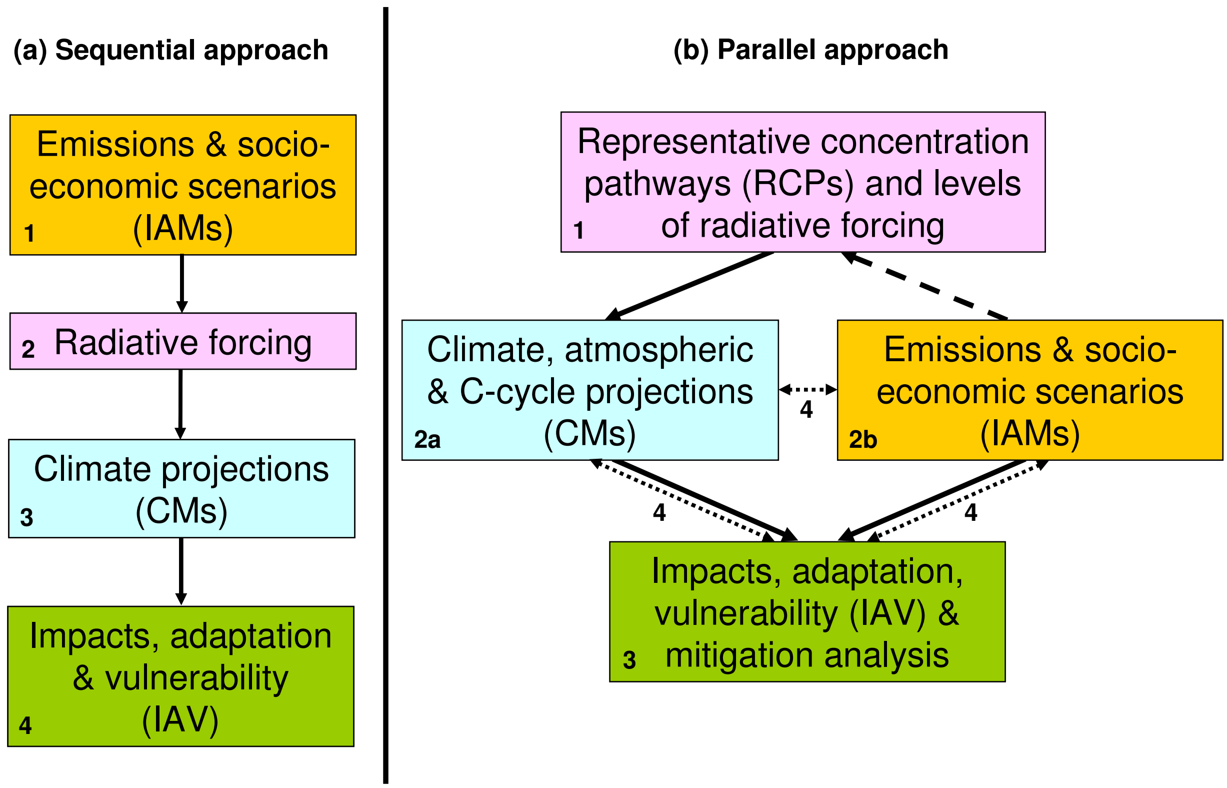


**Figure I.1.** Approaches to the development of global scenarios: (a) previous *sequential* approach; (b) proposed *parallel* approach. Numbers indicate analytical steps (2a and 2b proceed concurrently). Arrows indicate transfers of information (solid), selection of RCPs (dashed), and integration of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

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 different stabilization levels can be attained. 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, limited only by their plausibility. 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 Working Group I (WGI), as these no longer need to be rerun each time the emissions scenarios are changed. A parallel approach will also decouple climate science from the issues of socioeconomics. This link is only made when the climate scenario is constructed from an RCP. In the future, updated CMs can be run against the same scenarios, allowing modelers to isolate the effects of changes in the CMs themselves. New forcing scenarios can be used to interpolate 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 for 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.

### *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 emissions scenarios in the peer-reviewed 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. 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. Each RCP is intended to be representative of a larger class of multigas scenarios currently available, such as 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* 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 in addition the trajectory that is taken over time to reach that outcome.

### *I.5 Incorporating perspectives from developing and transition economy countries*

The IPCC's April 2006 decision, issued after its 26th Session in Mauritius, called for 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 economies 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 in 2005 by the IPCC's TGICA for the expansion of DC/EIT scientific capacity, 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 to the ESM community, considering the high costs and computing demands associated with their 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 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. 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.

*3. To what extent can climate changes be interpolated 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 "interpolated" for intermediate levels of forcing, or for entirely new scenarios. A key question is whether the results of interpolations between different atmosphere–ocean general circulation model (AOGCM)-derived climate scenarios could be sufficiently comparable to full AOGCM runs designed to achieve similar outcomes. The usefulness of interpolated 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 ESMs 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:

6. 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;
7. Ensemble climate scenarios consistent with the RCPs anticipated to be available in early- to mid-2010;
8. New pathways developed by the IAM community anticipated to be available in the fall of 2010;
9. Global narrative storylines anticipated to be available in the fall of 2010; and
10. Integrated ensembles of new IAM scenarios with associated scaled climate scenarios anticipated to be available in spring 2012.

The IAV community will use all of these products as inputs for research. 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.

***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 "reference pathway" without any climate policy in which radiative forcing reaches ~8.5 $W/m^2$ by 2100 but is still rising;[1] and three "stabilization pathways" in which radiative forcing is stabilized at approximately 6 $W/m^2$, 4.5 $W/m^2$, and <3 $W/m^2$. These scenarios will include time paths for emissions and concentrations of the full suite of greenhouse gases and short-lived species, as well as land cover. |
| Product 2: Ensemble Climate Change Scenarios | Parallel Phase | <24 months | Ensembles of gridded, time-dependent projections of climate change produced by multiple CMs including general circulation models, 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). Section III describes CM priorities and constraints for long-term scenarios. |
| Product 3: New IAM Scenario Pathways | Parallel Phase | 24 months | Ensembles of new scenario pathways developed by the IAM research community exploring 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 scenario pathways including traditional "not-to-exceed" scenario pathways, "overshoot" scenario pathways, and alternative representations of regionally heterogeneous mitigation policies and measures, as well as 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 such pathways developed as part of Product 3 as selected 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. 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: Integration | Integration Phase | 18 months | Ensemble climate change scenarios (Product 2) will be associated with combinations of new IAM scenarios (Product 3) to create combinations of ensembles. These scenarios will be applied in new IAV assessments. In addition, IAM research will begin to incorporate IAV data and models to produce 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 depicts the anticipated timeline for the production of these five products and Figure II.2 shows interactions across research communities.

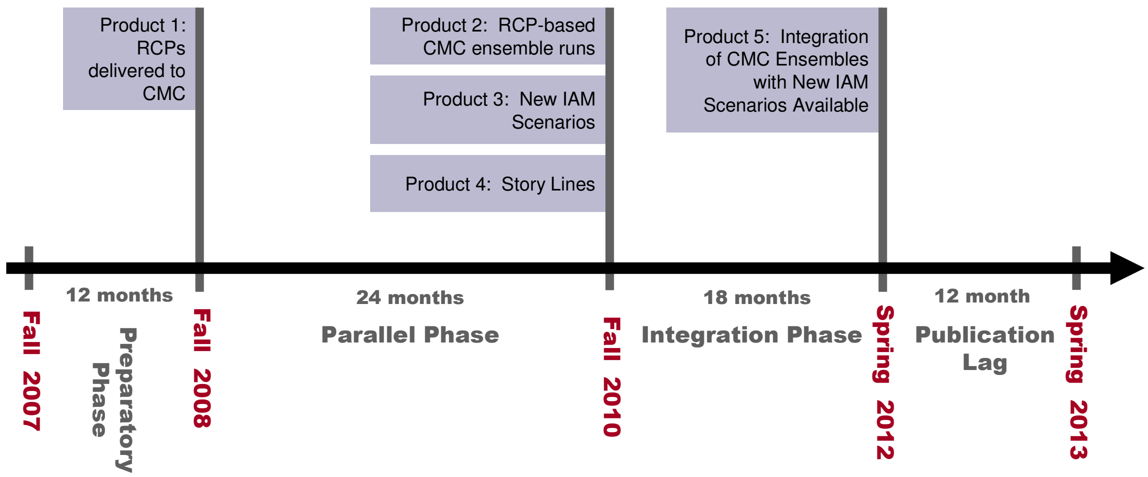


**Figure II.1.** Timeline of key scenario development products (CMC = climate modeling community).

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.

**Time Line & Critical Path of Scenario Development**

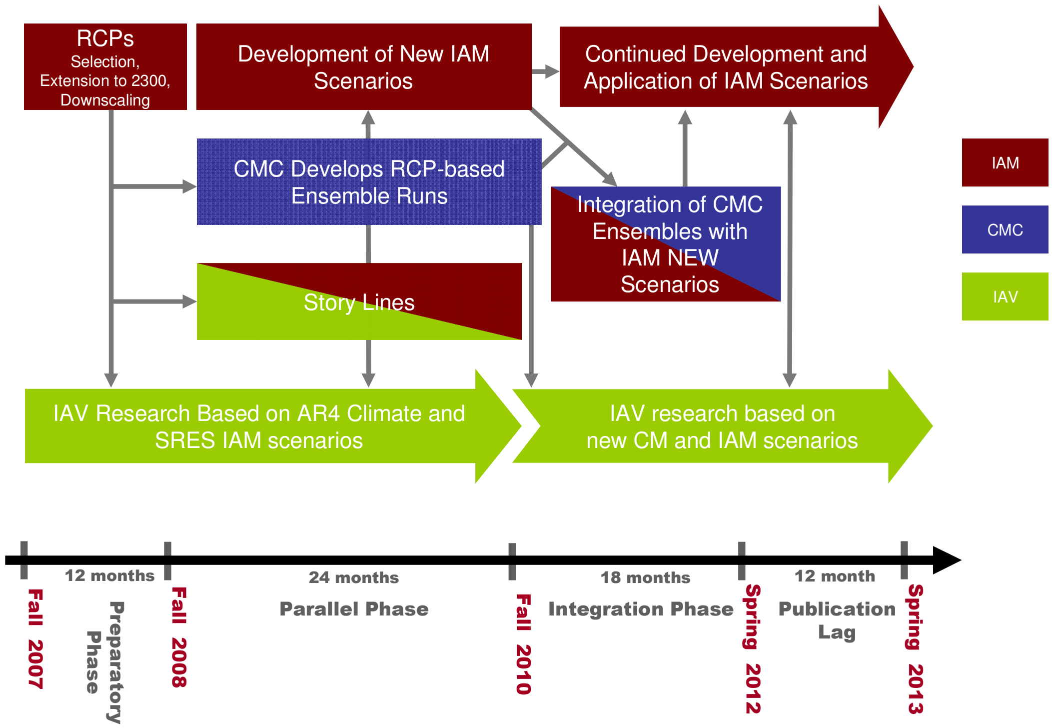


**Figure II.2.** Relationship of scenario-related activities in three climate research communities. Some of the major scenario-related activities across the IAV, IAM, and climate modeling (CMC) research communities, showing the preparatory phase and two subsequent phases. The boundaries between these 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). 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 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. 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 new IAM and IAV tools 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).

### *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 foundations; human activities 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 century-scale climate projections. The RCPs provide vectors of geographically disaggregated, gridded emissions and concentrations of GHGs, SLS, and land use and land cover extending from the present to 2300. These data are useful to a range of CMs including general circulation models (GCMs), 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.

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 and land cover. Much of those data need to be provided at a fine spatial (and temporal for the near-term scenario) 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. 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.

### *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- and long-term RCP-based climate scenarios;
Product 3: Development of new anthropogenic climate forcing scenarios by the IAM community; and
Product 4: Development of global "narrative storylines."

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

Climate modelers will use, at minimum, the high and low RCPs to examine long-term, centennial-scale climate change extending out to the year 2300. As computational and human resources allow, some groups will produce climate change simulations for mid-range RCPs as well. Some groups will also examine decadal processes in detail to 2035 using a mid-range (e.g., 4.5 $W/m^2$) stabilization scenario.

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 scenario ensembles* that explore alternative demographic, socioeconomic, land use, and technology scenario backgrounds;
- *Stabilization scenario ensembles* that explore alternative stabilization levels, including scenarios that explore the traditional "not to exceed" paradigm and the "overshoot" paradigm;
- *Technology scenario ensembles* that explore the effect of technology and mechanisms of technological change on the profile of reference and stabilization scenarios;
- *Climate science scenario ensembles* 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 institutional regimes and the application of alternative emissions mitigation policy tools for stabilization; and

- *Regional scenario ensembles* 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.

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 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. Qualitative, narrative descriptions, often referred to as "storylines," provide an explanation of conditions and relationships among key driving forces and their evolution over time that underlie the quantitative scenario. The storyline explains the relationship 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 analysis.

The IAV research community cannot evaluate an unlimited number of scenarios. While the RCPs represent a small, finite number of scenarios,[19] 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 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

[19] 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 that, setting aside differences in the limits that define stabilization pathway goals, whether the four RCPs spring from four different "storylines" or from one, two, or three different storylines.

past climate variability, and making assumptions about future developments based on national and regional plans, local knowledge, and practical experience ("bottom-up" approaches). Impacts, adaptation, and vulnerability 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). 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 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.

## *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 change, time-dependent 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."

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.

There are a variety of issues that emerge from this approach. First, pattern scaling produces an approximation to the behavior of a particular CM. There can be no substitute for actually forcing a model with a particular emissions/concentration pathway. Second, while there is evidence that some statistics such as average annual temperature and precipitation are reasonably well represented by pattern scaling, it is not clear that all climate statistics (e.g., extreme events) scale to the same degree.

Third, 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.

Fourth, 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.

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 ends in 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 and land cover. 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?

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, climate change, climate change impacts, and adaptation to climate change. Accomplishing this goal requires collaboration between the IAM and IAV research communities.

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-term 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 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.

### *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 for 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 recommended RCPs were selected from the literature. The selection process began by defining the desirable characteristics of RCPs for the research and user communities. A set of criteria for identifying candidate RCPs was then developed based on these characteristics, consideration of the scenarios literature, and specific requirements for providing data to CMs. The RCPs were then selected from the candidates. Each of the selected RCPs comes from a different IAM and includes the concentration pathway and corresponding emissions and land use pathways. The number, characteristics, and kind of RCPs described here reflect outcomes of the expert meeting while technical decisions, such as proposing which model runs will be used to realize the RCPs, are matters that have been decided by the IAMC.

The proposed RCP selection process, criteria, and strawman recommendation were presented, vetted, and finalized at the expert meeting in Noordwijkerhout. This section presents the finalized results. The section describes the desirable characteristics of RCPs (Section III.1); the process for identifying the specific RCPs, including the selection criteria, RCP candidates, and final recommendation for RCPs (Section III.2); and finally puts the RCPs in perspective in terms of their intended uses and limits, 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, robustness, number, separation, 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 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.

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). Such a scenario could also serve as a point of reference for policymakers. A low stabilization concentration scenario is useful to provide insight into the climate change and impacts resulting from pathways consistent with the lowest concentration scenarios currently in the literature. Intermediate-level stabilization scenarios are useful to explore how the climate response to radiative forcing, as well as physical responses such as changes in ice sheets, scale between different stabilization levels and what the impacts might be at these levels. Understanding whether climate response scales linearly between different stabilization scenarios 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 Robustness*

Given the substantial resource requirements associated with running CMs, it is prudent that the pathways and scenarios selected for RCPs are considered robust by the scientific community. In this context, robustness means that a scenario would be found to be technically sound after a detailed review of its assumptions, logic, and associated calculations, and that in addition it could be independently reproduced by other modeling teams. Thus a key criterion for judging robustness is whether several models exist that can produce plausible scenarios with similar outcomes. This implies that there could potentially be a tradeoff between the desire that RCPs span the full range in the literature and that the highest and lowest RCPs also be robust.

*III.1.3 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 with 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 scenarios, results that will be important to the IAM and IAV communities.

Finally, the number must also be small given the computational demands of the climate modeling to be carried out for each RCP. A number of factors will drive these increasing demands. Climate models will incorporate increased spatial resolution for a next assessment and, in the case of ESMs, are incorporating 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 these high computational demands, the CM community has prioritized the four RCPs (see section III.2.2) so that those groups not able to carry out simulations for all pathways will focus on those considered highest priority.

*III.1.4 Separation and shape*

Atmosphere–ocean GCM runs are most effective when the climate change signal to be detected is large compared to the noise of inherent climate variability. For the climate change outcomes of two pathways to be statistically distinguishable by models, they 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 benefits of avoided damages. 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 CM runs at intermediate forcing levels, than by producing new simulations for intermediate paths.

*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 include all of these sources, modeled so they are internally consistent. These include the full suite of GHGs, aerosols, chemically active gases, and land use and 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/cover. This list is a minimum set required to fulfill IPCC's call for adequately addressing aerosols, short-lived GHGs, and land use (see Box I.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 short- 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 provide a framework for regional analyses, particularly by the IAV communities; and (4) to provide insight into possible near-term policy options by providing better information about near-term impacts and potential adaptation. The modeling task is potentially quite different for these different aims 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 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 desirable types of RCPs that would best capture the set of desirable characteristics. These desirable types then 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 recommended to be used as RCPs.

*III.2.1 Scenarios in the literature*

The IPCC Working Group III (WGIII) AR4 assessed the literature on reference and stabilization scenarios published since the SRES and the Third Assessment Report (TAR). A total of more than 300 scenarios were identified in AR4, 147 and 177 of which were reference 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.[20] For the purpose of this report, the radiative forcing trajectories of more than 30 of these scenarios were collected to facilitate the identification of candidate RCPs. 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 ranges of these scenarios to the full range in the literature.

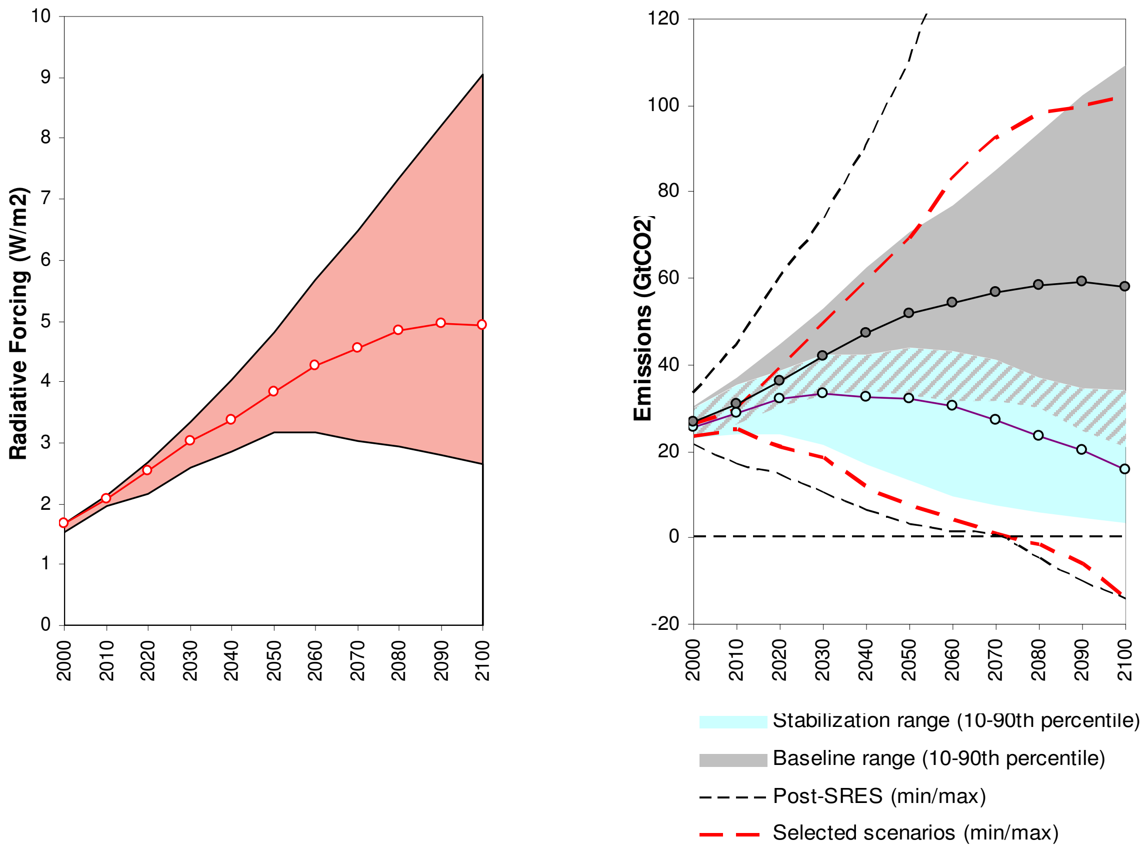


**Figure III.1.** Full range and median of the 30 radiative forcing pathways examined (left panel) and $CO_2$ emissions pathways for various ranges and medians (right panel). In the right panel, the lines connecting the filled and open circles are medians of the range of reference and stabilization scenarios, respectively. The red dashed lines correspond to the maximum and minimum of the range of $CO_2$ emissions pathways associated with the set of scenarios represented in the left panel. Data published for these scenarios extend only to 2100; RCPs will need to extend data to 2300.

The right panel of Figure III.1 provides perspective on the compatibility of the published scenarios capable of providing radiative forcing pathways with the entire published emissions scenarios literature. In general, the $CO_2$ pathways associated with scenarios providing radiative forcing pathways effectively cover the 10th to 90th percentile range of $CO_2$ emissions pathways across the post-SRES literature. The scenarios providing radiative forcing pathways also effectively represent the post-SRES 10th to 90th percentiles of the methane ($CH_4$) and nitrous

[20] This class of IAMs compute internally consistent projections of radiative forcing and its major 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 Table A1.1 in Appendix 1). A comprehensive assessment of radiative forcing pathways of all multigas scenarios in the literature is unfortunately not possible, since the forcing data for many multigas scenarios are not available.

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).

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.

*III.2.2 Desirable types of RCPs*

The scenarios literature was reviewed with respect to the desirable characteristics of range, robustness, number, separation, and comprehensiveness in order to define desirable 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).

***Table III.1.*** *Desirable 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 exceeding target level |
| RCP4.5 | ~4.5 $W/m^2$ at stabilization after 2100 | ~650 $CO_2$-eq (at stabilization after 2100) | Stabilization without exceeding target level |
| RCP3-PD[3] | <3 $W/m^2$ in 2100 | < ~490 $CO_2$-eq in 2100 | Peak & decline stabilization |

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 $CO_2$-equivalent 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 profile is similar to that of the SRES A2 scenario. When compared with a low scenario (e.g., RCP3-PD), a scenario of this type also has a good signal-to-noise ratio for forcing AOGCM simulations.

RCP3-PD is a low radiative forcing (and concentration) pathway with a radiative forcing level of no more than 3 $W/m^2$ by the end of the 21st century. Scenarios in the literature that achieve this long-term level are typically overshoot scenarios in which radiative forcing peaks earlier in the century and declines thereafter. This particular pathway 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 further declines thereafter. 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. Overshoot pathways 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 around 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.[21]

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.

One of the intermediate RCPs (RCP4.5 or RCP6) was considered desirable as the basis for the higher resolution near-term simulation. The intermediate position itself was considered desirable, as was the fact that there are a substantial number of scenarios at this level 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 pathways. However, there was substantial interest in a low stabilization pathway with a pronounced peak-and-decline shape in which the stabilization level was well below the peak radiative forcing level. At the meeting, agreement was reached on the general characteristics of the low pathway shown in Table III.1 (lower than 3 $W/m^2$ in 2100; overshoot character) 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 reference 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. Furthermore, the stabilization RCPs from 3 to 6 $W/m^2$ are also representative of the stabilization portion of literature in terms of radiative forcing and $CO_2$ emissions pathways assessed in AR4.[22]

Given that it is desirable that RCPs should be robust with respect to the literature, they do not represent the extreme boundaries of the ranges. While RCP8.5 and RCP3 are at the upper and lower boundaries of the radiative forcing pathways available, 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, is below the 10th

[21] 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.
[22] 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.

percentile of emissions pathways.[23] 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, stabilization of 4.5 $W/m^2$ via an overshoot pathway versus a pathway that never exceeds 4.5 $W/m^2$ was proposed. However, for the purposes of characterizing the climate space, exploring nonlinearity, and calibrating pattern scaling it was important that the RCPs represented the range of pathways and had distinguishable climate signatures. Interest was also shown 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.

Given the scientific and computing limitations and different resource constraints across CM teams, some 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 simulations is:

- The pair of the high and low RCPs (RCP8.5 and RCP3-PD);
- The intermediate-range RCP with near-term resolution (RCP4.5); and
- 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.

### *III.2.3 Criteria for identifying candidates for RCPs*

Based on the desirable 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 pathways and data requirements discussed in section III.2.2 and Appendix 1, respectively, and practical needs for the timely provision of IAM data to the CM community. Note that while 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, basic functionality to 2100 must be present in the IAM for a scenario to be a viable RCP candidate.

[23] Moreover, in the short run some of the low scenarios (included in the percentiles) assume that climate policy starts in 2000.

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

6) Peer-reviewed and published: the pathway must be reported in the current peer-reviewed literature.
7) Desirable 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 exceeding target)
    c. RCP4.5 (~4.5 W/m$^2$ at stabilization after 2100, stabilization without exceeding target)
    d. RCP3-PD (<3 W/m$^2$ in 2100, peak & decline stabilization)
8) 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 and 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 ESM communities. These include harmonization of output and base year data, downscaling, and extending published data to 2300 (see Appendix 1).
9) Modeling requirement: for reliability, radiative forcing results must have been generated with an IAM that contained carbon cycle and atmospheric chemistry representations.
10) 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, which includes (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.2.4 Candidates*

Using the criteria listed in Box III.1, the IAM community identified 18 RCP candidates from the literature (Table III.2). 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 by 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.

***Table III.2.*** *RCP candidates. Asterisks indicate that at least one scenario is available, although there may be more than one. The contents of the table are still under review to confirm that this is a complete listing of all candidates.*

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

Notes:
[1] AIM = Asia-Pacific Integrated Model, 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, ERM = , 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 stabilization criteria.

*III.2.5 Proposed RCPs*

Based on an assessment of the available scenarios to meet the identified data requirements, and the "strawman" recommendation presented to the expert's meeting, the IAMC is proposing the following RCPs:[24]

| **RCP** | **Publication – IAM** |
|---|---|
| RCP8.5: | Riahi et al. (2007) – MESSAGE |
| RCP6: | Fujino et al. (2006) – AIM[25] |
| RCP4.5: | Clarke et al. (2007) – MiniCAM |
| RCP3-PD: | van Vuuren et al. (2006, 2007) – IMAGE |

This proposal is broadly consistent with the strawman proposal. However, the revised definition of the low pathway (RCP3-PD) resulted in the initiation of a robustness assessment of the IMAGE scenario (discussed below).

Before the RCP data is provided to the CMs, it 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.

[24] See Table III.2 notes for definition of model acronyms.
[25] The AIM modeling team will revise this scenario to comply with the 6 $W/m^2$ stabilization criterion before 2200. The revised stabilization scenario will be published in Hijioka et al. (forthcoming).

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. 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.

This proposal is based on several considerations:

- Not all modeling groups whose scenarios were identified in the candidate list 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 in 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 large 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); and
- 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*

The background paper to the expert meeting identified two specific pathways from the literature as alternatives for the low RCP: the IMAGE 2.6 and IMAGE 2.9 scenarios from 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 and stabilization at a lower level beyond 2100.[26] The IMAGE 2.9 scenario peaks at over 3 $W/m^2$ and declines to a radiative forcing of 2.9 $W/m^2$ in 2100 and stabilization at 2.6 $W/m^2$ around 2150.

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. In that context, both the IMAGE 2.6 and IMAGE 2.9 scenarios are appealing, because: (a) in combination with the high RCP of more than 8.5 $W/m^2$ in 2100, both provide a broad span of potential future emissions and concentration pathways; (b) both follow

[26] Insights into results beyond 2100 obtained through consultation with the IMAGE modeling team.

peak-and-decline pathways to low stabilization levels beyond 2100;[27] and (c) the IMAGE 2.6 scenario also exhibits net negative $CO_2$ emissions towards the end of the century. The IMAGE 2.6 scenario was considered more appealing because of its more dramatic peak and decline and lower stabilization level. However, the IMAGE 2.6 scenario was exploratory in nature (as presented in the literature). The scenario requires very aggressive investment in mitigation early in the century and deployment of negative emissions technologies later in the century.[28]

The IAM community has not yet evaluated the technical feasibility of reaching such low radiative forcing levels. Specifically, the scenario has not yet been reproduced by other models in this class of IAMs.[29] It should be noted that the CM community would not expect the small difference in the projected climates in 2100 associated with the two scenarios to be distinguishable above the CM variability. However, this is a research question that could be addressed with individual models, ensembles, and with respect to different climate variables.

Based on the considerations above, the IMAGE 2.6 scenario is tentatively recommended as the selection for the RCP3-PD pathway. However, the robustness of the scenario needs to be assessed. Moreover, recent focus on the diverse consequences of widespread use of bioenergy (including associated $N_2O$ emissions), a requirement in this scenario, may have important implications. The IMAGE 2.9 pathway is considered robust in that other models have published similar results.

Based on the expert meeting discussion, the Integrated Assessment Modeling Consortium (IAMC) has offered to organize an IAM community exercise and assessment panel for evaluating the robustness of the IMAGE 2.6 scenario for selection as an RCP (see Appendix 1). If the robustness of the scenario in this context is established by mid-2008, it will be used for the low pathway. Otherwise, the IMAGE 2.9 pathway will be chosen. Thus, the robustness evaluation will ensure delivery of one of the two pathways via a scientifically rigorous process.

To ensure the scientific credibility and transparency of the evaluation, the IAMC will appoint a panel that will be responsible for the final judgment of the robustness of the IMAGE 2.6 scenario. Based on its robustness assessment, the panel will provide a consensus 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 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 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.

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[27] Both scenarios are included in the lowest class of stabilization scenarios assessed by the IPCC in the AR4 (this class contains only three multigas scenarios).

[28] 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 sequestration is assumed in both the IMAGE 2.6 and 2.9 scenarios, it is the combination with CCS that is novel in IMAGE 2.6.

[29] This class of IAMs compute internally consistent projections of 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.

An assessment process will be set up to evaluate the robustness of the IMAGE 2.6 scenario. The assessment will be based on two general criteria, both of which must be met: the technical soundness of the IMAGE 2.6 scenario, and the replicability of the IMAGE 2.6 scenario. For the former, 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 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 biomass combined with $CO_2$ capture and storage (CCS). If the team review reveals fundamental problems with the IMAGE 2.6 scenario, it will not be selected as an RCP. The findings from this assessment will be made available for consideration by the review panel.

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 satisfy the RCP3-PD definition. The modeling teams will be asked to employ their standard assumptions and include biomass and CCS, but avoid non-traditional assumptions like geo-engineering, dramatic dietary changes, or severe economic collapse. Replication will be deemed successful if after addressing any modest technical issues, the IMAGE team is able to generate the scenario using the latest version of the IMAGE model; and at least two of the other IAM teams in this class are able to generate a technically sound scenario.

The panel will ensure that the evaluation is conducted in a careful, scientific, and unbiased manner. Furthermore, the review panel will develop and apply a set of broad criteria that will 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 viability 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 report. See the letters in Appendix 2 for additional details on the planned robustness assessment.

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 $W/m^2$ or even 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 foreseen as:

- *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 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 will be used to investigate the extent to which they can be interpolated, using pattern scaling, 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 of forcing, using comparable CM simulations from at least three 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. It is an open research question as to how wide a range of spatial patterns of forcing could be consistent with a given climate change outcome. The RCPs will provide a new focus for work on this topic.

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” or most likely projection, and the near-term higher resolution CM simulations cannot be considered a forecast. In addition, 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 2100 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*. While all but the highest RCP represent mitigation scenarios, they are not meant to imply desirable policy outcomes. Rather, they are only intended to represent the range of mitigation scenarios in the literature.
- *The socioeconomic scenarios underlying each RCP should not be considered unique*. Each RCP is based on a scenario in the literature that includes socioeconomic development pathways. However, the scenario underlying each RCP is just one of many possible such 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, RCPs as a group were selected on the basis of their emissions and associated concentration and forcing outcomes. Therefore, there is no overarching logic to the socioeconomic assumptions or storylines associated with each RCP, implying several limitations on their use:
    - The set of underlying scenarios is not intended to span the range of plausible assumptions for any particular element of the scenario (population, Gross Domestic Product (GDP) growth, rates of technological change, land use, etc.) other than concentration outcomes.
    - The socioeconomic and technology assumptions are not consistent between the RCPs and thus 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.

*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 (CCSP; Clarke et al., 2007). Figures III.2 through III.6 provide an illustrative overview of how the RCP candidates and the recommended RCPs fit within 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 baselines 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), for $N_2O$ 138 scenarios (71 reference and 67 mitigation), and for sulfur 44 scenarios (15 reference and 29 mitigation).

In addition, thin colored lines represent the 18 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 (green $<3$ W/m$^2$; red 4.5 W/m$^2$; blue 6 W/m$^2$; brown: corresponding baseline scenarios (to about 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 two RCP candidates forcing values for all gases were not available, so only 16 of the 18 candidate pathways are plotted. Forcing and concentration data shown in the figures are taken from three main sources: (1) Bern model (Plattner et al., 2001) and Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC; Wigley and Raper, 2001) simple CM estimates of Van Vuuren et al. (submitted) for the IMAGE, IPAC, and AIM scenarios; (2) Clarke et al. (2007) for the CCSP scenarios, and (3) MAGICC estimates of the Riahi et al. (2007) MESSAGE 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 socioeconomic, 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 will be published in early 2008.
- The RCP4.5 (MiniCam 4.5 scenario) was published in Clarke et al. (2007). Scenario information is accessible via an interactive web database at http://www.climatescience.gov/Library/sap/sap2-1/finalreport/default.htm.
- Both candidates for the RCP3 (IMAGE 2.6 and 2.9 scenarios) were published in Van Vuuren et al. (2007).

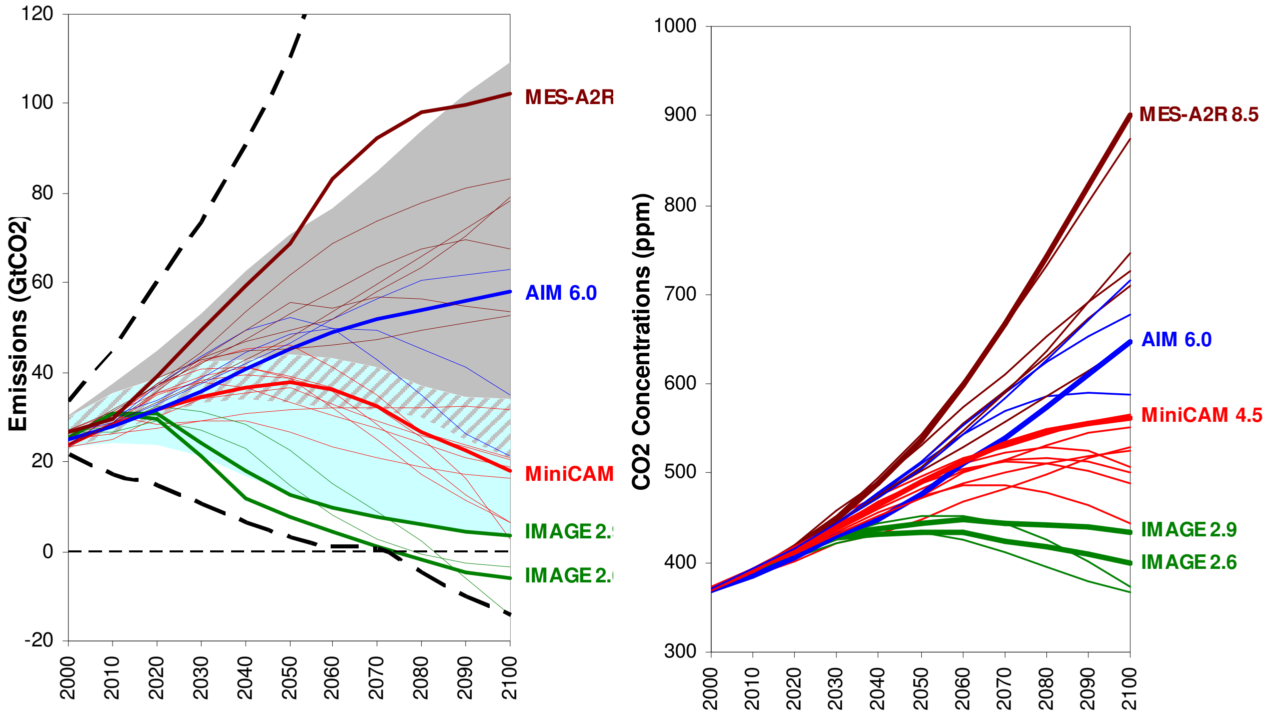


**Figure III.2.** $CO_2$ emissions and concentrations.

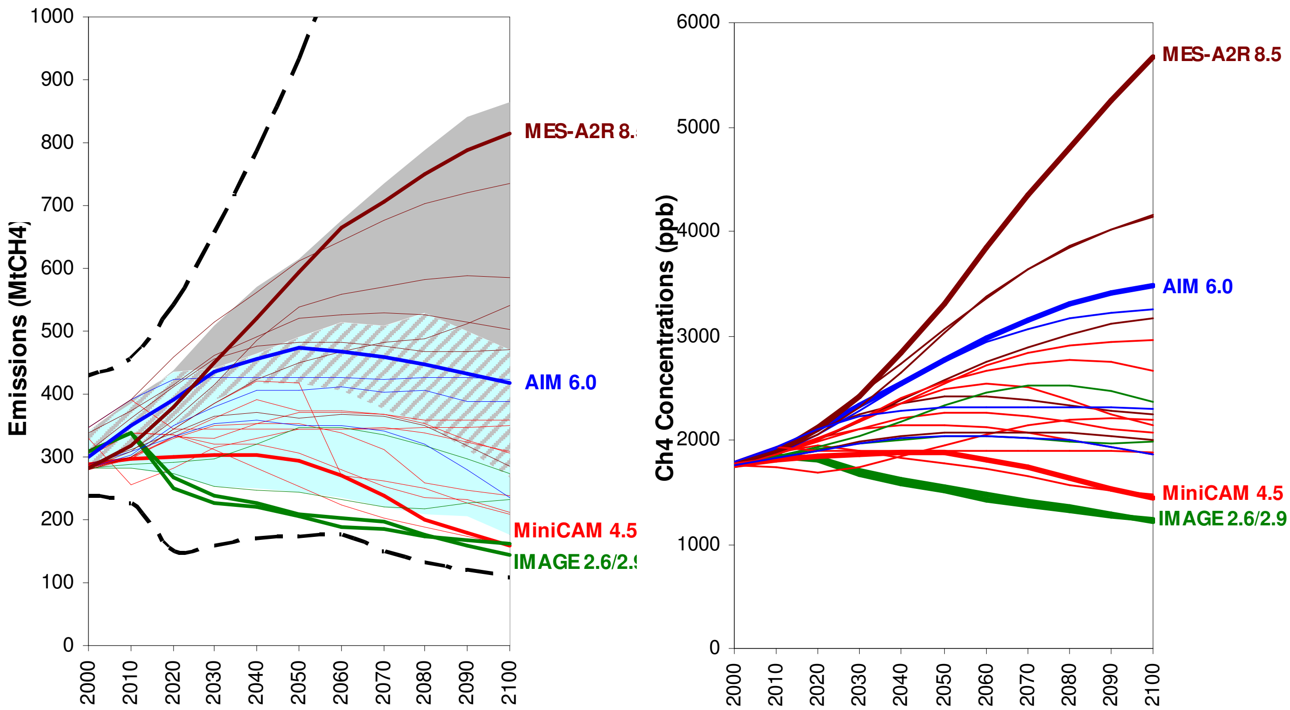


**Figure III.3.** $CH_4$ emissions and concentrations.

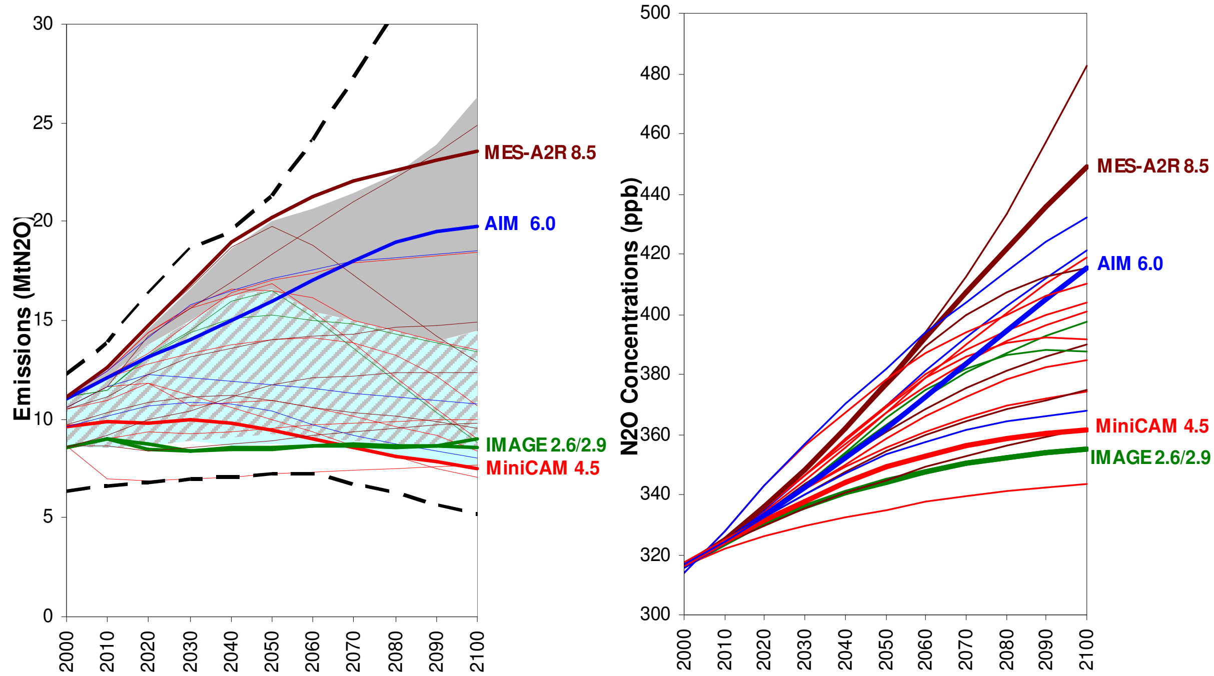


**Figure III.4.** $N_2O$ emissions and concentrations.

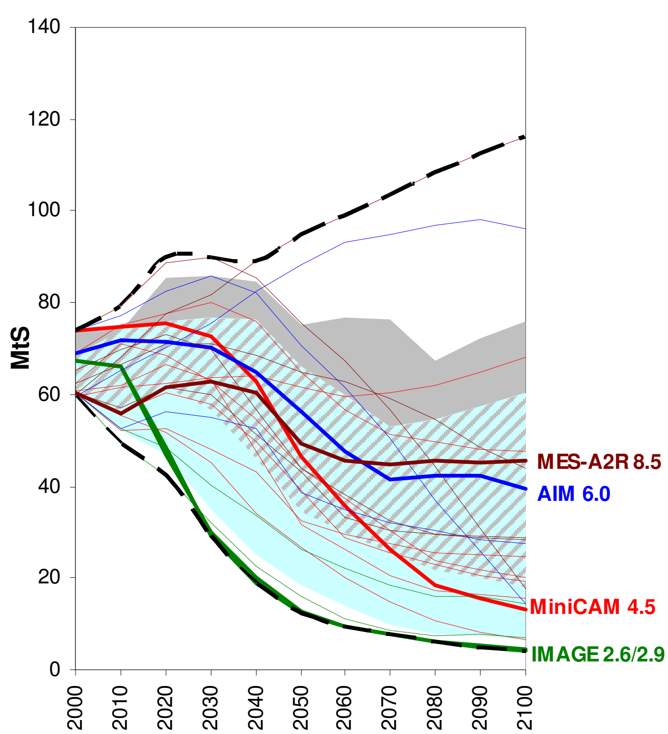


**Figure III.5.** Sulfur emissions.

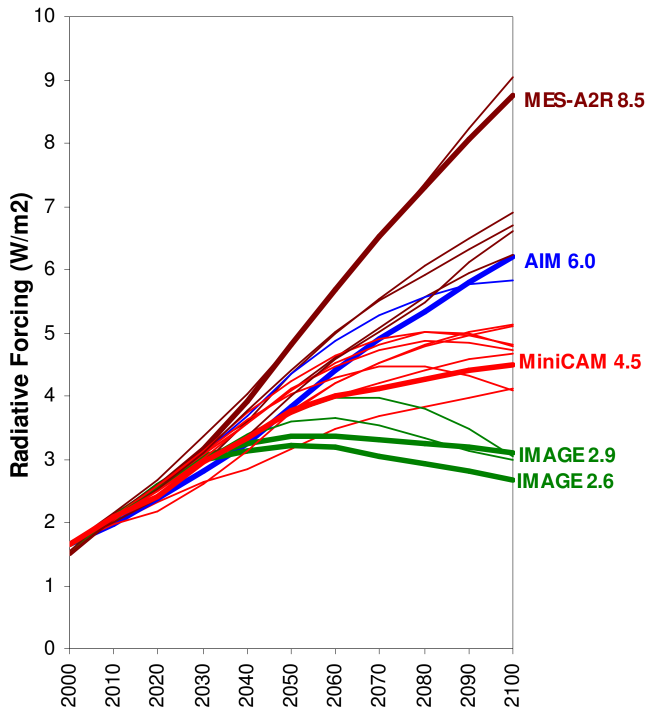


**Figure III.6.** Radiative forcing compared to pre-industrial. The AIM 6.0 scenario will be revised as explained in the main text.

# 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 UN 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 on 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 such as user consultation groups for representatives of the various user communities and regions to 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 FAO, the World Bank, UNEP, the World Health Organization (WHO), and major NGOs 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. 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. 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.

### *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) and and 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),[30] which started in 1994. This project evolved into the current Working Group on Coupled Models (WGCM) and subsequent incarnations of coupled model intercomparisons.

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

A joint activity between the previous Global Analysis, Interpretation and Modelling (GAIM) task force of the IGBP and the WGCM started in 2000 as a strategy to couple the global carbon cycle with 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 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.

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 WG I. To that end, discussions are underway to coordinate distributed data systems across the IPCC working groups, including PCMDI, BADC, MPI, and TGCIA. 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*

The Integrated Assessment Modeling Consortium (IAMC) was established in November 2006 to coordinate community activities among IAM teams, and between them and other communities involved in global change research. 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 ESM, 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 consortium meeting is planned for late January or early February 2008 in Washington, DC, at the same time as a major 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.

## Table IV.1.
## International consortium to facilitate the coordination of scenario development efforts

### 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
- *Rob 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

### *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.

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) 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 (e) contributing to the development of socioeconomic scenarios as an essential tool for assessing impact risks and vulnerabilities, especially for human systems.

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 the Netherlands expert workshop on new scenarios, 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 in relating CMs and IAMs and their findings to IAV research.

In addition, efforts are being made to convert informal networking into more standardized information exchange approaches and initial discussions of 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*

The goal of 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 three specific steps are proposed for action by the middle of 2008:

(4) 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;

(5) 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; and

(6) An IAM/IAV community meeting to develop plans for the scenario library.

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:

(5) 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;

(6) 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;

(7) 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

(8) 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 also to enhance communication among the communities (for example, 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 26th 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 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. 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 country and economies in transition modeling and scenario development, to the extent they are available, are often used 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. Climate change considerations rarely play a major role in either the development or application of these models.[31] 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.

[31] A notable exception is the use of models and scenarios by DCs in the preparation of National Communications under the UN Framework Convention on Climate Change (UNFCCC). 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."

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, accelerating economic growth rates, and institutional instability, all increase the 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 between national-level models in DC/EIT regions and the global models often used in climate assessments in time steps, data requirements, modeling detail, and policy objectives may constrain communications 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.[32] 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 individual DC/EIT countries (e.g., Brazil, 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.

[32] IPCC,TGICA, *Framework to facilitate development of appropriate data products and research capacity in developing and transition-economy countries*, 12 December 2005.

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 such as the System for Research, Analysis, and Training (START). 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 UN Framework Convention on Climate Change (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 the United Nations Development Programme (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, to a great extent, by following a networking process within a global team, with two main components: the global core team and regional teams based on UNEP Collaborating Centres.

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 (CEOS), 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 ESM and IAM communities, respectively.[33] 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

[33] DC/EIT member institutions of the IAMC currently include Universidad de las Americas, 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).

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), which 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 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 modeling 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 ESM 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 developing 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, ESM, and IAV communities. The more 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 has 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 ESM 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 ESM 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 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 but is likely to be reconsidered in light of new results from the more complex ESMs. Major tools for such work are simple CMs and models of intermediate complexity, and further research will be needed to ensure that these can be calibrated or matched to ESMs. 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 extremes. 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, such as soil moisture loss and land cover change, which are less likely to scale linearly with the applied radiative forcing.

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 in precipitation over 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 ESM 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 ESM 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 who are 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 damages.

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.

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# 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 will be organized in early 2008 (a proposal has been made for February 2008) in which the two working groups, IAM teams, and climate modelers reconvene and decide on methodologies that will be applied.

***Table A1.1.*** *Information needed by climate and ESM 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 community 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 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.[34] 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,

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

data might best be harmonized at the regional level (data could possibly be based on FAO; but interaction with institutes involved in the Global Carbon Project will also be considered).

### *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 will be worked out before the workshop in early 2008. 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. 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 socioeconomic information can be provided beyond 2100 that is meaningful. 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.

    Their 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 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, 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). An important factor is that different ESMs are using different historic land use maps. One possibility is that IAMs provide information on land use change at the level of regions—while downscaling to the grid is done 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 ESM communities. One possible minimum distinction for land use could be a) crop area, b) grazing area (to be defined), c) irrigated area, and d) plantation areas (indicating tree type). But both the resolution and the definition of land use types needs 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 ESM community will be useful.

# Appendix 2: RCP3-PD Review Correspondence

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1 November 2007

Dr. Rajendra K. Pachauri
Chairman, Intergovernmental Panel on Climate Change (IPCC)
Director, The Energy and Resources Institute (TERI)
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India
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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]

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[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

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(IIASA)

John Weyant
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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

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9 November 2007

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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 five of the six individuals that we proposed regarding their willingness to participate. Second, your letter proposed augmenting developing country participation on the panel. We support your suggestion. Given that the issue under consideration calls for experts most familiar with this class of models and their results, we propose to supplement the panel with Prof. P.R. Shukla. We have very high regard for the potential candidates you listed, and encourage the panel to consult with experts, such as these, for specific detailed expertise that is relevant to this assessment. Finally, your letter suggests that a consensus decision is required from the panel. We agree that a finding in favor of IMAGE 2.6 robustness should require consensus from the panel. However, we do not believe consensus should be required for a finding against robustness. Anything less than consensus, should be considered a rejection of robustness. We trust the Steering Committee will consider revising its recommendation to the IPCC plenary on this issue.

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 IMAGE modeling team to (a) review the published IMAGE 2.6 scenario for technical soundness in light of new insights, and (b) address any technical issues that arise from that review. The IMAGE team will be asked to 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 IMAGE team review reveals fundamental problems with the IMAGE 2.6 scenario, the scenario will not be made available for consideration as an RCP.

*2. Replicability:* The IAMC will ask all the IAM teams in this class of models[35] to participate in the design and development of low stabilization scenarios that limit radiative forcing to below ~3 $W/m^2$ during the $21^{st}$ 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. 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 the scenario.

Therefore, replication would provide validation of the IMAGE 2.6 by proving computation feasibility of similar pathways. The scenario assumptions and implications would be fully documented to ensure proper interpretation and handling by the scientific communities and policy users. All modeling teams with models in this class, i.e., able to satisfy the requirements for candidates for RCPs, would 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,

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[35] 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).

## 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

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| **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

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

**Sorbonne Lounge, 10.30– 11.00 Coffee break**

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

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| **Dali** | **13.00 – 14.30** | **Lunch** |
| **Sorbonne 2 Plenary** | **14.30 – 16.00** | **Long-Term Scenarios (Chair: Shuzo Nishioka)**<br>1. *ESM approach to long-term scenarios (2100 and beyond): Coupled climate-carbon cycle experiments*<br>**John Mitchell**<br>2. *IAV approach to long-term scenarios: impacts, vulnerability, and long-term adaptation needs*<br>**Tim Carter**<br>3. *Mitigation policy and IAM approach to long-term scenarios: policy analysis and mitigation requirements*<br>**John Weyant**<br><br>**Discussion** |
| **Sorbonne Lounge** | **16.00 – 16.30** | **Break** |
| **Sorbonne 2 Plenary** | **16.30 – 18.30** | **Near-Term Scenarios (Chair: Eduardo Calvo)**<br>1. *ESM approach to near-term scenarios (~2030): High-resolution modeling focusing on extreme events, regional climate, and interactive chemistry*<br>**Masa Kimoto**<br>2. *IAV approach to near-term scenarios: adaptation planning and management*<br>**Roger Jones**<br>3. *Mitigation policy and IAM approach to near-term scenarios: baselines, air pollutants, transitions, and developing country dynamics*<br>**Fatih Birol**<br>4. *Regional modeling and applications: relationship to global scenarios*<br>**Emilio La Rovere**<br><br>**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

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| **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:*

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|---|---|
| **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.

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| **Dali** | **12.30 – 14.00** | **Lunch** |

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

**Boston Lounge & Sorbonne Lounge**
**15.30 – 16.00 Break**

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| **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 interdisciplinary perspectives: agendas and key meeting deliverables (by Tim Carter)** **Plenary**

**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**

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| | **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: 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
Steve Rose, U.S. Environmental Protection Agency, USA
Cynthia Rosenzweig, NASA, USA
Dale Rothman, Macaulay Institute, UK
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
Kioshi 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 5: 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 |
| $C^4$MIP | Coupled Carbon Cycle-Climate Model Intercomparison Project |
| CCS | $CO_2$ capture and storage |
| CCSP | US Climate Change Science Program |
| 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 |
| ERM | |
| 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 |

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| 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 |
| WCRP | World Climate Research Programme |
| WGCM | Working Group on Coupled Models |
| WGCM | Working Group on Coupled Models |
| WGI | Working Group I |

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| WGIII | Working Group III |
| WHO | World Health Organization |
| WMO | World Meteorological Organization |