IPCC EXPERT MEETING ON EMISSION SCENARIOS

12 – 14 January 2005, Washington DC

Meeting report

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IPCC Technical Support Unit Working Group III

This expert meeting was agreed in advance as part of the IPCC work plan, but this does not imply working group or panel endorsement or approval of this report or any recommendations or conclusions contained herein.

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Preface

Emission scenarios are an important topic for IPCC, because they have been used in the Second and Third Assessment Report to project future climate change and climate change impacts and they form a basis for evaluating response options. In the past IPCC published long-term emission scenarios, the so-called IS92 and SRES sets in 1992 and 2000 respectively. For the Fourth Assessment Report (AR4) it was decided by the 21st IPCC plenary session (November 2003) that no new emission scenarios would be prepared but that new literature on emission scenarios, including criticism on the SRES scenarios, should be assessed in the Working Group III contribution to the AR4. The IPCC Plenary called for an Expert Meeting on Emission Scenarios to assist in that process.

This Expert Meeting on Emission Scenarios was held in Washington from January 12 – 14, 2005 and kindly hosted by the US Government. We would like to thank the US Government for their financial support and for all the efforts by the local organisers to make this meeting a success. We thank the Programme Committee for their valuable inputs in preparing the meeting and the session chairs and participants for making the meeting a success.

This report consists of a summary of the meeting sessions, the presentations and the discussions. Furthermore, the speakers have been requested to submit extended abstracts that can be found in Annex II. The material has undergone the following review process: the draft summary report was sent to all speakers and participants and comments were incorporated in the final version. Some of the papers are being revised, based on the discussions at the meeting, for publication in a special issue of Energy Economics.

We hope that the material will be used as a valuable input to the AR4, in particular to the chapter on long-term mitigation issues in the Working group III contribution. While this activity was held pursuant to a decision of the IPCC, such decision does not imply the Working Group or Panel endorsement or approval of the proceedings or any recommendations or conclusions therein. In particular, it should be noted that the views expressed in this report are those of the authors and not those of IPCC Working Group III or other sponsors.

Ogunlade Davidson
Bert Metz
Co-Chairs, IPCC Working Group III

The Programme Committee for the IPCC Expert Meeting on Emission Scenarios

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Dr. Rajendra Pachauri	Chair IPCC
Prof. Anthony Adegbulugbe	CLA Chapter 4
Mr. Francisco de la Chesnaye	LA Chapter 3
Dr. Brian Fisher	CLA Chapter 3
Dr. Henry Jacoby	MIT
Dr. Mikiko Kainuma	LA Chapter 3
Dr. Jiang Kejun	LA Chapter 3
Ir. Tom Kram	TG ICA
Dr. Emilio La Rovere	LA Chapter 3
Dr. Nebojsa Nakicenovic	CLA Chapter 3
Dr. Joaquim Oliveira Martins	OECD
Dr. Sarah Raper	Representative contact WG I
Prof. Ferenc Toth	Representative contact WG II

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1. Introduction

1.1. Background and goals

In 2001 the Intergovernmental Panel on Climate Change (IPCC) published a set of scenarios in the Special Report on Emission Scenarios (SRES). These scenarios have been developed in a four year process with many scientists involved in the writing and the review process. The SRES scenarios have played an important role in the Third Assessment Report (TAR) of the IPCC and will be used in the upcoming Fourth Assessment Report (AR4) as the 21st IPCC plenary session (November 2003) decided that no new baseline scenario would be prepared for the AR4, in view of the time it takes before new scenarios are taken up by the research community and used in publications. At the same time the plenary session called for an Expert Meeting on the issue of the use of scenarios in AR4 under the auspices of Working Group III. This expert meeting took place 12 – 14 January 2005 in Washington DC, kindly hosted by the US government.

In the Working Group III contribution of the AR4, Chapter 3: *Issues related to mitigation in the long-term context*, deals with long-term emission scenarios. It was therefore decided that the meeting should address new insights in the literature since the Third Assessment Report (TAR) on the issues to be included in Chapter 3.

The outline of this chapter contains the following issues:

- Baseline emission scenarios: assessment of new literature since SRES. The assessment should cover literature on emission scenarios that include climate feedbacks.
- Mitigation and stabilization scenarios and strategies, and costs and socio-economic implications (with appropriate uncertainties) including multiple gases.
- Development pathways, trends and goals.
- Role of technologies in long-term mitigation and stabilization: research, development, deployment, diffusion and transfer.
- Interaction of mitigation and adaptation, in the light of climate change impacts and decision making under long-term uncertainties. Not only present costs of mitigation but also avoided climate change damages and costs of adaptation should be included.
- Linkages between short and medium term mitigation and long-term stabilization, including the implications of inertia, risk and uncertainty for decision making.

In addition, it was decided to address the following issues:

- Criticism on the SRES scenarios and implications for their use for AR4 (including macro-economic projections for developing countries and PPP vs. MER based macro-economic scenarios);
- Possibilities to use simple climate models to evaluate the climate implications of stabilization and mitigation scenarios;
- Possibilities to get insight in the impact of climate change for these mitigation and stabilization scenarios and analysis of adaptation options for these scenarios;
- How to deal with multi-gas scenarios; metrics for equivalence across greenhouse gases and other radiative forcing agents; associated emission profiles; mitigation cost estimates;
- The advantages and disadvantages of the use of probabilistic approaches.

The meeting aimed furthermore at increasing the interaction between Lead Authors of Chapter 3 with non-Lead Authors and Lead Authors from other chapters of Working Groups I, II and III.

1.2 Organisation

The meeting was organised with extensive assistance of a program committee, chaired by Bert Metz, co-chair of IPCC Working Group III. The program committee decided on the program, the speakers and the participants. The members of the program committee were:

Bert Metz (Chair)	Co-Chair WGIII
Rajendra Pachauri	Chair IPCC
Anthony Adegbulugbe	CLA Chapter 4
Francisco de la Chesnaye	Host meeting 1, LA Chapter 3
Brian Fisher	CLA Chapter 3
Henry Jacoby	MIT
Mikiko Kainuma	LA Chapter 3
Jiang Kejun	LA Chapter 3
Tom Kram	TG ICA
Emilio La Rovere	LA Chapter 3
Nebojsa Nakicenovic	Host meeting 2, CLA Chapter 3
Joaquim Oliveira Martins	OECD
Sarah Raper	Representative contact WG I
Ferenc Toth	Representative contact WG II

Secretary of the Program Committee was Monique Hoogwijk of the TSU of Working Group III.

1.3 Program and participants

A program was put together that addressed all topics listed in Section 1.1. Experts were approached to prepare presentations. To ensure adequate exchange of views, half of the time was scheduled for discussions. The entire program is attached in Annex I.

The meeting was by invitation only and about 80 experts were selected in consultation with the Program Committee, based on a balance of expertise, geographical background and IPCC versus non-IPCC involvement. Invited were:

- All Lead Authors from Chapter 3 of the WGIII contribution to the AR4.
- Representatives from the other chapters of the WGIII contribution to the AR4. The chapters were asked for nominations.
- Experts on emission/stabilization scenarios.
- Heads of the TSUs, Lead Authors from WGI, WGII and members of the IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA).
- Non-climate researchers with expertise on economic growth, technological development or, land-use.

There were in total 71 participants, of which 13 work in a developing country, 33 are Lead Authors from Working Group III and 8 from other Working Groups and the TGICA.

2. Summary of the presentations and discussions

2.1 Opening session

The meeting was officially opened on behalf of the US government by **Mr Jeffrey Holmstead**, Assistant Administrator for Air & Radiation of the U.S. Environmental Protection Agency. He heads EPA's Office of Air and Radiation which is in charge of programs addressing global climate change, industrial and vehicle pollution, acid rain, stratospheric ozone depletion, radiation protection and indoor air quality. Mr Holmstead mentioned that President Bush personally recognizes the role of IPCC. He explained that reducing uncertainties related to climate change is one of the key objectives of US policy. He addressed several programs that have been introduced in the US on the reduction of greenhouse gas emissions. He explained that emission scenarios are considered important for the US government to understand the relationship of the greenhouse house gas intensity and economic growth, population and technological development.

Bert Metz, co-chair of IPCC Working Group III welcomed the participants on behalf of IPCC and gave a brief introduction on the background and the goals of the meeting. He introduced the planning for the Fourth Assessment Report and the cross cutting issues that have been defined.

2.2 Session 1: Emissions scenarios.

Chair: Bert Metz
Speakers: Brian Fisher, ABARE and Nebojsa Nakicenovic, IIASA/Vienna University of technology, *Emission scenarios: Introduction.*

Nebojsa Nakicenovic, IIASA/Vienna University of Technology and Coordinating Lead Author of Chapter 3, Working Group III, introduced the past emission scenarios developed in the context of IPCC, the SRES scenarios and its criticism. He presented the range of scenarios that have been published after the SRES (Post-SRES scenarios). These scenarios have been collected by the National Institute for Environmental Studies (Japan) (Mikiko Kainuma). From the comparison of the Post-SRES scenarios with the ranges of the SRES scenarios it could be concluded that:

1. Recent (Post-SRES) population scenarios assume significantly lower fertility rates in the world that result in lower population growth that is reflected in a downward shift of the whole range;
2. The range of Gross World Product from recent non-intervention scenarios over this century is extended upwards. However, the median does not change significantly;
3. The range of carbon emissions from recent non-intervention scenarios is slightly higher on the upper limit than the SRES range (more than 20GtC). The SRES scenarios have been criticized for overestimating future emissions; however, the Post-SRES literature shows a higher emission range. Independent population projections from the UN and IIASA that have not been integrated with the emission scenarios are lower. But again, the median of all emission scenarios has not changed significantly compared to SRES.
4. The concept of "non-intervention" reference scenarios is increasingly becoming elusive and hypothetical as climate policies are becoming a reality in many parts of the world. Much of the Post-SRES literature still includes reference, non-intervention scenarios however.

Brian Fisher, ABARE and co-Coordinating Lead Author of Chapter 3, continued the presentation by addressing one item of uncertainty that will also be addressed in Chapter 3: the differences in (base year) starting points for scenarios based on historical data. He showed several examples of statistical data that has been updated as a result of new information and statistical data that varies by source. Examples of revised or inconsistent data included statistics on historical coal production in China, electricity generated from coal and gas in India, gas production in Japan and population statistics in China. These historical data, which provide the starting point for scenarios, are therefore associated with an element of uncertainty that should not be neglected. He also pointed out that forecasting errors with respect to generation of scenarios over long time horizons are likely to increase with the length of projection and are likely to be larger than predicted due to the effects of forecast 'anchoring'.

Discussion
Several questions were addressed on the type of literature that will be assessed in Chapter 3 of the AR4. It was explained that no new IPCC scenarios will be developed for the AR4, but literature review of all types of scenarios will be included, covering, if literature is available: back casting scenarios, more regional aggregation, and the linkages between long term and short term scenarios. Scenario literature from IEA, EEA and OECD will be evaluated, as well as peer-reviewed scientific journal publications. The LAs of SRES did not provide a recommendation on what SRES storyline is most likely. Chapter 3 in the AR4 will however assess literature on probabilistic scenarios. A specific suggestion was made to include statistics of probabilistic ensembles, such as the median and the percentiles in the comparison of deterministic and the probabilistic scenarios in Chapter 3. The difficulty of reference case definition and comparability in SRES and post-SRES scenarios was also raised.

2.3 Session 2: Keynote speaker

Speaker: Bill Nordhaus, Yale University, *Should Modellers Use Purchasing Power Parity or Market Exchange Rates in Global Modeling Systems?*

Bill Nordhaus addressed in his presentation what would be the most appropriate unit to use for the conversion of local currencies to comparable values when modelling economic growth and related energy use and emissions scenarios on a global scale: Purchasing Power Parities or Market Exchange Rates? He postulated a matrix with a PPP versus MER dimension and a domestic versus international prices for all goods and services dimension. He proposed to use what he calls the "Superlative PPP accounts" (originally called a "hybrid account"). This approach uses PPP exchange rates and combines these with actual market prices for each country. These are called "superlative PPP accounts" because they rely upon superlative indexes over both space and time to compare outputs of different countries. Under ideal circumstances, this approach will provide accurate and consistent cross sections and time series. Nordhaus recommended that modellers need to consider whether behavioural and reduced-form relationships in their models have been correctly estimated when moving to PPP cross-sectional valuations. He addressed that whether the PPP method is feasible depends also on the type of PPP approach considered. The superlative PPP accounts are very close to existing approaches and require relatively few technological conversion issues. It is important to note is that there is no one-to-one mapping from MER data to PPP data in global models. This fact makes converting from MER to PPP difficult, given present data and model parameters. However, a simple, linear conversion is unlikely to hold in practice because of non-linearities in the aggregation of country data and in the economic and technological behavioural relationships within and between countries. Recent studies with PPP indicated that emissions could be 17 – 40% lower when using PPP compared to MER. However, Nordhaus added that he was not certain whether these studies have recalibrated their models correctly. Therefore, to study the impact of using MER instead of PPP in emission scenarios, new models are needed that have properly recalibrated all behavioural and reduced-form relationships. Furthermore, data on PPP are about two orders less abundant than MER data; this also needs attention.

Discussion
In the discussion after the presentation, several questions were raised on aspects of the proposed method, for example, the importance of the starting year chosen to derive the PPP rates. This is important and does have an influence, but if data are constructed correctly with superlative indexes there should not be a cross sectional bias going backwards or forwards with data. Whether the method is also applicable when using a regional model that aggregates country data, Nordhaus stated that this is possible as you can aggregate national economies using PPP weights for the base year and then use national growth rates to run the model forward for national outputs. There was furthermore some discussion about how to handle goods that are traded at (international) markets at MER prices. Finally, it was stated that more work is also needed on the long-term relationship between MER and PPP. This relationship changes over time; for example it is certainly different now than 100 years ago.

2.4 Session 3: Development pathways, trends and goals in relation to scenarios. What is the role of socio-economic driving forces in scenario development?

Chair: Emilio La Rovere, Federal University of Rio de Janeiro
Speakers: Brian O'Neill, IIASA, *Role of demographics in emission scenario*
Joaquim Oliveira Martins, OECD, *Long-term Economic Growth Projections: could they be made less arbitrary?*
Jeffrey Sachs, Columbia University, *Scenarios and Development pathways*

Brian O'Neill, IIASA, presented the relationship between population size, other demographic factors and emission scenarios. He started by presenting the changes in demographic outlook since SRES. The changes since SRES are similar as presented by Nakicenovic in the previous presentation; there is a general downward shift in projected population size. The global results seem to be mainly driven by developing regions. Compared to these new projections, the A2 scenarios seem to be implausibly high, and the low end of the current range is not well represented in SRES. Regarding the age structure, new projections foresee the possibility of significantly more aging than before, and SRES scenarios cover about the median, but do not cover well the high end of the aging range of these post-SRES studies, particularly in industrialized countries. O'Neill stated that the inclusion of demographics in emission models should not be limited to population size, because age structure, household size and rate of urbanization may differ and have implications. However new work is required on this. He showed some preliminary results for China and the US on urbanization, household structure and income and some preliminary modelling results with the PET model (Population – Environment- Technology model). This general equilibrium model has 4 world regions. This new work showed that inclusion of these demographic factors could substantially affect energy and emission scenarios.

Joaquim Oliveira Martins, OECD, presented a joint paper with Giuseppe Nicoletti focusing on the main drivers of economic growth, in the context of long-term projections. GDP per capita growth can be decomposed into *labour utilization*, which is a function of the hours worked per worker and the employment rate, and *labour productivity*, which is a function of the capital per hour worked and the multi-factor productivity. For the projection of *labour utilization* a cohort approach is required, that looks at how labour participation of population cohorts changes over time. On average, though, over the long run, cohorts are assumed to have a similar participation rate. For the projection of long-term *labour productivity*, it is important to identify the productivity leaders and the convergence process of the followers. Identifying the leaders is not easy because technological shifts are not easily predicted. Regarding convergence, the features and determinants for catch up are often not known. Nevertheless, Oliveira Martins distinguished three scenarios: 1. all countries converge to the same labour productivity level; 2. all countries converge to the same labour productivity growth but stay at different levels; 3. no convergence, neither in growth rates or levels. Without policies, scenario 2 seems the most likely one. In this regard, it is important to understand growth accelerations that take place in developing regions. The main driver of long-run *labour productivity* growth is the prediction of multi-factor productivity. The latter depends on four factors: 1. Shifts in sector composition, 2. Changes in labour quality (there are conflicting forces at work in OECD); 3. Changes in capital quality (with new technologies this is likely to increase in OECD); and 4. Pure technical progress. Oliveira Martins stated that only limited catch up in labour productivity levels should be factored in projections, because a) we know little about the determinants of multi-factor productivity growth, the most important driver of long-run labour productivity; b) labour quality is likely to drag down productivity growth in a number of countries, unless there are massive investments in education. This is somewhat compensated by the expectation that capital quality is likely to push up labour productivity in most countries, especially in those that lag behind. He stressed that scope and complementarity of policies play an important role in the convergence process and often this aspect is not make explicit when convergence scenarios are designed.

Jeffrey Sachs, Columbia University presented on his views on development pathways and emission scenarios. He stated that the most interesting regions to include in the GHG emission scenarios would be the regions with the largest emission that are on track to full convergence with industrialised countries. These are not the same regions that are interesting in terms of development. Asia (India and China) would be the regions to look at because of the following points: (1) Asia will likely achieve converging economic growth over the next 25 years with increasing energy use and related GHG emissions; (2) rapid growth regions are more interesting places to reduce emissions with new technologies compared to retrofitting old technologies elsewhere; and (3) the fast growing Asian countries have significant coal resources; how these are used is important for emissions. Because of these reasons, Sachs stated that modelling economic growth in an aggregated model using GDP only is not as good as capturing regional structural change, including, for example, details on energy supply systems, land-use patterns, power plant choices, building design, and urban design. Sachs stressed that when it comes to technological development, the question of who pays for this development is an important issue. From the point of equity, this should be paid by developed regions. This is often not included in models. Sachs mentioned another issue that should be incorporated in emission scenarios and could become important for development: the feedback from climate change. Examples of this are water stress, desalination, variation in energy use (heating and cooling), changes in agricultural productivity and land-use changes. He also suggested that modellers should develop crisis scenarios, for example where energy resources become scarce. As a final remark he stated that fine-tuning economic development at an aggregated level is not that important for emission scenarios; scenarios usability is rather limited due to the aggregation of important underlying factors. More effort should be put in disaggregating the scenarios.

Discussion

The discussion started with methodological questions on relations between demographics and emissions. It was suggested that there might be different approaches to link income distributions to demographic change and indirectly to emissions. O'Neill answered that he has done this by linking income distribution effects to fertility and mortality rates. Another important issue that might have an impact is the recent insight that people take along their lifestyles from younger ages throughout their lives. This might have substantial impacts on projected consumption patterns. Also inter-regional migration might have impacts on emission scenarios, but this has not yet been studied adequately. There are also many linkages between level of education between regions and distribution of investment. It might be worth looking at this when modelling development at a regional level.

The issue of technology development and diffusion was also raised. There is a reason to believe that in Asia, for instance, the growth patterns will change from technology importing to technology development. The share of R&D in GDP would then increase. This could have important implications for the rate of innovation and capital investment.

2.5 Session 4: How to treat different economic approaches in the AR4?

Chair: Ken Ruffing, OECD
Speakers: John Weyant, Stanford University, *PPP vs MER in EMF implications for climate scenario development*
Hans Timmer, World Bank, *PPP vs MER: a view from the World Bank*

John Weyant, Stanford University, presented the implications for climate scenarios of the economic approach used: PPP versus MER. A number of modelling teams that developed the IPCC SRES scenarios did experiments with both approaches. The first point to note is that best practice can differ between making historical welfare comparisons and model projections of GDP, energy and carbon emissions. He stated that to compare current and past incomes between countries PPPs are preferred, although they are far from perfect. When making long-run global economy-energy-environment projections he recommended working in local currencies for as long as possible and using basic drivers of economic growth rather than reduced form convergence formulations. Weyant recommended using MERs or PPPs consistently, especially in implementing convergence assumptions, but referred to Nordhaus', earlier statement that a complication in using PPPs is how to re-estimate structural economic relationships based on PPP data when the required PPP data is generally not available. Weyant concluded that the SRES scenarios are probably correct when climate change or its impacts are of interest, whether PPP or MER was used. However there could be significant differences for mitigation cost projections depending on the method of GDP convergence. Most studies on projections using both conversion methods that get significantly different results have not made all appropriate adjustments in their structural relationships. Important to note is that trade effects may cause further complications.

Hans Timmer, Worldbank, in his joint presentation with Andrew Burnes, started by stating that he will come up with different conclusions than Bill Nordhaus. He argued that there is nothing wrong about using the MER method as long as this is done for the right applications. He raised three questions: 1. Why do we use PPPs in international comparisons of poverty and living standards? 2. Why do we use MERs in growth and economic analysis? 3. Which is better, PPPs or MERs in convergence scenarios? He discussed these questions based on a very simple example of two hypothetical countries (one poor, one rich) and two goods (tradable and non-tradable). For certain economic expenditures analyses MERs are preferred, for example when analysing the economic importance of low-income countries, remittances, and energy. The impact of an oil-price hike, payable in international currency, is larger for poor countries. When estimating economic growth, MERs are used because of consistency in national accounting. Timmer's summary included the following key points: (1) Use different method for different purposes; (2) One should not mix methods, especially within a modelling framework; (3) One should not apply national account growth rates to PPP based income levels to avoid over-stating poor-country incomes at convergence; and (4) Model explicitly relative-price developments.

Discussion
In the methodological discussion, Hans Timmer explained that in his examples he uses the full PPP method and not the so called Superlative PPP method recommended by Nordhaus. He supported the idea advocated by Nordhaus and Weyant that one should use MER national accounts in growth rate analysis and PPP based income levels as the starting point for country comparisons;

2.6 Wrap up discussions and conclusion of day 1

Chair: Bert Metz, co-chair IPCC WGIII
Panel: Emilio La Rovere, Federal University, Rio de Janeiro
Ken Ruffing, OECD
Bill Nordhaus, Yale

The main issue discussed was whether the SRES scenarios can still be used in the AR4 assessment given the recent population projections and the PPP vs MER issue. One important notion was that they cover the range of the latest emission scenarios quite well, which indicates they are certainly valuable for the AR4. Many participants stressed the point that while there may or may not be a difference in emissions projections depending on the use of either MER or PPP, there are many other variables that will have a much greater influence emissions and resulting temperature projections. These variables which include population growth, technological development and deployment, and climate sensitivity deserve much more attention than the PPP/MER debate.

Issues that were raised include the following:
On PPP vs MER:

- The difference in projected economic growth between using MER or PPP in a consistent manner for SRES convergence scenarios is not known. New model approaches, calibrations, and model runs would be required for this analysis.
- For consistent comparisons of long-term economic growth between countries both PPPs and MERs should be used in a combined method as proposed by Nordhaus
- Convergence scenarios should also address the relationship between PPP exchange rates and MER which depends on productivity trends at the sector level; thus, the PPP/MER ratio should be endogenous.
- There is an indication that the emissions are not very much affected by the use of PPP or MER, because of the offsetting effect of rates of change of energy intensity and carbon dioxide intensity (if these are expressed in the same metric). It seems that the chosen approach may have more impact on the assessment of mitigation and abatement costs.
- Regarding the impact of the use of PPP vs MER on mitigation and adaptation costs, this would not be a problem if the analysis was country specific. To the extent welfare considerations are made across countries, then there may be a larger issues in the aggregation problem.

On population, development pathways and convergence

- We see a downward trend in population projections compared to SRES in recent literature. Furthermore, the changing household structure and age structure could be important for scenarios.
- Regarding convergence it is important to consider not only the degree of converge (in incomes) but it is also necessary to spell out policies required to sustain required high productivity rates.
- Thinking through so called crisis scenarios could be a very interesting exercise, e.g., abrupt climate change scenario.
- On the issue of the difference between baseline and policy scenarios it was stated that it is important to be clear and transparent on what policy assumptions have been made in the baseline scenarios when there are emerging climate policies.

2.7 Session 5: Climate and impact scenarios: Evaluating climate impacts and analyzing adaptation options.

Chair: Tom Kram, RIVM
Speakers: Reto Knutti, UCAR, *Evaluating climate impacts with intermediate models*
Monirul Mirza, University of Toronto, *The Use of SRES for Vulnerability, Impacts and Adaptation Assessments*
Ferenc Toth, IAEA *Climate change mitigation: Costs and avoided damage*

Reto Knutti, UCAR, showed the importance and possibilities of climate models of intermediate complexity. He showed that these models are the linkages between simple climate models and GCMs. A limitation for climate modelling is often computing power. Knutti showed the differences in computing time for two GCMs and intermediate models. The intermediate complexity models run in the order of minutes to hours, compared to several weeks or months for some GCMs. Knutti has run his intermediate complexity model and has analysed the significance of several assumptions (sensitivity analysis). Key assumptions for sea level rise in stabilisation scenarios turned out to be the ocean mixing rate, climate sensitivity and the stabilization level, while for surface warming ocean mixing matters only for the transient evolution of climate. Knutti also showed the use of intermediate complexity models for probability estimates as they are suitable to run hundreds or thousands of simulations, because of the short running time. The climate impacts community needs emission scenarios to translate these into climate and impacts, and intermediate models can be useful for such impact studies. Knutti presented examples of this type of analysis for the possible future evolution of the thermohaline circulation (THC). Typical (policy relevant) questions that can be addressed based on these analyses are: How dangerous may a THC disruption be for regions? When is the best time to act? Although intermediate models have many benefits, it is important to note that the degree of detail is limited compared to GCMs.

Ferenc Toth, IAEA and **Monirul Mirza**, University of Toronto held a presentation on the use of SRES scenarios for vulnerability, impact and adaptation (VIA) assessments. Climate change scenarios have a role in impact and adaptation analysis to communicate potential consequences, to analyse the implications of policy decisions and to facilitate the formulation of policies. But VIA assessments require socio-economic assumptions as covered in the emission scenarios. Mirza presented several studies that have used SRES scenarios for impact analyses. For many impact assessments, the regional resolution of the SRES report is not sufficient and further downscaling to grid cell level is required. He presented several examples of VIA analysis with SRES and lessons learned from the applications. SRES scenarios have been used for analyses of biophysical, social, and economic damages, but not for assessing adaptation costs. Limitations of SRES include the uncertainties in the downscaling of required land-use, population and GDP data; the omission of population migration that is important for these analyses; and the assumption of uniform regional economic growth rates.

Ferenc Toth, IAEA/Hungary, presented on long-term adaptation versus mitigation costs in the context of avoided damages. This is important because one can then assess the trade-off between mitigation versus adaptation and between mitigation/adaptation efforts and avoided damages. Toth described three methods: Cost Benefit Analysis, Cost Effectiveness Analysis and Safe-Landing/ Tolerable Windows Approach. He explained that the definition of avoided damages as the baseline damage minus the damage with mitigation is too simplistic. In reality it is more complicated as ancillary effects play a role. He showed examples of Global Cost Benefit Analyses from Nordhaus and Tol. The uncertainties and problems are high when dealing with CBA and particularly the discounting assumptions have been a controversial topic. Based on work by Nordhaus he proposed that Cost-Effectiveness Analysis might be a better approach. This is looking for the least-cost strategy to achieve a specific environmental target. The problem is that CEA models do not have impact/damage modules and cannot directly say anything about benefits. Another approach is the Safe Landing/Tolerable Windows Approach that searches for "long-term tolerable conditions" in the climate/impact domains and converts those through backcasting into emissions constraints. Benefits are then defined as the baseline damages minus the damages of the chosen maximum transformation. The Zero Order Draft of the WGII contribution of AR4 includes hardly any studies reporting bottom-up estimates of mitigation benefits and avoided damages. A message of this meeting to the Lead Authors of WGII could be to look carefully and report regional/national benefits mitigation/stabilization scenarios to inform mitigation decisions.

Discussion

The first point made was that there is currently no consensus in the scientific community on the quality of available downscaling (GDP, population) data from SRES scenarios. This is a problem for VIA assessments. Related to that, there seems to be consensus that current climate change impact models may not be ready for much detail.

The discussion continued on climate sensitivity. It was stated that there seems to be consensus now that the range as given by IPCC TAR (1.5- 4.5 C) remains large and recent studies have even widened the range of uncertainty for climate sensitivity. Short term projections are however not so dependent upon climate sensitivity, say out to 2050.

Regarding the trade off between adaptation, mitigation and vulnerability, it was mentioned that mitigation efforts require resources that may lead to higher vulnerability to climate change. It was furthermore mentioned that, for vulnerability assessments, more attention might be needed for physical damages in addition to economic damages (using multiple metrics), although there are some doubts on how multidimensional benefits can be communicated to the policy community.

2.8 Session 6: Simple/intermediate climate models to evaluate climate change for a range of mitigation scenarios.

Chair: Peter Stone, MIT
Speaker: Sarah Raper, CRU/Alfred Wegener Institute for Polar and Marine Research: *Outline of climate change projection chapter in AR4 WGI*

Sarah Raper, CRU/Alfred Wegener Institute for Polar and Marine Research, presented an outline of the projection chapter of the WGI contribution to the AR4 and showed how mitigation and stabilisation scenarios emerging out of AR4 Working Group III might be evaluated in that chapter. The projections chapter for AR4 WG1 will draw on model results from two model inter-comparison exercises. The first inter-comparison is for coupled atmosphere-ocean general circulation models (AOGCMs) and the second is for models of intermediate complexity (EMICs). Some challenges for the interpretation of the modelling results are:
(1) The calculation of forcing for the different species differs between the models; (2) Differences between models result from differences in forcing as well as differences in climate model formulation (a metric for the latter being the climate sensitivity); (3) Gas cycle feedbacks are not generally included - in particular there is temperature feedback on the carbon cycle of uncertain magnitude; (4) Presentation of results to policymakers.

The MAGICC model will be updated based on new insights from AR4. Amongst others, the new features will include the tuning of the climate model to reproduce AOGCM results and a representation of carbon cycle feedback uncertainties. The model will then be run to extend the results over a range of emissions scenarios for inclusion in AR4. The emissions scenarios will include all SRES scenarios with a full compliment of emissions and perhaps some post-SRES scenarios. To address a longer timeframe some stabilization scenarios will be run over several centuries. For the presentation to policymakers, the use of probability distributions may be of help. Raper showed results of a study together with Wigley that assigned probabilities to temperature projections for different time frames. The probabilistic projections were based on PDFs of inputs to the MAGICC model. This required assigning probabilities to the emissions scenarios, which is a subjective choice.

Discussion
Raper indicated that there is time before the AR4 closing deadline to do runs with simple climate models and Working Group III may want to provide stabilization and mitigation scenarios that that are emerging from the WGIII contribution to AR4. The runs that are planned will use historical probability density functions on aerosols and forcing and projections are taken from there onwards.

The discussion continued on the importance of carbon cycle feedbacks in climate models. Most GCM/intermediate complexity models have not yet included this feedback. The Hadley model has more extensive feedback. Other (GCM) models take the concentrations from the TAR simple climate model calculations that do include feedbacks, so they cover feedbacks indirectly. The WGI contribution to AR4 will assess literature on feedbacks to looking at linkages between feedback in the climate and geo-chemical cycles. This will be done more thoroughly than in TAR. All simple models used in TAR had carbon cycle feedbacks, but each model in a different way.

A recommendation was made to include multi-gas scenarios in the WG I assessment and pay more attention to land-use emissions given their uncertainty and magnitude. Regarding the latter it was mentioned that from the AOGCMs who have submitted runs thus far, two of those have included terrestrial biosphere and changes in biosphere/real vegetation. It is not clear whether or not these have climate feedbacks, but they include human changes to vegetation. Resolution is coarse, but albedo and surface roughness are reflected.

2.9 Session 7: Role of probabilistic assessments in emission scenarios

Chair: Michael Schlesinger, University of Illinois
Speakers: Mort Webster, Univ. of North Carolina, *Constructing Probabilistically-Based Emissions Scenarios*
Marty Hoffert, New York University, *The disadvantages of probabilistic emission scenarios*
Richard Tol, Hamburg University., *Scenarios and probabilities*.

Mort Webster, University of North Carolina, in his joint presentation with John Reilly, MIT, presented on the construction of probabilistic emission scenarios. He laid out the following objectives in the design of scenarios assessments: (1) Frame the debate; (2) Provide common assumptions; (3) Reduce the number of cases to study; (4) Span a useful range of uncertainty; and (5) Provide a detailed storyline to enhance communication. Webster stated that there is a debate within the scenario community whether to use probabilistically based scenario designs or to use a deterministic storyline approach. He stated that these two approaches are not necessarily mutually exclusive and proposed that deterministic storyline scenarios can be constructed, using probabilistic uncertainty analysis. He presented a simple example for the construction of scenarios using six basic steps: (1) conduct a sensitivity analysis of parameters; (2) construct probability distributions for key parameters; (3) evaluate uncertainty propagation (Monte Carlo); (4) use distributions of outcomes (emissions) to identify interesting targets; (5) find an appropriate set of parameters that give the target emissions; and (6) choose a small set of scenarios based on combinations of parameter assumptions and their resulting outcomes. He showed an example for steps 1 - 3 using the MIT EPPA model showing the distribution of global CO_2 emissions in 2100. Webster stated that to improve the probabilistic design of scenarios, one should rather focus on the output (radiative forcing) than on the input (emissions), because this would give a better coverage of the relevant ranges. In summary, there is a need for a coherent and rigorous approach to span and communicate the range of uncertainty appropriately. That is why probabilistic approaches have an added value. Probabilistic design approaches are not inconsistent with a deterministic storyline approach to communication.

Marty Hoffert, New York University, presented on the disadvantages of probabilistic approaches. He showed the huge uncertainty in the SRES and other scenarios. He also showed the outcome of a study published in *Science* from Caldeira et al. on the uncertainty in climate sensitivity. His main point was that it is better to approach the problem from the other end: how can we provide all that energy without CO_2 emissions to meet different climate objectives, given different assumptions about climate sensitivities? Hoffert stated that without assumptions on significant new sources of carbon free fuels, low emissions scenarios cannot occur in the future. The bottom line would be that we will need 10TW emissions-free energy by 2050 according to a (IS92e) BAU scenario and 8TW additional emissions-free energy to reach 500 ppm from IS92e BAU. Therefore, much more bottom-up technological information is needed in the scenarios

Richard Tol, Hamburg University, gave a presentation on the likelihood of the SRES scenarios. He reminded that the SRES scenarios were built using models that were originally designed for the analysis of energy policies. He stated that detailed knowledge of the energy system is not enough for scenario building. He furthermore stated that the models used are calibrated with short-term data-sets – validation over longer time spans was never a priority. To assess the likelihood of SRES scenarios he used a simple Kaya Identity method. He took long-term data for 16 regions on population (1500 – 2000), GDP (1500 – 2000), energy (1960 – 2000) and carbon (1850 – 2000). These data were plotted and the mean and the standard deviation of the growth rates were computed. He then computed the likelihood of the SRES projections assuming a Gaussian distribution. Based on this analysis using historical growth rates he concluded that: (1) The SRES scenarios are not equally likely; A2 is by far the most probable; (2) The SRES scenarios do not span the range of not implausible futures; emissions may be higher as well as lower; (3) The SRES scenarios do not correspond well with past trends, in the long run but also in the short run; (4) All this is less pronounced for emissions (cancelling errors), but more pronounced for development; and (5) It matters less for climate change, but more for impacts and mitigation

Discussion

The discussion focused on the use of probabilistic scenarios and some methodological issues. The data but also the methods used by Tol were seriously criticised amongst others because they are based on the assumption that historic conditions do apply in the future. Tol did explain that he is aware of the simplicity of his method and admitted that the method is not mature enough to evaluate the SRES probability.

There was a request for more clarification on the complementary of the storyline and the probabilistic approach suggested by Webster. It was explained that after selecting a storyline, probabilistic approaches can help inform the quantification of that storyline by taking information from probabilistic analysis to provide parameter values. However, storylines, that still are the main way to address emissions scenarios contain certainly more elements than scenarios themselves, and contain information than cannot necessarily be modelled. Probability assessment across storylines might not be correct. However, this issue requires further discussion.

An important other aspect discussed was policy intervention in scenarios. In theory it is preferred to have a distinction between policy intervention and baseline assumption. This is difficult to establish and even more for future analysis. In probabilistic approaches this means that policy choices should also be described in terms of probability but that is very difficult.

2.10 Session 8: What gaps in knowledge in stabilization /emission scenarios can be addressed in new publications, accepted before finalising AR4?

Chair: Francisco de la Chesnaye, US EPA

Speakers: Michael Grubb (Imperial College/Cambridge University), Ottmar Edenhofer (PIK), Claudia Kemfert (German Institute for Economic Research), *Technological change and the Innovation Modeling Comparison Project (IMCP)*

Keywan Riahi (IIASA), *Present and expected research activities (EMF-21) and gaps in knowledge in stabilization/emission scenarios*

Michael Grubb, Cambridge University/Imperial College, **Claudia Kemfert**, German Institute for Economic Research, and Ottmar Edenhofer , Postdam Institute on Climate Impact Research, presented on the Innovation Modelling Comparison Project (IMCP) that focuses on improving the modelling of technological change. Michael Grubb gave a short overview on technological change. He stated that technology is central to address long-term climate change. But the economics literature on technology reflects a long-standing divergence of views on the main driver of technology change: 1) Supply / technology push, vs 2) Demand / market pull ('induced'). In reality, to get from idea to market requires investment across a long and risky chain of innovation with a mix of 'push and pull' forces. Grubb introduced the Innovation Modelling Comparison Project (IMCP) that aims to explore different innovation modelling approaches and its implications for reaching different stabilisation levels, with particular reference to: investment trajectories; mix of policy instruments; international technology spill-overs; and, implications of uncertainty. This project is still in its early stages. **Claudia Kemfert** then presented the common reporting scheme and overview of participating models. The models were classified according to the type of technological change that is included; "learning-by-doing'; 'learning-by-searching'; R&D investments; 'path dependent investments'; 'externalities from capital accumulations' and 'vintage capital'. She showed some preliminary results. The scientific challenges for the project are to improve the model comparability; the incorporation of aspects of technological change like vintages and externalities induced by physical and human capital accumulation; analysing implicit assumptions about technological change; analysing the empirical relevance of different aspects of technological change; calibration and empirical validation of the models; assessing capability of policy instruments to affect the dynamics and direction of technological change.

Keywan Riahi, IIASA, gave a presentation on current (Multi-gas Study - EMF-21) and future research activities under the Stanford Energy Modeling Forum and gaps in knowledge in stabilization/emission scenarios. He started with a brief assessment of SRES by comparing SRES projections with other recent short and long-term projections (to be published by Van Vuuren & O'Neill, forthcoming).

For the *short term projections* he concluded that the SRES scenario ranges are broadly consistent with current near-term projections for most of the scenario indicators, both globally and for individual regions. The most important changes between current insights and SRES are: (1) the upper bound estimates for population & GDP projections, which have shifted downwards since SRES (2) F-gases, where new inventories for the year 2000 are significantly lower compared to SRES, and (3) sulphur emissions, where recent sulphur control legislation in some parts of the world has lead to revisions of projections of emissions (peak earlier and at lower levels) as compared to the estimates in SRES.

For the *long-term projections* he concluded that the SRES scenarios are still consistent with ranges from the recent scenario literature. Also here the most significant difference concerns population projections, which have shifted downwards. Moreover, some recent very high energy demand scenarios extend the SRES range on the upper side. He showed some examples of forthcoming research, which extend the SRES scenarios by new emissions sources and their spatial coverage. He highlighted two main extensions. First, an increasing body of literature (Streets, et al., Smith et al., Rao & Riahi, etc.) analysing the future prospects of black and organic carbon emissions consistent with the SRES scenario families. Riahi pointed out that the development of future emissions scenarios for these substances is necessary as they are contributing to radiative forcing with significant (though uncertain) climate effects. Second, he showed new national & spatially explicit projections of drivers for economic and demographic change based on improved methodology (RIVM, IIASA). He highlighted the importance of this downscaling information for impact, adaptation and vulnerability assessments based on SRES.

Addressing the recent critique on the SRES scenarios concerning their economic convergence assumptions, Riahi showed a sensitivity analysis for SRES scenarios looking into the implications for GHG emissions at slow rates of income convergence. He summarized that, in general, less economic convergence leads to higher emissions. As the main reasons for this he listed slower factor productivity growth, slower capital turn-over rates as well as lower levels of adoption of advanced and cleaner technologies in developing countries. He also highlighted that stabilization scenarios require global application of climate policies and convergence in adoption of low emissions technologies. As a result the consistency of low economic convergence scenarios with climate stabilization scenarios might be questionable. Moreover, he presented a comparison of economic convergence assumptions in SRES with regional evidence on income convergence for selected OECD regions. He concluded that the SRES scenarios are in general consistent with empirical data, and that those SRES scenarios, where globalization is a main element of the storyline (A1 & B1), depict extreme cases of convergence representative for the upper bound of the uncertainty range for convergence assumptions.

Riahi also presented some recent results from work done since the TAR within EMF-21. An important difference with TAR is that new stabilization scenarios also include the basket of non-CO_2 GHGs. Multigas mitigation adds flexibility to reduce emissions from other sources than CO_2, hence multigas stabilization is significantly cheaper than CO_2-only.

He ended his presentation by giving his view on knowledge gaps in integrated assessment modelling at this moment, including: (1) Non-cooperative behaviour; (2) Uncertainty; (3) Endogenous technological change (including option values of innovations); (4) Climate feedbacks); (5) Location-specific vs. regional & global mitigation/adaptation; and (6) How to construct emissions scenarios with PPP-parameterization

Discussion

It was clarified that the deadline for new literature to be included in the WGIII contribution to AR4 is “accepted for publication” before July 2006 (i.e. when the Second Order Draft goes out for review). The rationale is that reviewers need to be able to trace underlying sources and read it for themselves. The results of EMF-21 will be published on time for the AR4. For EMF-22 this is uncertain. There is some work ongoing on land use, which should be ready in some form for AR4. Other work in progress is on stabilization scenarios, but it is uncertain if that is ready on time.

Some discussion emerged on the issue of the impacts of slow convergence scenarios. Riahi had shown historical convergence data at country level within three OECD regions; US, Japan, Europe, and compared these with SRES world regions convergence under these conditions. It then is essential what has been assumed within the respective regions about factors like currency and movement of labour. Regarding convergence, it was explained that the main reason why less convergence leads to higher emissions is that the reductions in carbon intensity will also be slower. Convergence is not an absolute prerequisite for stabilization, but in very poor regions it would probably be very difficult to get agreement on shared global climate targets without convergence.

It was observed that for the IMCP it is important to be transparent on what is included in the models on methods for the modelling of endogenous technological change and on for instance carbon cycle feedbacks. Also when comparing the models it is considered important to acknowledge that there are differences between the models.

2.11 Session 9: Role of technology development in long-term mitigation and stabilization scenarios.

Chair: Mikiko Kainuma, NIES

Speakers: Sjak Smulders, Tilburg University, *Modelling endogenous technological change; a reflection for emission scenario builders*
Jae Edmonds, PNL: *Technology and climate stabilization*
P.R. Shukla, Indian Institute of Management: *The role of endogenous technology development in long-term mitigation and stabilization scenarios, a Developing Country perspective*
Ernst Worrel, LBL, *The use and development of bottom up technological scenarios*

Sjak Smulders, Tilburg University, presented an econometric approach to model endogenous technological change. He showed what lessons can be learned from simple models. He gave a brief overview of economic models: partial equilibrium; general equilibrium models; growth models. The characteristics of an ideal model are: (1) general equilibrium; (2) inclusion of technological learning versus push by research and development; (3) inclusion of technology diffusion and innovation; (4) inclusion of different directions of technological change like reductions in unit abatement cost, production cost, emission intensity; (5) coverage of integrated and end-of-pipe technologies; (6) should have general production functions. Based on his discussion he concluded that (1) modelling R&D realistically requires inclusion of market power, which implies that there are distorted incentives for innovation; (2) when opportunity costs of R&D and learning expenditures are properly included in the models, the introduction of induced technological change most likely leads to an *increase* in the cost of a climate policy, rather than a decrease that many models are showing.

Jae Edmonds and Leon Clarke, Pacific Northwest National Laboratory, began by noting that technological change is central to the issue of dealing with climate change and plays a crucial role in simultaneously achieving environmental goals and controlling costs. As a consequence, the ways by which technologies change and improve have generated renewed interest and have implications for near-term decision-making, including for example, emissions mitigation, RD&D investments and policies, and the cost of achieving environmental goals. The problem is that the pathways by which technology is created, developed and deployed are varied and poorly understood. There is a rich literature whose roots predate general interest in anthropogenic climate change, which has explored the sources of technological change. While this literature has failed to produce a simple deterministic representation for technological change, it has produced a variety of useful insights. It has demonstrated that induced environmental innovation is a reality, but it has also shown that technology advances in part as a function of activities originating outside of the sector ("spillovers"), which are largely unresponsive to climate policies. Further, it has demonstrated the existence of both R&D-based advance and experience-based advance (e.g., learning-by-doing). The relative importance and precise nature of each of these factors is not well understood. GHG emissions models incorporate technology and technological change either explicitly or implicitly. The present generation of models treats technological change simplistically, often neglecting important sources of advance. Therefore, their associated analysis is subject to misspecification errors. Any simple deterministic model of technological change will likely lead to incomplete or erroneous implications at some point. The goal in modelling the influence of technological change on emissions and abatement costs should be to develop representations of technological change that build on a broader framework.

P.R. Shukla, Indian Institute of Management, presented on the role of endogenous technology development in long-term mitigation and stabilization scenarios from the perspective of a developing country. He stated that it is important to recall that growth models assume: perfect markets; perfect property rights; and enforceable contracts. Whereas real world development can only be understood when considering: dual economy; multiple transitions; informal activities; subsistence production; poor market performance; disequilibrium conditions; non-commercial fuels; non-economic concerns; and, policy distortions. This means there is a big gap between current models and realities in developing countries. The drivers for technological change in developing countries are 1) the international labour market: the wage differentials, income gaps and migration; 2) human capital; 3) knowledge flows, including shifting comparative advantage in knowledge services and the role of local and contextual knowledge; 4) governance, risks and investment flows. To include technological change for developing regions in models, the representation of the economy should include development processes and scenarios should cover at least the international labour market, human capital and local and contextual knowledge. Furthermore he suggested aligning development (endogenous change) and climate (induced change) policies.

Ernst Worrell, LBL/Ecofys, presented on the use and development of bottom-up technological scenarios. He mentioned that policymakers rely on models to evaluate, ex-ante, the potential effects of certain developments and policy-choices. Current IAMs lack a disaggregated representation of activity, end use, and technology. However, mitigation activities—and policies—depend on specific attributes of sectors, regions, and end-use technologies. Important for the WGIII contribution to the AR4 is that the chapters 4 -10 have to assess sectoral mitigation potentials. Therefore they need consistent baselines with sufficient detail on for instance, emissions, technology and efficiency, type of activities, energy end-use, assumed energy prices, etc. SRES scenarios have limited disaggregation information on these aspects. For AR4 disaggregated scenarios are therefore needed, either from bottom-up data in models or by disaggregating top-down scenarios. He showed an example for China where a B2 scenario has been disaggregated. He also discussed several models that use various forms of bottom-up representation of end-use and technology, e.g. AMIGA (Argonne National Laboratory) and the World Energy Model (International Energy Agency). Generally these models cover medium term time ranges (until 2030), and include detailed representation of activity and efficiency levels on a regional basis. Unfortunately, end-use data are difficult to collect, evaluate and assemble. Many sources cover certain regions or sectors in detail, and some groups have made significant progress in assembling comprehensive global databases, but a consistent, well-documented database that covers all regions and all sectors is lacking. LBL started an initiative on a shared resource: the Global Energy Demand (GED) Database. This will be a collaboratively designed and created resource, for the use of all contributors. Each sector in each region will be built up from detailed data on energy consumption, technology, and drivers. Participating modelling groups and data availability will determine GED Database content. Users will be free to determine applications.

Discussion

The feeling, expressed by several participants after the presentations, was that the area of endogenous technological change is very complex and not yet well understood. There is a gap between the theoretical models and the empirical data. There seemed consensus on the need for bottom-up technology information in emission scenarios. There is a need for more empirical research, the more detail the better, and only then theoretical models can be validated. It was mentioned that many models handle the amount of technological change in an aggregated way, while it would be important to distinguish among volume and distribution of technological changes. It was also observed that all economies are far away from their efficiency frontier; getting closer would require innovation. This would not only be technological but also institutional innovation.

2.12 Session 10: Analysis of multi-gas mitigation and stabilization scenarios, and related issues of gas weighting procedures.

Chair: Henry Jacoby, MIT
Speakers: Detlef van Vuuren, RIVM, *Multi-gas stabilization scenarios*
Kejun Jiang, Energy Research Institute, *Multi-Gas mitigation analysis by IPAC*
Rich Richels, EPRI, *Developing stabilization targets*

Detlef van Vuuren, RIVM, presented a comparison of multigas and CO_2-only mitigation strategies based on work that was done as part of the Energy Modelling Forum (EMF-21). He explained that there has been a change in focus in the research community since the TAR towards multi-gas scenarios. In 2000, non-CO_2 gases represent about 25% of the emissions – a first indication that considering these gasses in mitigation strategies might be important. In that context, for EMF-21, the aim was to conduct a comprehensive, multi-gas policy assessment to improve the understanding of the effects of including non-CO_2 GHGs (NCGGs) and sinks (terrestrial sequestration) into short- and long-term mitigation policies. A large number of modelling groups and technology experts participated in the study, including 21 climate, economic and integrated assessment models and various U.S. and European non-CO_2 experts. Including non-CO_2 gasses into models immediately leads to three fundamental questions: (1) What are relevant targets for (multigas) scenarios (temperature, radiative forcing, concentrations)? (2) On what basis does one substitute among different gasses (GWP, cost-optimisation)?); and (3) How does one incorporate the information on non-CO_2 abatement options in assumptions on technology development beyond 2020? Another question emerging from the EMF exercise is whether the potential for NCGG reduction should be restricted to 10-20% (as is currently assumed) or is it (at high carbon costs) possible to reduce much higher percentages of NCGG emissions? In the study, the models have handled these questions differently.

The EMF-21 results give some tentative answers to these questions. The first results showed the role of CO_2, CH_4, N_2O and Fluorinated-gas emissions in the baseline: the share of non-CO_2 emissions over time went from about 25% in 2000 to about 17 % in 2100. Stabilising radiative forcing at 4.5 W/m^2 (the target chosen for this comparison) in all cases required a substantial emission reduction (on average about 70% across the models compared to 2000). In a multi-gas approach CH_4 is reduced (on average) by 50%, N_2O by 25% and the F-gasses by 50-75%. As a result, the required reduction of CO_2 is reduced to 60%. (compared to 75% in a CO_2 only approach). The timing of CH_4 reduction strongly depends on the optimisation method (GWP based or otherwise). Models without GWP optimisation (cost-optimisation on the basis of the long-term target) tend to reduce CH_4 only at the end of the century. Models using GWP optimisation tend to reduce CH_4 early, directly benefiting from their lower reduction costs. On average, the marginal abatement costs decrease about 30-50% (in most models) when using a multi-gas strategy compared to a CO_2 only approach, with the strongest impact early in the period. For stringent targets most reductions still need to come from reducing CO_2 emissions.

Kejun Jiang, Energy Research Institute, presented on multi-gas scenarios for China and the world. Jiang used the IPAC- Emissions model which is a global partial equilibrium model that covers 9 regions and 3 economic sectors: industry, building and transport. It includes about 40 technologies and 9 gases and is run for the time-frame to 2100. He used a reference baseline scenario, based on IPCC SRES B2, a CO_2 mitigation scenario, and a multi-gas mitigation scenario. He showed graphs for the different gases for the three scenarios.. He showed that the carbon tax per abated ton C is about 40% lower for the multi-gas scenario in 2100. The global GDP loss in 2100 was estimated at about 2.4 % for the CO_2 only and about 1.7% for the multi-gas strategy. For China the GDP loss in 2100 decreased from 4.5% to 3.5% if moving to a multi-gas approach.

Richard Richels, EPRI, noted that initial studies on the costs of stabilization focused on atmospheric CO_2 concentrations primarily from the combustion of fossil fuels. More recently, the analyses have been expanded to include non-CO_2 greenhouse gases and terrestrial sequestration. The addition of other trace gases has highlighted problems associated with the use of Global Warming Potentials (GWPs) and has led to the exploration of alternative approaches for making tradeoffs among gases. Most recently, the discussion has been expanded to include what constitutes an appropriate stabilization metric (e.g., concentrations, radiative forcing, temperature change, or impacts). Since the TAR, there have been a number of efforts to incorporate multiple greenhouse gases into stabilization analyses. These studies suggest that total abatement costs are reduced (in some cases substantially) when multiple greenhouse gases are included in the abatement strategy. Although the focus of these studies was primarily on limiting radiative forcing, the models also showed the concentration levels associated with each gas in order to meet a particular target.

Discussion

There was a discussion on what would be the most appropriate metric to use for the multi-gas scenarios: equivalent-CO_2 concentrations, radiative forcing, or temperature. There was a discussion on the most appropriate metrics to be used in multi-gas scenarios, and rlate dto this, in real world climate policies. This relates to the metrics used to define the end-points of climate policies, where alternatives are (stabilisation of) temperature, raditaive forcing, or possible emissions. Implication of using temperature (or climate impacts) is that one has to deal with uncertainties (in particular climate sensitivity).

A second discussion on metrics relates to the basis of substitute among gases, which can be done by using GWP or by cost optimisations with a particular model. It was recognized that although GWPs have been used in various analyses, policy formulations, and are explicitly used under various requirements of the UNFCCC and the Kyoto Protocol, the concept has been criticized in the literature and this critique was not included in the TAR. A few participants strongly recommended that the AR4 should include an assessment of the critiques of the GWPs. There was a discussion as to how the GWP issues will be addressed in the different AR4 Working Groups. WG1 will assess GWPs and will provide new values based on the literature. At the same time, WG1 does not have the expertise to deal with critiques that are outside the area of climate science. The critiques of GWPs for use in economic and policy analysis do fall to WG3 where they will be taken up. A point was made that there may need to be more than a single approach and that some alternatives may be plausible for the short-run. Two specific points were made in this context: (1) the use of GWP or cost optimisation for methane, which is highly relevant for WG3 due to the implications for mitigation scenarios and costs; (2) the importance of evaluating the significance of black carbon.

3. Overall conclusions and key messages for the writing team

In the final session of the meeting, the CLAs of Chapter 3, Brian Fisher and Nebojsa Nakicenovic, presented what they considered the main findings of the meeting. This section on the overall conclusions and main findings for the AR4 writing teams includes their presentations and the discussion that followed.

The main lessons learned were divided in five themes: (1) Post-SRES scenarios; (2) the modelling of economic growth and the treatment of PPP and MER in models; (3) the treatment of uncertainty; (4) the role of technology on emission scenarios; (5) beyond post-SRES scenarios and what would be interesting research questions.

1. The comparison of post-SRES scenario literature with the SRES range provided the following insights:
   - In general, the ranges are not very different; SRES seems to cover the range rather well and a comparison can be made and explained in AR4.
   - The estimated emissions (CO_2) of the post-SRES scenarios have a similar lower limit and median but a higher top end of the distribution.
   - The Post-SRES scenarios differ on population assumptions. They have lower population estimates, both in range and median.
   - There are only few scenario quantifications that used a proper PPP calibration.
   - The post-SRES economic development projections (MER based) have the same lower limit and median but a lower high end of the distribution

2. The analyses and discussion on economic growth and the use of PPP and MER in models provided the following insights:
   - A distinction needs to be made between full MER, full PPP, and Superlative PPP ("hybrid") approaches; the hybrid approach, if properly handled, seems preferable.
   - The use of PPP seems important for cross-sectional income comparisons between countries, especially when there are large income differences.
   - Convergence assumptions do affect PPP vs MER relationships which would be expected to change over time (there has been too much focus on base year exchange rates in the recent discourse on whether PPP or MER is a "better" metric for measuring GDP).
   - PPP data are sparse (Nordhaus indicated by at least two order of magnitude) and thus do not include all relevant information required for calibrating integrated assessment models (especially the bottom-up approaches).
   - When discussing the distinction between PPP and the MER approach in the IPCC context, the focus of the discussion should be on its impact for emissions.
   - It is unclear whether the use of PPP vs MER in post-SRES scenarios would influence the results for the economic growth analysis. New models and new calibrations would be required for this analysis and would be desirable although the practical difficulties should not be underestimated.
   - There is no indication at this moment that the use of PPP or MER significantly changes the results for the aggregated emissions because of the offsetting adjustments made by most modellers in the assumptions regarding changes in energy intensity and GHG intensity over time. There was uncertainty whether the recently published studies that show lower emissions when PPP is used have recalibrated their models correctly.
   - The use of PPP vs MER may have more significant impact on the assessment of mitigation and adaptation costs.

- Regarding convergence it is important to consider not only the degree of convergence (in incomes) but it is also necessary to spell out policies required to sustain required high labour productivity rates.

3. Regarding the treatment of uncertainty and communication to policy makers, the following lessons seem important:
   - There are large base-year ambiguities and uncertainties that should be included in the AR4.
   - It is important to span the ranges of drivers and possible emissions outcomes (different modelling approaches).
   - Explicit consideration of dependencies (covariance) is essential in probabilistic approaches.
   - To build the treatment of uncertainties into emission scenarios, it is important to explore how to achieve complementarity of probabilistic and "storyline" approaches.
   - It is not clear how to assess the role of (climate) policies in probabilistic ensembles.
   - A method has been proposed for characterizing probabilistic ensembles in scenario comparisons (by medians and percentiles).
   - Assessment of subjective likelihood of scenarios is one possible method for assigning probabilities to scenarios sets, but this remains controversial and not generally accepted; so for the time being scenario ranges remain the main way to characterize uncertainties.
   - Initial comparison of Post-SRES literature with SRES uncertainty ranges indicates that they are still broadly representative but that there are some significant changes, such as in the underlying population projections.
   - The concept of "non-intervention" (reference) scenarios seems increasingly ambiguous because of implemented climate polices. It is therefore important to be clear and transparent on what is the baseline scenario when there are emerging climate policies. Considering also scenarios "with" climate policies is essential to cover the full range of emission scenarios.
   - IPCC should put effort in communicating better to policy makers what are uncertainties; especially for long-term scenarios. There is an increasing uncertainty the further emission scenarios go out in time; clear language and transparency is therefore important.
   - It should be accepted that there will always be intrinsic uncertainties when doing long-term analysis; attention should also be paid to scenarios on the short-term mitigation policy options and how these can be linked to longer-term analysis.
   - Chapter 3 of WGIII contribution to the AR4 should discuss how different metrics for multi-gas approaches influence the choices made in stabilization strategies.

4. Regarding the role of technology in emission and mitigation scenarios that the following conclusions can be drawn:
   - For characterising technological change in emission and mitigation scenarios both research, development, deployment, diffusion and transfer are important
   - Technological change is fundamental for (reducing) stabilization (costs).
   - The modelling of technological change is extremely complex (not limited to technology as such but encompasses the boarder social framing)
   - There is a gap between theoretical models and empirical data.
   - There is a strong need for scenarios with more disaggregated (technology) data, especially for AR4.
   - It should be studied what has been published in the literature on radical mitigation options in case very low level stabilization would be needed.

5. Beyond Post-SRES scenarios; new interesting research topics include:
   - The impact of aging, household structure, fertility, migration, pandemics (HIV/AIDS) on emissions scenarios.
   - The use of other scales might be helpful, for instance urban/rural, location-specific, sector-specific scales, (downscaling and bottom-up).
   - Interesting regions to focus on are regions that matter most for emissions (e.g. Asia).
   - Development paths and sustainability transitions; aligning of climate and development goals.
   - New types for scenarios may be interesting like: Divergence of incomes ("poor stay poor"), disaster scenarios ("fortress world"), "surprises".
   - Multi-gas issues – improve modelling of aerosols and air pollution precursors (organic and black carbon).
   - To run SRES and Post-SRES (multi-gas stabilization) sets with new simple climate models (updated MAGICC) for inclusion in AR4; it is important to get insight in expanding the range that SRES covers, especially regarding extremes.
   - The needs of the scenario user's community need to be addressed. In particular, the impacts and adaptation scientific community needs regional level socio-economic data that are coherent with the emission scenarios considered (including stabilisation scenarios).
   - In both SRES and post-SRES scenarios, emissions from land-use received little attention relative to their historic and projected future role. This issue could not be fully covered at the meting because of lack of expertise. In AR4 it is important to pay more attention to land-use emissions given their uncertainty and magnitude

Annex I: Programme

IPCC Expert Meeting on Emission Scenarios 12 – 14 January

Day 1: Wednesday, January 12

9:00 am		**Plenary room**
9:15 am	**Official opening:** • Jeffrey R. Holmstead, Assistant Administrator for Air and Radiation, Environmental Protection Agency (EPA) • Bert Metz, IPCC, co-chair Working Group III, *Background and objectives*.	
10:00 am	**Session 1: Emissions scenarios** • Brian Fisher, ABARE and Nebojsa Nakicenovic, IIASA/Vienna University of technology Discussion	
11:00 am	**Break**	**Coffee Corner**
11:30 am	**Session 2: Keynote Speaker:** • Bill Nordhaus, Yale, *Should Modelers Use of Purchasing Power Parity or Market Exchange Rates in Global Modeling Systems?* Discussion	
12:30 pm	**Lunch**	**Restaurant**[1]
1:30 pm	**Session 3: Development pathways, trends and goals in relation to scenarios. What is the role of socio-economic driving forces in scenario development?** Session Chair: Emilio La Rovere, Fed. Univ. of Rio de Janeiro • Brian O'Neill, IIASA, *Role of demographics in emission scenario* • Joaquim Oliveira Martins, OECD, *Long-term Economic Growth Projections: could they be made less arbitrary?* • Jeffrey Sachs, Columbia University, *Scenarios and Development pathways* Discussion	
3:45 pm	**Break**	**Coffee Corner**
4:15 pm	**Session 4: How to treat different economic approaches in the AR4?** Session Chair: Ken Ruffing, OECD • John Weyant, Stanford University, *PPP vs MER in EMF implications for climate scenario development* • Hans Timmer, Worldbank, *Impact of using different economic approaches from a developing country prospective* Discussion	

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[1] As we only have one hour for lunch each day, we have arranged seating in the restaurant for our group. There is a daily lunch buffet for $10.95 plus tax. Please plan to join us each day.

6:00 – 6:45 pm	**Conclusions and discussion from day 1: assessment of SRES** Chair: Bert Metz • Panel with chairs of sessions
8 – 10 pm	Meeting of the program committee on the scoping of the second meeting on emission scenarios (Laxenburg)

Day 2: Thursday, January 13

8:30 am	**Session 5: Climate and impact scenarios: Evaluating climate impacts and analyzing adaptation options.** Session Chair: Tom Kram, RIVM • Reto Knutti, UCAR, *Evaluating climate impacts with intermediate models* • Monirul Mirza, University of Toronto, *The Use of SRES for Vulnerability, Impacts and Adaptation Assessments* • Ferenc Toth, IAEA *Climate change mitigation: Costs and avoided damages* Discussion
10:30 am	**Break** **Coffee Corner**
11:00 am	**Session 6: Simple/intermediate climate models to evaluate climate change for a range of mitigation scenarios.** Chair Peter Stone, MIT • Sarah Raper, CRU/Alfred Wegener Institute for Polar and Marine Research: *Outline projection chapter in AR4 WGI* Discussion
12:30 pm	**Lunch** **Restaurant**
1:30 pm	**Session 7: Role of probabilistic assessments in emission scenarios** Session Chair: Michael Schlesinger, University of Illinois • Mort Webster, Univ. of North Carolina, *Constructing Probabilistically-Based Emissions Scenarios* • Marty Hoffert, New York University, *The disadvantages of probabilistic emission scenarios* • Richard Tol: Elsevier Science Ltd., *Scenarios and probabilities*. Discussion
3:30 pm	**Break** **Coffee Corner**

4.00 pm	**Session 8: What gaps in knowledge in stabilization /emission scenarios can be addressed accepted for publication before September 2006** Chair: Francisco de la Chesnaye, US EPA • Michael Grubb (Imperial College/Cambridge University), Ottmar Edenhofer (PIK), Claudia Kemfert (German Institute for Economic Research), *Technological change and the Innovation Modeling Comparison Project (IMCP)* • Keywan Riahi (IIASA), *Present and expected research activities (EMF-21) and gaps in knowledge in stabilization/emission scenarios* Discussion
6:00 pm	**Day 2 Closure**
6:30-8:00 pm	**Reception**

Day 3: Friday, January 14

8:30 am	**Session 9: Role of technology development in long-term mitigation and stabilization scenarios.** Session Chair: Mikiko Kainuma, NIES • Sjak Smulders, Tilburg University, *Modeling endogenous technological change; a reflection for emission scenario builders* • Jae Edmonds, PNL: *Technology and climate stabilization* • Shukla, Indian Institute of Management: *The role of endogenous technology development in long-term mitigation and stabilization scenarios, a Developing Country perspective* • Ernst Worrel, LBL, *The use and development of bottom up technological scenarios* Discussion	
10:45 am	**Coffee break**	**Coffee corner**
11:15 am	**Session 10: Analysis of multi-gas mitigation and stabilization scenarios, and related issues of gas weighting procedures.** Session Chair: Henry Jacoby, MIT • Detlef van Vuuren, RIVM, *Multi-gas stabilization scenarios,* • Kejun Jiang, Energy Research Institute, *Multi-Gas mitigation analysis by IPAC* • Rich Richels, EPRI, *Developing stabilization targets* Discussion	
1:15 pm	**Lunch**	**Restaurant**
2:15 pm	**Session 11: Wrap up: Key messages to writing teams of WG III** • Brian Fisher and Nebojsa Nakicenovic	
3.45 - 4 pm	**Concluding words**	

Annex II: Extended abstracts of presentations

Should Modelers Use of Purchasing Power Parity or Market Exchange Rates in Global Modeling Systems?

William Nordhaus
Yale University

1. Introduction

Most global energy-economic-environment models constructed over the last three decades have relied on market exchange rates (MER) to put countries in a common currency for estimation and calibration. This approach has been the subject of considerable discussion in recent years, and the alternative of purchasing power parity (PPP) exchange rates has been proposed. The present analysis reviews the issues and describes a reconciliation of the debate.

The plan of this report is the following. After an overview and summary of the findings, the first and longest section reviews current practice in constructing international accounts, with particular attention to construction of PPP accounts. The second section reviews the relative merits of different systems for measures of real income and output. The third section discusses the quality of the data in different systems. The fourth analyzes the relative merits of different price measures in model construction, after which issues of convergence are addressed. The fifth then surveys the principle arguments regarding different accounting approaches to constructing global models.

There are four different approaches to constructing comparative national accounts, as shown in Figure 1. This matrix shows a two by two combination of the exchange rate convention and the disaggregated price convention. Here, there are two possible approaches to converting incomes of different countries: purchasing power parity exchange rates (PPP) and market exchange rates (MER). Similarly, there are two different sets of relative prices: actual market prices (AMP) and International Prices (IP). From this table, we see three potential accounting systems:

MER accounts. The usual approach, shown in the upper left, uses actual market prices and market exchange rates.

Full PPP accounts. Alternatively, we might use both PPP exchange rates and International Prices, as shown in the lower right entry.

Hybrid PPP accounts. A third appropriate, shown in the upper right, uses PPP exchange rates to calculate the aggregate outputs of different countries, but combines these with prices and real growth rates of aggregates and sub-aggregates measured using national prices and weights.

As I will be suggested below, the third alternative is both analytically most satisfactory and empirically practical. The basic reason for this conclusion is simple: Estimates of output or income at MER are simply wrong – they are constructed on an economically incorrect basis. The hybrid technique provides estimates that are consistent both across space and across time.

2. Major conclusions

Conclusion on PPP theory and practice: Purchasing power parity (PPP) accounts are designed to provide accurate estimates of "real" incomes, outputs, and expenditures in countries with widely varying price structures. Current practice in construction of PPP accounts is to use multilateral indexes that estimate the cost in a benchmark year of purchasing a nation's quantity bundle in other countries or at International Prices. In most PPP accounting systems, these estimates for benchmark years are extrapolated to non-benchmark years using growth rates from national accounts using national prices and quantities. Under ideal circumstances, the hybrid technique, using PPP incomes for estimating cross sections and national prices and weights for calculating growth rates, will provide accurate and consistent cross sections and time series of real income and output.

Conclusion on PPP and MER accuracy: Current measures of relative outputs and incomes using market exchange rates (MER) provide inaccurate estimates of relative incomes and outputs. Moreover, the errors using MER in today's world are large – underestimating incomes in low-income countries by a factor of around three relative to high-income countries. Different techniques for measuring real incomes and outputs using PPP valuations give different estimates, but they all indicate that MER valuations are highly misleading. While we might be reluctant to employ PPP estimates, in this area it is better to be imprecisely right than precisely wrong.

Conclusion on data quality: PPP accounts today are conceptually unsettled and empirically imprecise relative to construction of national income and product accounts and national price indexes. PPP accounts are limited to expenditures in a sample of countries. There are no comprehensive PPP production accounts. Moreover, the databases used for constructing PPP accounts are perhaps two orders of magnitude more sparse than that of national economic accounts and price indexes.

Conclusion on prices for model construction: For purposes of constructing detailed global models of energy-economy-environment, substituting International Prices or individual-commodity PPP valuations for actual local or national prices is not recommended. A major problem with this approach is that local and national behavior is conditioned by actual prices, not by some artificial set of uniform International Prices. A particularly important example is the response of different countries to nationally different global warming policies; using International Prices would defeat attempts to measure differential national responses to policies (such as participation or non-participation in the Kyoto Protocol).

Conclusion on calculating convergence: When calculating convergence among different countries, we should rely on the hybrid technique described here. That is, convergence should use true (PPP) measures of output differentials and growth rates at national prices. These will provide accurate estimates of the growth factor required for countries to attain the same output and price structure. In making these projections, it would be best to use consistent index calculations and data for the cross sections and time series.

Conclusion on aggregate models: In light of current data and conceptual limitations, the best approach for constructing global energy-economic-environment models would be a hybrid set of accounts that (a) uses cross-sectional PPP measures for relative incomes and outputs and (b) relies on national accounts price and quantity indexes for time-series extrapolations. Under ideal circumstances, this approach will provide accurate and consistent cross sections and time series. In moving to PPP cross-sectional valuations, modelers will need to consider whether behavioral and reduced-form relationships in the models have been correctly estimated. However, data willing, the hybrid approach will provide more accurate income and output estimates, will ensure that relative incomes and outputs better correspond to realistic magnitudes, and can ensure that welfare comparisons among regions are more accurate.

The role of demographics in emissions scenarios

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International Institute for Applied Systems Analysis (IIASA), Austria &
Watson Institute for International Studies, Brown University, USA

1. Introduction

Demographic factors are potentially important determinants of energy use, land use, and greenhouse gas emissions. I focus on two key issues: (1) how the outlook for global demographic change has evolved toward smaller, older populations relative to projections used in the *Special Report on Emission Scenarios* (SRES; Nakicenovic, 2000); and (2) how demographic factors beyond population size, such as changes in age structure, urbanization, and living arrangements, might be better accounted for in modelling of future energy use and emissions.

2. Changing demographic outlook

Development of the SRES scenarios took place between 1996 and 1999, and sufficient time has now passed to make it worth examining the consistency of these scenarios with more recent population data and projections. The SRES emissions scenarios used three population projections produced in 1996 by the UN (UN, 1998, for the B2 scenario) and the International Institute for Applied Systems Analysis (IIASA) (Lutz et al., 1996, for the A1/B1 and A2 scenarios). These projections all had a base year of 1990. Van Vuuren and O'Neill (submitted) show that SRES population values for 1990 and 2000 are quite close to the most recent estimates of population size for the world and four SRES macro regions. Substantial differences can exist at the country level, due to updated information from censuses and surveys, but these generally cancel out at higher levels of aggregation.

Comparison of the population projections used in SRES to more recent projections shows that the outlook for future population size has generally shifted down. Thus, while the SRES population assumptions were consistent with the demographic outlook at the time SRES was developed (Gaffin, 1998), in some cases they now lie above the range of current projections. For example, Figure 1 shows that the upper end of the SRES range for world population, represented by the A2 scenario, lies above the most recent high projection from the UN (UN, 2003) and the 95th percentile of IIASA probabilistic projections (Lutz et al., 2001). The projections used for the other three SRES storylines (A1, B1, and B2) still lie within the current range. However, the low end of the current range of projections is not well represented.

Comparison at a more disaggregated level shows that global results are driven primarily by changes in the outlook in the developing countries, due mainly to changes in the outlook for Sub-Saharan Africa, the Middle East and North Africa region, and the East Asia region. Recent data showing lower than expected fertility in these regions has led to less projected population growth. In addition, a much more pessimistic view on the extent and duration of the HIV/AIDS crisis in sub-Saharan Africa has also lowered anticipated growth in that region.

Comparison to recent projections in the industrialized country regions show less of a systematic difference. Projections have shifted down substantially for the regions included in the Former Soviet Union, but in other regions changes are smaller. One notable contrast with recent projections is that, by design, SRES does not include a low population scenario for the industrialized country region as a whole. Thus outcomes below the median expectation in current projections are not represented.

Partly as a result of this choice, the SRES population assumptions also do not include a scenario in which aging near the high end of the current range occurs in the industrialized country regions. Since aging is driven partly by low fertility, which is also associated with low population growth, the lack of a low population growth scenario implies the lack of a rapid aging scenario as well. Thus the upper half of the current range of plausible aging outcomes in industrialized countries is currently not represented. For example, while Western and Eastern Europe could have over 60% of their population above the age of 60 by the end of the century (Lutz et al., 2001), the most extreme SRES scenario only reaches just above 40%. In developing country regions, the range of projections of aging has also shifted upward (toward older populations), although differences with the range covered by SRES are less pronounced.

3. Beyond population size

Most models used to develop energy and emissions scenarios do not explicitly consider demographic factors other than population size. One exception to this is that in some cases, a measure of age structure is used to define the labor input to production. However age structure, urbanization, and living arrangements (such as household size measured as number of members, and age composition of household) have all been shown to be potentially important determinants of energy demand, and consumption more generally (O'Neill and Chen, 2002; Schipper, 1996).

Making progress in this area requires a better understanding of the scope for future demographic change, as well as methods for including demographic heterogeneity within energy-economic growth models used for emissions scenario development.

Simultaneous and consistent projections of population, urbanization, and households is a challenging demographic task. For China, we have recently completed a preliminary household projection that suggests that the next 50 years could witness a doubling of the fraction of the population in 1- or 2-person households (to over 25%), a decline in the proportion of population in households of size 4+, and extremely rapid aging. Substantial additional analysis is necessary to support the development of alternative scenarios, in order to bound the range of plausible outcomes. Our initial analysis of the potential for future urbanization suggests that current UN projections, which foresee urbanization rising in China from 35% currently to 60% in 2030, may be near the upper end of plausible outcomes; substantially slower urbanization should be considered a real possibility.

To study the effect of shifts in population composition over time on energy demand and emissions, we recently introduced heterogeneous households into a general equilibrium model of the U.S. economy with detail in the energy sector (Dalton et al., in prep.). We incorporated different types of households, each with its own demand for consumption goods, capital stock, labor supply, and other household level variables, into the U.S. region of the Population-Environment-Technology (PET) model (Dalton and Goulder, 2001). The methodological approach taken is a combination of the infinitely lived agent (ILA) approach typical of the Ramsey growth models used in the development of many current emissions scenarios, and overlapping generations (OLG) frameworks more common in economic demography. We use projections for households grouped by age of the household head, and construct "cohorts" of households; i.e., the population living in households headed by individuals belonging to particular cohorts. We assume altruistic behavior to link cohorts that form infinitely lived dynasties. Households in different age groups are associated with distinct income and consumption levels, based on data from the U.S. Consumer Expenditure Survey. Differences among age groups imply that each dynasty is associated with a specific pattern of income and consumption, based on its age distribution at each point in time. These differences have implications for energy demand, both directly and indirectly. These dynamics, and other relationships implied by the household projections and CES data, create interacting effects that feedback, and forward, to influence each dynasty's current and future consumption and savings decisions.

We find that including age heterogeneity among U.S. households reduces emissions (relative to the representative household case), by almost 40% in our low population scenario. Effects of heterogeneity are more modest in other scenarios, and our results show that emissions are around 15% lower. In our preliminary results, the most important effects are caused by differentials in labor income across age groups that create complex dynamics for consumption and savings. We have also conducted analyses showing that results are sensitive to the values assumed for the inter-temporal substitution elasticity and the elasticity of substitution across consumer goods.

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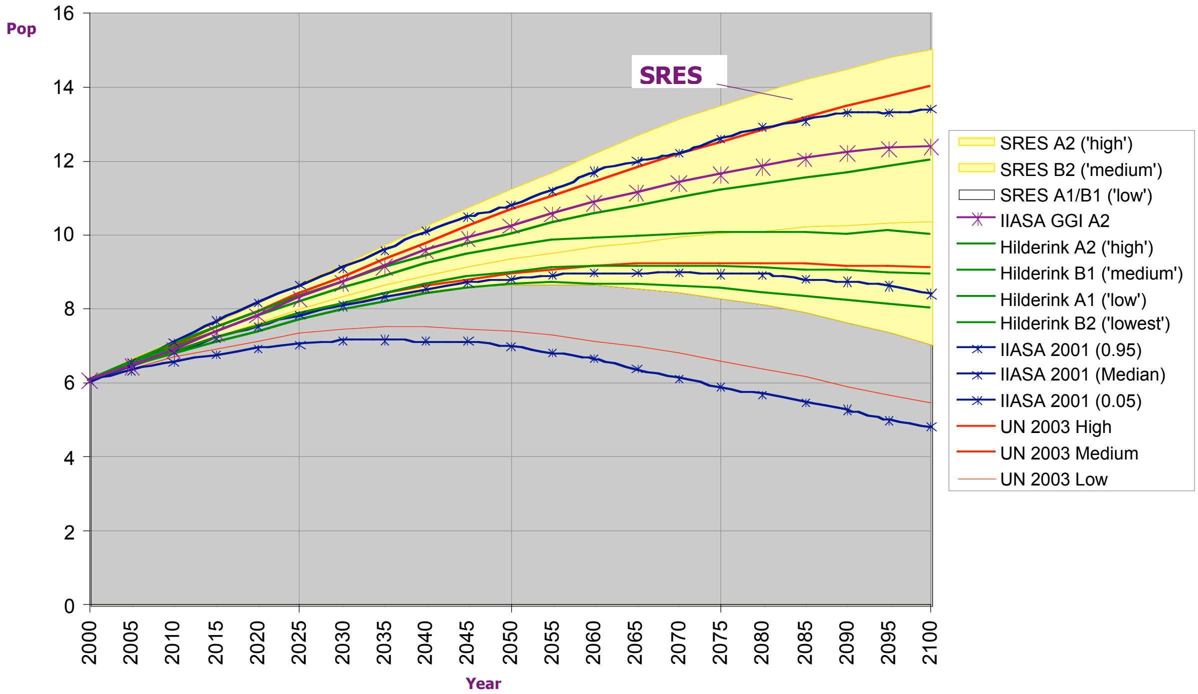
5. Figures

Figure 1: Global population size in billions, SRES range vs. recent projections.



Evaluating climate impacts with intermediate complexity models

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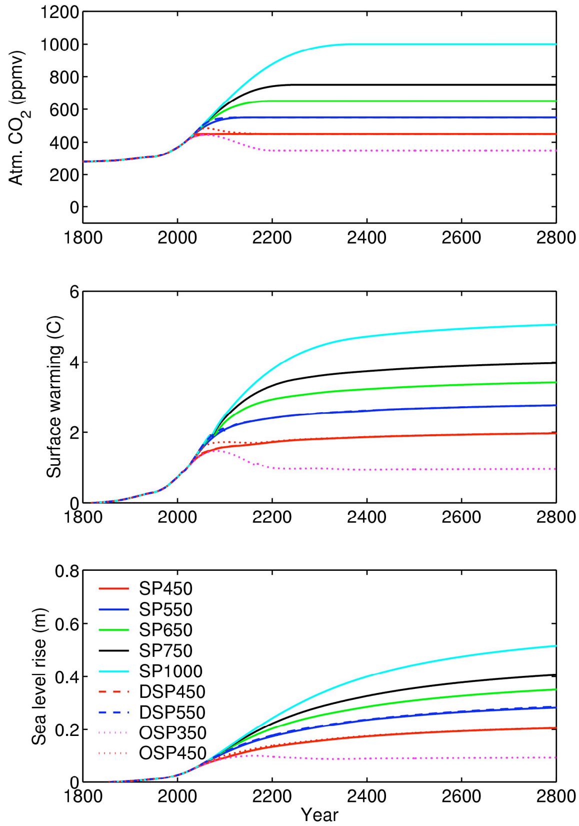
1. Introduction

Estimates of impacts as well as adaptation and mitigation strategies related to anthropogenic climate change require a precise understanding of the anticipated changes as well as the uncertainties associated with them. Numerical models are the only tools to provide those projections of future climate. Three types of climate models exist, although the separation is not always clear. The most sophisticated are comprehensive atmosphere-ocean general circulation models (GCMs). Climate models of reduced complexity (also named EMICs, Earth Models of Intermediate Complexity, [*Claussen et al.*, 2002]) are dynamically simpler than comprehensive GCMs, although they might well be more "complete" in terms of climate system components that are included. Typically, EMICs are a composite of simplified versions of atmospheric, and/or ocean models and a suite of parameterizations for other processes. Simple climate models, on the other hand, are usually not stand alone models but are rather emulation models that rely on tuning to more complex models. The increasing complexity and resolution of comprehensive GCMs increase the computational costs and limits the number of scenarios and ensemble members that can be calculated to typically only a few. Long-term projections covering many thousands of years and sensitivity studies are unfeasible. Simple models have therefore been tuned to match the GCM responses and have been used as substitutes to run large numbers of scenarios and simulations [*Wigley and Raper*, 2001]. To bridge the gap between GCMs and simple models and to study the physical processes and feedback mechanisms in the climate system, intermediate complexity models are applied successfully to a variety of questions in past and future climate change. Three examples are given below.

Figure 1: Long-term projections of global mean near surface warming and sea level rise from thermal expansion for a series of stabilization (SP), delayed stabilization (DSP) and overshoot-stabilization (OSP) pathways, calculated with the Bern intermediate complexity climate model [*Stocker et al.*, 1992; *Knutti et al.*, 2002]. Intermediate complexity models around the world are supposed to run these and many more scenarios to bridge the gap between the GCMs and the simple climate models in AR4.



2. Long-term climate projections

Intermediate complexity models will be used to calculate projected long-term global changes for idealized CO_2 stabilization pathways in the IPCC Fourth Assessment Report (AR4).

Preliminary results from the Bern model [*Stocker et al.*, 1992; *Knutti et al.*, 2002] are shown in Fig. 1. A number of questions can be addressed with those model runs, for example the effect of a delayed CO_2 stabilization (SP550 vs. DSP550) or the change in global sea level, an issue that involves timescales of many centuries until a new equilibrium state is reached. An intercomparison of these results from a series of models with different sensitivities and ocean mixing parameterizations will further allow to study the sensitivity of these results to various parameter settings.

3. Nonlinear changes in sea level

An intermediate complexity model was used to show that a shutdown of the Atlantic thermohaline circulation would have a non-linear effect on ocean heat uptake and thus on sea level [*Knutti and Stocker*, 2000]. If the Atlantic deep overturning were to stop, an issue that is still under debate, global ocean temperature would increase due to strongly reduced transport of cold water from the North Atlantic into the deep ocean. This would result in a long-term contribution to sea level of about 0.5 m, in addition to the sea level rise from global warming itself.

4. Uncertainties in future warming

Climate model projections are inherently uncertain. Ranges of uncertainties for the projected warming were based on expert opinion only for many years, and only recently new methods were suggested to objectively quantify uncertainties [*Knutti et al.*, 2002; *Stott and Kettleborough*, 2002]. One way to derive probability density functions or uncertainty ranges is to run many simulations with models of intermediate complexity, thereby taking into account uncertainties in climate sensitivity, ocean heat uptake, radiative forcing and the carbon cycle. Each member of this resulting multi-thousand member ensemble is then weighted according to agreement with the observed warming over the instrumental period. This approach allows for a more objective statistical estimate of global warming uncertainty over the 21st century than by expert judgement only.

5. Conclusions

Given the fact that models of intermediate complexity are relatively easy to adapt and calculate a model run typically within minutes to hours, they are powerful tools to be linked with impact or policy models, either directly [*Webster et al.*, 2003] or offline in the sense that projections, uncertainties, or constraints found in the climate model are implemented afterwards into impact or economy models [*Bahn et al.*, 2005]. However, since many simplifications are made in these reduced complexity models, the interpretation of results is usually limited to large spatial scales, and these models should not be seen as a replacements for comprehensive GCMs. Those provide much more detailed and accurate information, in particular on climate variability, extremes, regional patterns, as well as on quantities other than temperature, which are inherently more complex to model.

Figure 2: Surface warming, strength of the thermohaline circulation and sea level from thermal expansion in two idealized global warming simulations with the Bern intermediate complexity model. Climate sensitivity in the two cases is chosen close to a threshold and is slightly higher for the blue (dashed) case. Although equilibrium surface warming is essentially the same for both cases, sea level rise is more than 0.5 m higher if the thermohaline circulation stops. Figure adapted from [*Knutti and Stocker*, 2000].

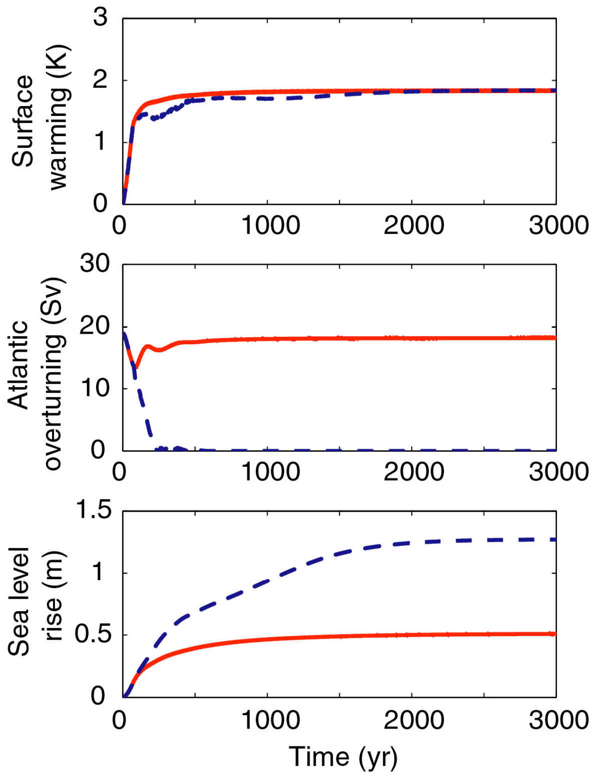
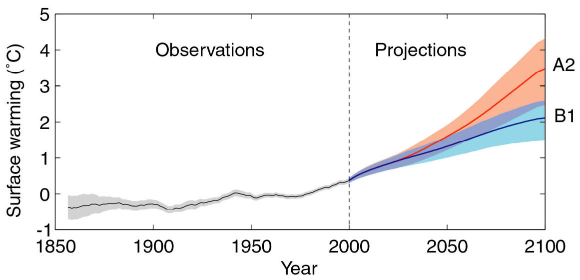


Figure 3: Observed global mean near-surface warming over the instrumental period (black) and projected changes for IPCC SRES B1(blue) and A2 scenarios (red), calculated with the Bern intermediate complexity model. Uncertainties given by the blue and red band mark the 5 to 95% confidence range and are derived from a multi-thousand member ensemble, taking into account uncertainties in radiative forcing, ocean heat uptake and climate sensitivity. The observed surface warming [*Jones and Moberg*, 2003] and ocean heat uptake [*Levitus et al.*, 2000] were used to constrain the ensemble over the years 1860 to 2000. Figure adapted from [*Knutti et al.*, 2002]



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The Use of SRES Scenarios in Climate Change Impacts and Adaptation Assessments

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1. Introduction

Scenarios of climate change have been used by the vulnerability, impact and adaptation (VIA) community for many years in a number of roles. In 2000, Intergovernmental Panel on Climate Change (IPCC) released "Special Report on Emission Scenarios (SRES)" (IPCC, 2000) which explored pathways of future greenhouse gas emissions, derived from self-consistent sets of assumptions about energy use, population growth, economic development, and other factors (see below for details). In recent times, there is an increasing effort of use of SRES in global and regional biophysical impact assessment studies (Arnell, 2004; Rosenzweig et al., 2004; Nicholls, 2004). In doing so, some VIA researchers encountered a number of problems. Efforts are undergoing also to identify threshold GHG concentrations to avoid dangerous impacts (ECF, 2004). Policymakers may be interested to know about trade off between a certain mitigation/adaptation effort and the avoided damages compared to a baseline situation. In these contexts, this brief paper has two specific objectives. First, it summarizes the relationships between the information required for conducting climate change impacts, adaptation, and vulnerability assessments and the information available in the SRES scenarios. Second, to discuss impact/adaptation assessments based on the post-SRES mitigation scenarios.

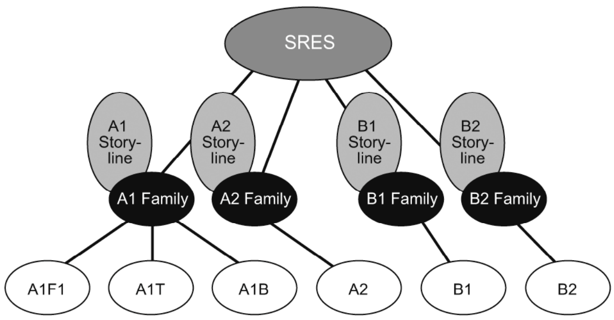
2. General features of the IPCC SRES Scenarios

The SRES scenarios cover a finite and a very wide range of future emissions. The approach involved the development of a set of four alternative scenario families-A1, A2, B1 and B2 comprising 40 SRES scenarios (Nakicenovic, 2000). From SRES, six illustrative "marker" scenarios (*Figure 1*) were selected for use in the climate projections of the IPCC Third Assessment Report.

Scenario descriptions

	Global integration	Regionalism
Economic emphasis	A1B-Balanced energy A1FI-Fossil fuel intensive A1T-hightech renewables	A2
Environmental emphasis	B1	B2

Figure 1. SRES storylines and six illustrative "marker" scenarios. Source: Taylor *et al.*, 2003.



3. Features of SRES scenarios relevant to the assessments of impacts, adaptation, and vulnerability

According to the IPCC Terms of Reference, the SRES scenarios focus on key driving forces that shape future socio-economic development, the availability and use of energy resources, and the evolution of other sources of greenhouse gas (GHG) emissions. The foundations of the SRES scenarios are assumptions about the evolution of the global population, economic growth, and the distribution of incomes between developed and developing countries. Although land-use changes are primarily intended to underpin land conversion, land-use, and agriculture-related emissions, the direction and magnitude of changes in the main land-use categories are important clues for sectoral impact and adaptation assessments concerning the evolution of agriculture and forestry under the four scenarios.

4. Applications of SRES and other socio-economic and technological scenarios for vulnerability, impact and adaptation assessments

An increasing number of climate impact assessment projects extend their scope and attempt to superimpose biophysical impacts of different climate change scenarios onto different socio-economic conditions that might prevail by the time those impacts are expected to manifest themselves. A number of attempts have recently been made to use the SRES scenarios in vulnerability, impact and adaptation assessments.

US National Assessment: In 1997, the United States initiated its first comprehensive national assessment of potential consequences of climate variability and change, completed in 2000 (U.S. Global Change Research Program, 2000). For this assessment, which included twenty regional assessments and five sectoral assessments, emission scenarios were taken from IPCC sources and Hadley Centre and Canadian Centre for Climate Modelling efforts. Based on the SRES storylines, the study team created three internally consistent socio-economic scenarios considering high and low economic growths and thirteen economic sectors. Under the scenarios, population, income and employment information are generated at county levels until 2050 and at national level until 2100.

The United Kingdom Climate Impacts Programme (UKCIP, 2001): The UKCIP team developed a scenario framework for use in various regional and national climate impact assessment studies. Its conceptual foundations are similar to those of IPCC SRES: the range of possible futures is structured into four quadrants by two axes that are declared to represent diverging orientations of socio-economic development: consumerism versus community orientation and autonomy versus interdependence. The resulting four quadrants partly coincide with the four SRES storylines: world markets (A1), national enterprise (A2), global sustainability (B1), local stewardship (B2).

EU ACACIA Project: A similar exercise was carried out at the scale of the European Union (EU) as part of the Europe Acacia Project (Parry, 2001). The Acacia scenarios draw on both the SRES and UKCIP storylines and use their internal logic to contemplate the future of climate-sensitive sectors in Western Europe in the period 2020-2080. They delineate the four futures in five main dimensions: political, economic, social/environmental, technical, and regional aspects. The Acacia scenarios also outline policy changes at the EU level that are likely or outright unavoidable given the logic of the underlying global storyline. These scenarios are certainly worth considering in national and sub-national climate impact/adaptation studies because they provide a useful link between the global socio-economic scenarios in SRES and the national or regional scenarios required for the climate impact project.

AIACC Projects: A different case is an effort to inform Assessments of Impacts and Adaptations to Climate Change (AIACC) in multiple developing regions and sectors. The AIACC has commissioned climate change impact and response studies in priority countries and regions, both to provide valid information about impacts and to strengthen developing capacities to conduct such research (see www.aiaccproject.org). There is a wide range of SRES, downscaling methods and resolution is considered for these projects, which are distributed over Asia, Latin America and Small Island States. When contacted about this, Dr Neil Leary, Science Director of the AIACC particularly mentioned two points. *First*, the main emphasis of the AIACC projects is focusing on past climate variability and extremes and related vulnerability and adaptation. *Second*, although the projects' leaders have been advised to consider construction and application of future climate scenarios as a capacity building exercise but it is not a major thrust.

The development of national or regional socio-economic scenarios for assessments of climate impact and adaptation studies by using the global SRES scenarios is relatively easy task. The driving forces and the cross-boarder linkages of the national scenarios must be consistent with the underlying logic of the corresponding global storylines but, as presented above, there is a considerable degree of freedom in depicting the national futures. The situation is entirely different when a set of national and regional scenarios derived from global storylines is used for a global scale impacts/adaptation study. In this case, the logical consistency of the national scenarios with their global sources is necessary but not sufficient: the quantitative characterization of the disaggregated driving forces must also match the original global scenario quantification. This requires more rigorous procedures for "downscaling" global scenarios. Arnell *et al.* (2004) and Gaffin *et al.* (2004) recently attempted downscaling of SRES socio-economic data at country levels and they encountered a number of problems among which particularly important are: use of regionally averaged population and GDP growth rates. Their application at country level may produce unrealistic population and GDP scenarios. There are also problems of population discontinuity after 2050 for the A1 and B1 scenarios which may not be the case for all countries. Downscaling the land-use change components of the SRES scenarios appear to be more problematic because they are calculated by the integrated assessment models used in the SRES process and the projections diverge widely even under the same storyline. Considering the limitations, examples of application of the SRES in the water, food production and coastal flooding are given below.

Water Resources: Arnell (2004) applied SRES socio-economic and climate scenarios projected by six climate models driven by SRES emissions. These models are: HadCM3, ECHAM4, CGCM2, CSIRO, GFDL and CCSR. Following time-slices were used for the assessment: 30-year mean climate relative to 1961-1990 by the 2020s (2010-2039), 2050s (2040-2069) and 2080s (2070-2099). A macro-scale hydrologic model with a resolution of 0.5 x 0.5° was run to simulate present and future climates on monthly basis and average annual runoff was derived. Population was derived at watershed levels under each population growth scenario. Finally, indicators of water resources stress for each watershed were calculated from the simulated runoff and estimated population.

As a result of decrease in runoff, climate change may increase water stresses in some parts of the world including the Mediterranean, in parts of Europe, central and Southern America, and southern Africa. The problem of South and Eastern Asia is different from these regions as most of the runoff will occur in the monsoon and that may not be available during the dry season which may result in water stress. By 2050, under the A2 population scenario, between 1092 and 2761 million people may experience increase in stress. On the other hand for the B2 scenario, the range is 670-1538 million. Note that population assumptions under these two SRES played a dominant role in generating the effect compared to the emission scenarios.

Food Supply: Parry *et al.* (2004) analyzed the global consequences of SRES socio-economic and emission scenarios to drop yields, production and risk of hunger. They applied climate change scenarios projected by the HadCM3 model with regard to SRES A1F1, A2, B1, and B2 emissions. Transfer functions were derived from crop model simulations with observed data and projected climate change scenarios and were used to calculate projected changes in yield. In order to evaluate consequent changes in cereal production, cereal prices and the number of people at risk, the basic linked system (BLS) was used. Some adaptation measures were also considered in the analysis which includes particularly planting date, and application of additional fertilization and irrigation. The greatest decrease in yields is expected under the A1F1 scenario which will produce large increase in global temperature. Under the A2 ensemble scenario, the contrast between the developed and developed countries is the largest while the least contrast is visible under the B1 and B2 scenarios.

Coastal Flooding: Due to sea level rise in future, flooding in the coastal areas in many parts of the world and loss of coastal wetland could emerge as serious problems. Nicholls (2004) examined these issues in the context of four SRES storylines-A1F1, A2, B1 and B2. With these scenarios, the HadCM3 model projects global mean sea level rise (relative to 1990) in the range of 22 cm (B1) to 34 cm (A1F1) by 2080s. Flood incidence from surges will increase until 2020 under all scenarios because of lagged improvement in defence standards. By 2080s, the incidences of flooding may decrease due to increased investment in defence standards. The estimates are: £ 5 million people/year (B2), £ 2 million people/year (B1) and £ 1 million people/year (A1F1). However, the A2 world is disappointing under flooding incidence will continue to occur until 2080 and estimated vulnerable population is 18-30 million. Sea level rise increases flooding impacts for all scenarios, however, significant impact will emerge by 2080. By this date additional impacted people are: 7-10 million (A1F1), 29-50 million (A2), 2-3 million (B1) and 16-27 million (B2). Maximum wetlands (5-20%) will be lost under the A1F1 scenario.

5. Use of Stabilized/Long-Term Response Scenarios

It is now assumed that the equivalent of doubling atmospheric CO_2 will occur by 2050. Land surfaces and higher altitudes will experience larger increases. Temperatures will continue to rise long after emissions are reduced and greenhouse gas concentrations stabilize. However, it is important to stabilize emissions of GHGs to reduce vulnerability to adverse effects of climate change and sea level rise. Stabilization has a number of benefits, viz.: global distribution of benefits; benefits will spread over decades to centuries; will reduce cost of adaptation; will allow longer time-scale for adaptation to succeed; and will reduce threats to many vulnerable unique ecosystems.

5.1 Climate and Sea Level Changes under the Stabilized Scenarios

Schlesinger and Malyshev (2001) examined near-surface temperature and sea level for the post SRES CO_2 stabilization scenarios. They examined seven stabilization scenarios with their corresponding SRES marker scenarios-A1, A1S550, A1/S650, A2/S550, A2/S750, B1, B1/S450, B2 and B2/S550 (S denotes the stabilized CO_2 concentrations). The experiments indicate a range of reductions in temperature and sea level rise under all stabilized scenarios. Example, for the S550 stabilization scenarios, the reductions in global warming and sea level rise in 2100 range from 0.29°C and 3.31 cm for B2/S550 with ΔT_{2x} = 1.5°C to 1.23°C and 11.81 cm for A2/S550 with ΔT_{2x} = 4.5°C. Spatially the near-surface temperature changes under the B2/S550 in 2100 were found to be smaller than those for the B2 scenario. The values vary from about 0.3°C in the tropics to 0.5°C over Antarctica and 07°C in the Arctic.

5.2 Potential Impacts on Agriculture and Human Health

Mikiko et al. (2004) assessed the impacts of stabilized scenarios on agriculture and human health in South and South east Asia. Under the EMF 19 scenarios, they found that productivity of wheat would decrease significantly in Sri Lanka, Malaysia, Korea-PDR, Burma and other tropical countries. Decrease in rice productivity is also expected in most countries with exceptions in Bhutan and Taiwan, which may experience in decrease. The productivity decrease in India is projected to be the highest.

Mikiko et al. (2004) indicated that global warming would result in increasing temperature and changing vegetation close to the ground. This modified environment would allow the anopheles mosquito, the malaria vector, to increase its population. Although under the 550 stabilized scenarios temperature increase will be smaller than that of the reference (B2) scenario, the population living in the areas at malarial risk will be doubled in 2100 as against the 1990 level.

6. Concluding Remarks

SRES the only starting point for national VIA studies. For any such study there are two main components for which scenarios need to be constructed: *First*, space and general direction of development: population, incomes, education & human capital, social relations, institutions, technologies; and *second*, future evolution of climate-sensitive sectors: agriculture, water resources, coastal areas, forestry, ecosystems. In this context the challenge is to minimize the uncertainty when downscaling the information at country level/catchment level using the large SRES regional values.

Migration/relocation of people is very important for VIA assessments. In developed countries there has been a tendency of movement of people to the flood plains and coastal areas. In developing countries migration occurs between rural and urban areas.

Equity is another important issue that need to be factored into VIA assessments. Equity could be of many forms: intra- and inter-generational, geographic, income groups, gender, etc. A country may have plenty of water but some regions are deprived of that resource. High-income group uses much more water than the low-income groups, etc.

Bottom-up approach for scenario construction may be more suitable but may emerge as a big challenge when comparing regional and global consistency with the SRES storylines.

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Climate change mitigation: Costs and avoided damages

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The mandate of this short paper is to evaluate long-term adaptation-mitigation costs in the context of avoided climate change related damages (corresponding to the benefits of mitigation) and to briefly assess the literature on remaining impacts (the rest of the climate change costs) and adaptation options for a range of long-term mitigation and stabilization scenarios. An OECD conference in 2002 addressed many aspects of the benefits of climate change mitigation (Corfee Morlot and Agrawala, 2004a,b). This paper complements those publications rather than summarizes them.

1. Accounting for climate change costs and mitigation benefits

The concept of the benefits of climate change mitigation on the impact side is straightforward. It is equivalent to the avoided damage relative to some baseline and can be calculated as the difference between the damages associated with baseline or reference emissions and the damages that result if greenhouse gas emissions are reduced relative to the reference emissions. It follows that in the baseline case the social costs of carbon and other GHG emissions are equal to the properly calculated damages. In the mitigation case, however, the social cost of climate change and its management has two components: the mitigation cost itself and the damages resulting from the mitigated but not fully eliminated climate change.

Reality is somewhat more complicated. Damage costs in both the baseline and the mitigated cases should be calculated as net damages that account for the damages averted by adaptation and for the associated adaptation costs plus for the ancillary (indirect) effects of adaptation that can be positive or negative. The mitigation costs should also be adjusted for the ancillary effects of mitigation activities that can also be positive or negative. The possibility to consider costs and benefits of GHG mitigation and the exact form of counting and balancing them depends on the adopted decision analytical framework as well as on the spatial scale and the time horizon of their applications.

2. Global Cost-Benefit Analysis (CBA)

Integrated assessment models of climate change conceived in a cost-benefit framework cover the full range from economic activities and resulting emissions (together with mitigation cost functions of reducing those emissions) to climate change impacts and damages in monetary units. Examples include the DICE/RICE family of models by Nordhaus (1992) and Nordhaus and Boyer (2000), and the FUND model by Tol (1997). Baseline emissions and related baseline damages in CBA models are calculated by turning off their optimization part. This represents the case when the external effects of GHG emissions (damages) are allowed to be ignored by those who produce those emissions. In contrast, optimal emissions balance the costs of GHG emissions reduction against their benefits accruing from avoided climate change damages. This requires a benevolent global social planner whose goal is to maximize social welfare which involves minimizing the sum of GHG mitigation costs and climate change damages. Properly formulated in a dynamic framework, CBA provides not only the optimal level of climate change but also the temporal path of the efficient control.

In general, results of cost-benefit models show that the optimal path only slightly diverts from the baseline emission path. It follows that in this framing any diversion from the optimal path involves higher total social costs: mitigation above or below the optimal level reduces welfare. Specifically, mitigation beyond the optimal level leads to welfare loss because mitigation costs exceed the benefits, i.e., the avoided damages. Yet several concerns have been raised about the applicability of CBA to guide global climate policy.

3. Cost-effectiveness analysis (CEA)

Least-cost strategy to achieve an environmental target in general is based on the notion that beyond a certain level, impacts of pollution becomes unacceptable irrespective of the damages caused. It is often used in environmental management when the damages are manifold and difficult to value in monetary terms. In the climate context, the threshold or target levels are associated with the level and/or rate of change in climatic attributes that lead to unacceptable impacts. Triggered by Article 2 of the UNFCCC, Working Group I of IPCC (1994) depicted a set of emission paths that stabilize CO_2 concentrations at pre-specified levels. This was followed by the study by Wigley et al. (1996) who show that the same concentration targets can be achieved via alternative paths along which the mitigation costs are significantly lower than those of the corresponding IPCC paths. Inquiries into cost-minimizing stabilization of CO_2 or CO_2-equivalent GHG concentrations have become widespread and subsequent years. Dozens of models, hundreds of model runs propose cost-effective emission paths. They are assessed in Chapters 2, 8, and 10 of IPCC (2001).

CEA models usually lack impact/damage modules and therefore cannot say anything about benefits directly. However, there are conceivable ways to resolve this problem by using impact/damage information form other models. One possibility to calculate benefits is to take stabilization targets and costs from CEA applications and to get the corresponding baseline and avoided damage estimates from other studies: e.g., from damage-modules of CBA such as the DICE/RICE model. The difficulty is, however, that damages depend not only on environmental change but also on the affected society, particularly on factors that determine its ability to avoid or countervail at least some part of the climate change damages.

Another possibility is to take CEA stabilization targets and costs and to use global (perhaps with some regional resolution) damage functions, e.g., those developed by Tol (2002). The procedure would be to calculate baseline emissions by using the CEA model and the associated damages by using the damage functions; to calculate the mitigation costs along the least-cost stabilization path provided by the CEA model; to estimate the climate-dependent damages along this stabilization path; and to take the difference between the damages under unrestricted emissions and those under mitigation to calculate the benefits of cost-efficient stabilization.

4. Safe-landing/Tolerable windows approach (SL/TWA)

The search for limits beyond which anthropogenic interference with the climate system might become "dangerous" extends the question of long-term stabilization targets into the domain of climate attributes (temperature and precipitation change) and impacts. Given their distinctive formulation of the decision problem, the Safe landing and the Tolerable windows approaches have established themselves as a separate decision analytical framework. The main objective of the safe landing analysis (SLA) (Alcamo and Kreileman, 1996; Swart et al., 1998) is to establish ranges of near-term emissions called Safe Emissions Corridors that keep long-term climate change (i.e., long-term stabilization objectives) within predefined limits. The safe emission corridor determines a range of possible near-term (for the next decade or two) GHG emissions levels that includes at least one long-term (century-scale) emissions path that satisfies the externally defined long-term and intermediate climate protection goals. The latter are typically formulated as climate change features such as the limits to the change in global mean temperature and to its rate of change, and the limit to sea-level rise and its rate of change. The benefits associated with an SLA-derived emissions corridor are difficult to measure. Even if near-term emissions remain in the pre-specified range, the long-term actual paths can still progress towards different targets in diverse ways and accrue widely diverging damages. One possible approach might be to measure the SLA-related benefits in terms of option value, i.e., the value of keeping open the possibility not to exceed certain magnitudes and rates of climate change.

The Tolerable Windows Approach (TWA; see Toth, 2003) calculates long-term emission corridors that secure certain benefits under a cost limit, both specified by the user of the model to represent personal judgment or social preferences. Climate impact response functions (CIRFs) describe the relationships between relevant environmental variables (e.g., incremental temperature, precipitation, and CO_2-concentration change) and the valued features of the climate impact sector (e.g., changes in potential yields in agriculture or ecosystems change measured as replacement of current biomes with another one). These response functions intend to support the decisions about limiting climate change impacts. For example, one can conduct a TWA analysis to derive a long-term corridor of CO_2 emissions that would preserve at least $2/3^{rd}$ of the natural vegetation in non-agricultural areas without major change such that the costs would not exceed 2% of consumption any time over the entire time horizon. The benefits in this specific case would be derived by deducting the chosen maximum transformation (underlying the primary emission corridor) from the baseline transformation associated with the underlying scenario without mitigation intervention.

5. National/regional levels

For many small countries, especially those with emissions reduction commitments in Annex B, mitigation and impacts/adaptation remain two separate domains. On the one hand, governments and private stakeholders are interested in how to comply with the agreed short-term emission commitments. This requires a cost-effectiveness analysis on the mitigation side to generate least-cost implementation, including transaction costs. The required framework is a detailed CEA, for example, a technology-rich computed general equilibrium model. The burden will be born by the fossil energy sector, other energy-intensive sectors of the economy, and the intermediate and final consumers of their products. On the other hand, public and private actors need to adapt to emerging and prepare themselves for foreseeable impacts of climate change. The applicable framework for private actors/sectors is CBA to measure the marginal costs of adaptation against the marginal benefits of averted damages. This is the case in all market sectors, like agriculture and forestry. The relevant decision framework for public organizations responsible for providing public goods is CEA based on some safe minimum standard. In both cases costs are carried by the affected sectors and communities. There is little chance for compensation from those whose mitigation costs might be lower now to those whose adaptation costs will increase in the future.

For a given country, the benefit of mitigation is basically equal to the residual net damage. It can be calculated by taking the baseline (unmitigated) climate change damage and deducting the damage averted by mitigation (at globally shared costs), the damages averted by adaptation (at local costs), adding the costs of adaptation and also considering the ancillary effects mitigation (partly from global spillover, partly as a result of national mitigation actions) and adaptation (predominantly from local adjustments). It follows that the total costs of climate change for a particular country is the sum of this net damage and the mitigation costs. The country's own mitigation hardly affects the gross damage (because it depends on the aggregated global effort), but it may affect the net damage if the resources devoted to mitigation reduce the amount of resources available for adaptation. Nonetheless, there is hardly any balancing between the national mitigation and adaptation expenditures.

6. Summary and conclusions

This short paper addresses the possibilities of calculating the benefits of GHG mitigation in different decision analytical frameworks. In general, mitigation benefits are defined as the difference of impacts (whether or not measured and aggregated in monetary terms) between the baseline damages (in the absence of climate policy) and those accruing under some level of GHG mitigation. Global CBAs provide both the efficient level of climate change (stabilization level) and its cost-effective realization (stabilization path) in an internally consistent manner. Yet they raise many problems and therefore the implementation of their results might be infeasible and would likely be undesirable anyway.

Global CEAs focus on the least-cost achievement of environmental targets, in the climate case CO_2- or GHG-concentrations or maximum levels of climate change. CEA models do not have damage functions and are therefore ignorant of the benefits. Other sources are needed to determine the benefits associated with different concentration or climate stabilization limits. One could use the damage modules of CBA models or stand-alone damage functions. The SLA/TWA frameworks focus on avoided damage at affordable cost. Their damage representation is fragmented and incomplete. This makes benefit estimates from such frameworks difficult and the results will be partial. All these global studies are useful for providing ballpark estimates of risks, hedging costs, and benefits but the real action takes place at the national level.

Calculating the costs of and designing policies for climate change happen in two almost fully separated domains in most countries. On the mitigation side, public regulators, increasingly involving affected private actors, seek cost-minimizing strategies for compliance with international mitigation commitments in the near term. On the impact side, a different group of public agencies and private stakeholders prepare for and start implementing national and local adaptation strategies over the medium and long term. These two domains are separated by the economic arenas they belong to, their ownership, and decades of time when their respective outlays are due. Trade-offs in such cases is not very meaningful to contemplate because compensations between the two domains are highly questionable.

There are many models and studies exploring the global stabilization costs and proposing cost-effective implementation strategies. A first comprehensive review is presented in IPCC (2001). In contrast, little attention has been devoted to quantifying benefits at the globally aggregated level. Moreover, there is hardly any sign of studies reporting bottom-up estimates of mitigation benefits. This is a major missing piece of information for various reasons. First, such information could contribute to verifying and recalibrating the global damage functions and thus improve the global benefits estimates. Second, this information could shed light on the national-level benefits of different mitigation-stabilization scenarios and indirectly inform mitigation decisions.

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Outline of the Projections Chapter in AR4 WGI: with Reference to the Emissions Scenarios

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1. Introduction

The projections chapter for AR4 WG1 will draw on model results from two model inter-comparison exercises relevant to the AR4. These model inter-comparisons will form a major part of the projections chapter. The first inter-comparison is for coupled atmosphere-ocean general circulation models (AOGCMs) and the second is for models of intermediate complexity (EMICs).

The scenario runs requested for these inter-comparisons are summarised in Box 1 and 2. Many of the scenarios are not directly relevant to policymakers but are rather idealized scenarios for an inter-model study of processes. The more realistic multi-gas scenarios are represented by three SRES scenarios: A1B, A2 and B1.

There will be some challenges to the interpretation of these model results. The calculation of forcing for the different species differs between the models. Consequently differences between model results result from differences in forcing as well as differences in climate model formulation (a metric for the latter being the climate sensitivity). In addition, gas-cycle feedbacks are not generally included in the inter-comparison runs (the exception being the EMIC runs 6a-d), though there is growing evidence for a temperature feedback on the carbon cycle.

Towards meeting these challenges to the presentation of results for policymakers and to compliment this work, these runs will also be performed with a tuned simple climate model (SCM). This SCM will be used to extend the scope by assessing the climate response to additional scenarios. It is anticipated that these scenarios will include the full set of SRES scenarios comparable to what was done for the TAR. Other pertinent post-SRES emissions scenarios may also be run with the SCM, allowing the representation in WG1 of the more recent work on emissions scenarios. Longer-term (several centuries) stabilization scenarios will also be represented using both the SCM and an EMIC model, the latter having an important supporting role on this longer time scale . It is hoped to obtain advice and open channels of communication during this session as to which emission scenarios should be used in addition to the SRES scenarios.

The TAR WG1 projections with a SCM presented a range of warming over the 21st Century for all the SRES scenarios. The construction of the TAR WG1 Figure 9.14 was pragmatic. It used a simple model tuned to AOGCMs that had a climate sensitivity within the long-standing range of 1.5 - 4.5 o C advocated by the IPCC. Models with climate sensitivity outside that range were discussed in the text and allowed the statement that the presented range was not the extreme range indicated by AOGCMs. The figure was based on a single anthropogenic-forcing estimate for 1750 to 2000, which is well within the range of values recommended by TAR WG1 Ch 6, and is also consistent with that deduced from model simulations and the observed temperature record (TAR WG1 Ch 12.). To be consistent with TAR WG1 Ch 3, climate feedbacks on the carbon cycle were included. The resulting range of global mean temperature change from 1990 to 2100 given by the full set of SRES scenarios is 1.4 to 5.8 oC. The uncertainty due to the emissions scenarios is comparable to that due to climate model uncertainties.

For the AR4, radiative forcing, carbon cycle feedback and climate sensitivity, together with their uncertainties, will be based on assessments across the AR4. Where possible a probabilistic approach will be used. Probabilistic estimates of 1765 to 2000 forcing is anticipated from the forcing chapter. Uncertainties in the magnitude of the carbon-cycle feedback will be included. Several assessments of the uncertainty in the magnitude of the climate sensitivity may be brought forward, resulting in more than one set of temperature change projections. One of these will be based on the climate sensitivities of the AOGCMs, others may be based on published probability density functions of the climate sensitivity. The challenge is to present the results in the most informative way for policymakers.

Box 1: AOGCM runs requested for PCMDI inter-comparison data set

1. 20th century simulation to year 2000, then fix all concentrations at year 2000 values and run to 2100 (CO_2 ~ 360ppm)
2. 21st century simulation with SRES A1B to 2100, then fix all concentrations at year 2100 values to 2200 (CO_2 ~ 720ppm)
3. 21st century simulation with SRES B1 to 2100, then fix all concentrations at year 2100 values to 2200 (CO_2 ~ 550ppm)
4. 21st century simulation with SRES A2 to 2100
5. 1% CO_2 run to year 80 where CO_2 doubles at year 70 with corresponding control run
6. 100 year (minimum) control run including same time period as in 1 above
7. 2xCO_2 equilibrium with atmosphere-slab ocean
8. Extend one A1B and B1 simulation to 2300
9. 1% CO_2 run to quadrupling with an additional 150 years with CO_2 fixed at 4xCO_2
10. 1% CO_2 run to doubling with an additional 150 years with CO_2 fixed at 2xCO_2

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Box 2: Summary of EMIC model runs for inter-comparison

Integration time 0 to 3000 years
1a-c Idealized CO_2 stabilization runs: 0.5, 1, 2%/yr to 2xCO_2 then constant.

2a-c Idealized CO_2 stabilization runs: 0.5, 1, 2%/yr to 4xCO_2 then constant.

3a-c Idealized reduction scenarios of -1%/yr after 0.5, 1, 2%/yr to 4xCO_2.

Integration time AD 1765 to 3000
4a-e Smooth CO_2 stabilization profiles: SP450, 550, 650, 750, 1000ppm.
4f-g Stabilization profiles with delayed turning point: DSP450, DSP550.
4h-i Stabilization profiles with overshoot: OSP350, OSP450.

5a-c Stabilization profiles for comparison with PCMDI results (all species) A1B, A2, B1 then constant.

6a-d Emissions commitment for EMICs with dynamic carbon cycle component: CO_2 emissions as SP450, SP550, SP750, SP1000 then set to 0ppm after 2100

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Constructing Probabilistically-Based Emissions Scenarios

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1. Background

The problem of designing effective and appropriate climate policy is one of reducing and managing the risks of severe climate impacts in the future. Therefore, scientific guidance should characterize the uncertainties and risks for decision makers.
The objectives in designing scenarios for assessment are:

- To help frame the debate,
- Provide common assumptions,
- Reduce the number of cases to study
- Span a useful range of the uncertainty,
- Provide a detailed storyline to enhance communication.

2. Probabilistic vs. Storyline Approaches

There is a debate within the climate science community between whether to use probabilistically based scenario designs or to use a storyline approach to scenario design. The best example of the storyline approach is the IPCC Special Report on Emissions Scenarios (SRES) (Nakicenovic et al, 2000). The SRES developed a set of six "marker" scenarios, each of which represents a different complete picture of how the world might develop socially, economically, and technologically over the next century.
The advantages of the SRES approach include the provision of small set of common scenarios that have been used extensively in the climate research community, and that the intuition for the scenario assumptions is enhanced by the storyline. One critique of the SRES, however, is that no statement as to the relative likelihood was attached to the scenarios (Reilly et al., 2001). Rather, all scenarios were defined as equally plausible.
The probabilistic approach is grounded in the practice of using probability distributions to formally characterize and communicate the uncertainty in a particular outcome variable (e.g., global mean temperature change in a given decade). The advantages of this approach are that it organizes our current knowledge about possible outcomes and their relative likelihood, and that it allows for the explicit exploration of risk-reducing strategies through policy (Webster 2003). Critiques of this approach include that communication is limited by the less intuitive nature of probability distributions, the difficulty in linking the results from one set of possible assumptions across multiple outputs, the reliance on expert judgment for socio-economic future trends, and the false sense of accuracy that may be accorded to numerical probabilities.
The perspective of the authors is that these two approaches are not necessarily mutually exclusive. We propose, and show an example below, that storyline scenarios can be constructed based on probabilistic uncertainty analysis, after which the discrete scenarios can be communicated and used as common assumptions.

3. Simple Example of a Probabilistic Scenario Design

This presentation builds upon the uncertainty analysis in Webster et al (2002), and uses it to design small sets of emissions scenarios as an illustration of the proposed approach.
The steps for this procedure are:

1. Conduct sensitivity analysis of parameters,
2. Construct probability distributions for key parameters,
3. Perform uncertainty propagation (Monte Carlo),
4. Use distributions of outcomes (emissions) to identify interesting targets,
5. Find an appropriate set of parameters that give the target emissions, and
6. Choose a small set of scenarios: combinations of parameter assumptions and their resulting outcomes.

Steps 1-3 are described in detail in Webster et al (2002). The model used for this exercise is the MIT Emissions Projection and Policy Analysis (EPPA) model (Babiker et al., 2001).
The results of an uncertainty analysis, probability distributions of projected outputs of interest, can be used

to locate percentile values to define scenarios, as shown in Figure 1a. For each targeted outcome value, such as global CO_2 emissions in 2100, there are many possible combinations of the uncertain input assumptions that would yield that result within some small error. The task then is to choose one such representative assumption. One obvious choice is to choose the set of input parameter values that are the most likely, in the sense of having the highest joint density. In the case of EPPA, the input parameters are the labor productivity growth rate and the autonomous energy efficiency improvement rate. The emissions from the chosen parameter sets are shown in Figure 1b.

We define a set of 15 emissions scenarios using the above procedure as follows: seven scenarios that results in global CO_2 emissions at 1%, 10%, 33%, 50%, 66%, 90%, and 99%, and additional four scenarios that result in other greenhouse gases at 10%, 33%, 66%, and 90% conditional on CO_2 at its median, and four additional scenarios that result in urban pollutant emissions (SO_2, NO_X, etc) at their 10%, 33%, 66%, and 90% conditional on CO_2 emissions at their median.

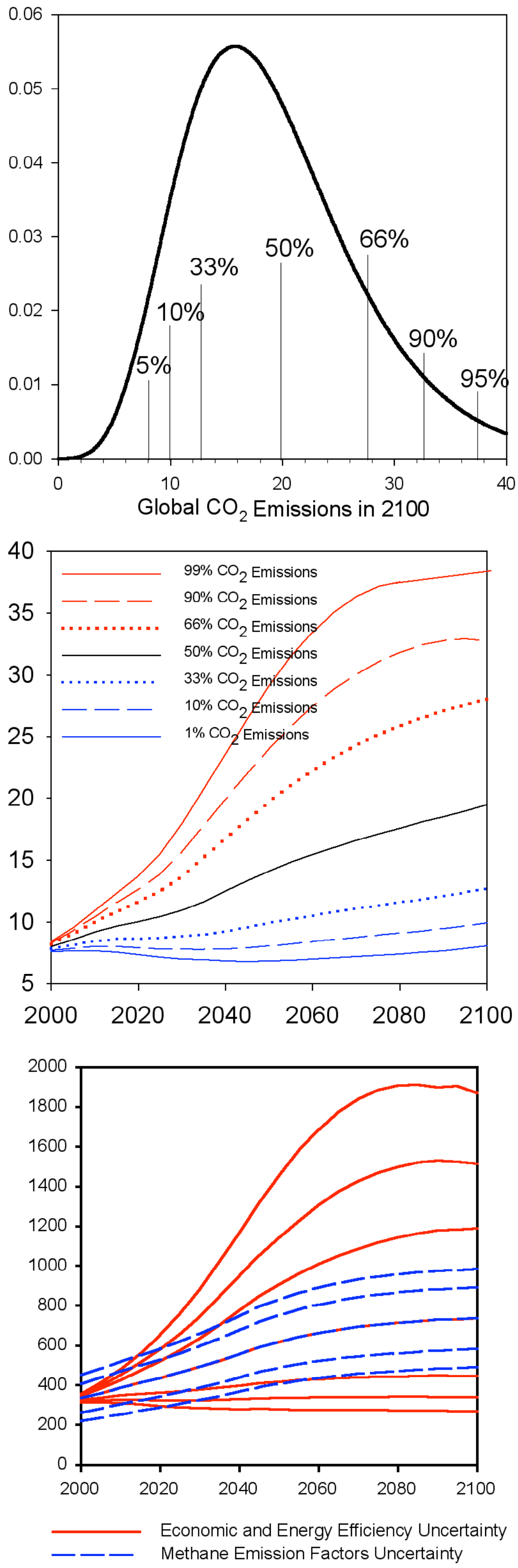
4. Integrated Approach to Emission Scenario Design

Using percentiles from distributions of emissions is a simple way of using probabilistic bounds to guide scenario design. However, because emissions scenarios serve as common assumptions for climate and impacts projections, the design can be improved by considering the role that emissions play in climate modelling.

From a climatic perspective, emissions are primarily interesting only in terms of their aggregate impact on total radiative forcing in the climate system. Designing scenarios that span the probability space across multiple emissions will not necessarily result in a useful spread across the probability distribution of radiative forcing.

A better approach would be to design scenarios to explore percentiles of the radiative forcing distribution. Then one can choose emissions scenarios that result in the desired radiative forcing with other interesting properties. For example, we could choose to design scenarios at the 5%, 50%, and 95% values for radiative forcing. The scenario set above is less well spread out (Figure 2a). An alternative set of ten scenarios (Figure 2b) contains three

Figure 1: a) PDF of CO_2 emissions is used to locate interesting fractiles for scenarios; b) set of emission scenarios that result in desired fractiles; c) CH_4 emissions from scenarios that vary economic growth, energy efficiency, and emissions factors.



that give 5% RF with different combinations of emissions, four that give 50% RF and three that give 95%.

5. Challenges

This simple illustration has several limitations, including the fact that even better bases for design exist, such as global mean temperature change or cumulative forcing. Critics may still object to the use subjective probabilities for some quantities. In the end, we still a means of designing scenarios that are most useful and efficient for scientific assessment to advise policy. Probabilistic methods provide one aide in this design problem.

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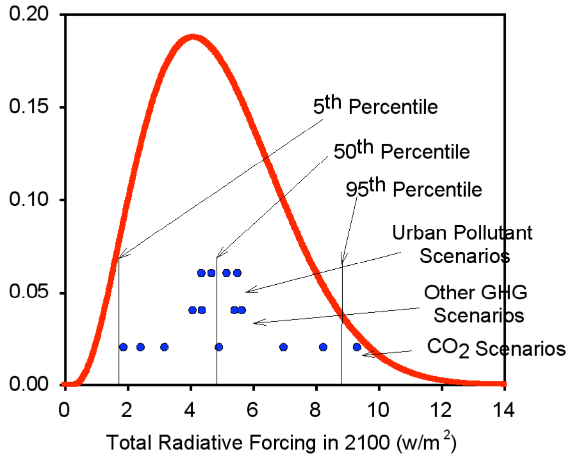
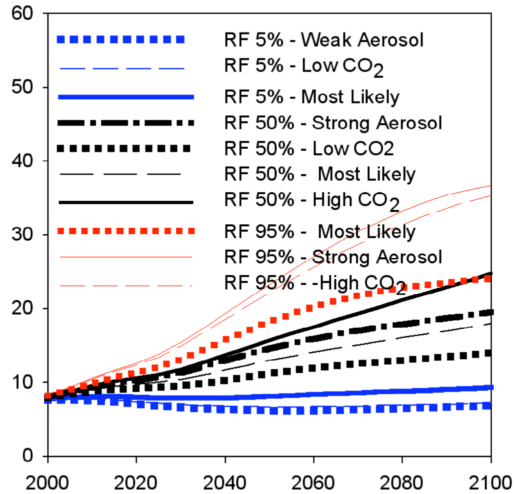
Figure 2: a) Probability distribution of net radiative forcing with scenario forcings shown; b) alternative set of emissions scenarios based on radiative forcing.





How likely are the SRES scenarios?

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Probabilistic scenarios cannot be avoided. If one is mainly interested in quantitative results, this is obvious. A number is meaningless without a confidence interval. If one is mainly interested in qualitative results, probabilistic analysis is not necessarily called for, or so it seems. However, an insight is meaningless if it is not robust. Alternative scenarios are needed to test robustness. Alternative scenarios should span the range of not implausible futures. That range can only be derived from probabilistic scenarios. Besides the question in its title, this paper investigates whether the SRES scenarios span the range of not implausible futures.

The SRES scenarios were severely criticised by Castles and Henderson. That critique focussed on the use of exchange rates. The choice of exchange rates, however, does not matter much (relative to the other uncertainties) for carbon dioxide concentrations and hence for climate change. On the other hand, the choice of exchange rates does matter for assumed development pathways, and hence vulnerability to climate change, and for the distribution of carbon dioxide emissions, and hence the distribution of mitigation costs and responsibilities. The choice of the discount rate matters so much, primarily because of the convergence of per capita incomes and emission intensities assumed in the SRES scenarios.

The SRES scenarios were build with model that were originally designed for the analysis of energy policies. Such models use scenarios, but here they were used to build scenarios. Using and building scenarios are different things. Also, for building emissions scenarios, more knowledge is required than knowledge of energy systems. Furthermore, the models used were calibrated to data sets with a relatively short time span. Because of funding constraints, validating the models against longer time series was never a priority.

I collected long term data on population, per capita income, energy use, and carbon dioxide emissions from energy use. I plotted these data together with the four alternative projections according to the IMAGE 2.2 model. I used the data to estimate the Kaya identity in differential form. I extrapolated the model, and used the forecast error to calculate the relative probabilities of the four SRES scenarios. The following results emerge.

The population scenarios are largely in accordance with history. It is peculiar that the A1 and B1 scenarios have the same populations, even though their economies are very different.

The per capita income scenarios for developed countries are largely in accordance with history. For developing countries, this is not the case. China's economy, for instance, has been stagnant if not declining for most of the last five centuries. Only the last two decades saw rapid economic growth in China. All four scenarios continue the pattern of most recent times. Rapid economic growth is also foreseen, in all scenarios, for other developing countries. For Africa, this is a clear break with the past. The four scenarios foresee rapid convergence of incomes across the world in the current century, even though the past two centuries witnesses income divergence.

The projections of energy intensities only partly conform with history. The fastest decreases of energy intensities in the scenarios are not faster than was observed in the past. However, the scenario foresee decreases only, even though energy intensities have increased as well in the past. Energy intensities across the world converge in all scenarios, not faster than the maximum observed rate, but always faster than the minimum observed rate.

The projections of emission intensities for individual regions span the range of observed past behaviour. All scenarios foresee further convergence of emission intensities first – in line with past observations – but divergence later. The scenarios all show the same qualitative pattern of convergence, and diverge only minimally quantitatively.

The above pattern suggests that the SRES modellers know a lot about the supply side of the energy system, but less about the demand for energy. Their knowledge of economic development is lacking. Their demographic expertise is sound, but strangely separated. My personal knowledge of the SRES modellers confirms this assessment.

The relative probabilities of the four alternative SRES scenarios confirms this picture. The scenarios for the period 2000-2050 for populations each have probabilities of over 10%; for emission intensities, the A2 and B1 scenario are most likely, but the other two scenario have more than a 0.1% chance For the scenarios for per capita incomes and energy intensities, the situation is different. Here, the A2 scenario is by far the most likely, and the other three scenarios are extremely unlikely.

For the period 2050-2100, a similar picture emerges, albeit less extreme. The Kaya trend projection method used here is, however, less suitable for projecting this far into the future.

If one applies the same trend projection method directly on emissions, the relative probabilities SRES scenarios are all acceptable (that is, not lower than 10% chance) for the period 2000-2050. This suggests that the errors in the underlying scenarios largely cancel each other out.

The following conclusions can be drawn. The SRES scenarios are not equally likely. The A2 is by far the most realistic. The SRES scenarios do not span the range of plausible futures. The range of emissions can be somewhat wider, and the range of underlying development can be much wider. The SRES scenarios do not accord with past trends. On the one hand, this makes for interesting scenarios. On the other hand, it is odd that all SRES scenarios break with past trends at the same time, and that this trend break is sometimes at the point where data end and scenarios start.

The SRES scenarios are therefore useful as emissions scenarios. When used in climate models, they more or less span the range of not implausible futures. The SRES scenarios are less useful for climate change impact analysis, at least for those studies in which impacts do not only depend on climate change but also on vulnerability and hence development. The SRES scenarios are less useful for emission abatement studies, at least for those studies that use regional models and are interested in the distribution of mitigation costs and responsibilities.

Technological Change: Exploring its Implications for the Economics of Atmospheric Stabilisation

Preliminary insights from the Innovation Modelling Comparison Project

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1. Introduction

This paper reports some preliminary results of the Innovation Modelling Comparison Project (IMCP). The IMCP is an international collaboration with the objective of improving the understanding of the insights from differences in model formulations and their results on the one hand, and to identify robust results across models on the other hand. The IMCP focuses on mechanisms of endogenous technological change and its impact in the context of climate policy. Technological change is widely recognised as key to tackling climate change; less well understood are the mechanisms by which such change occurs, and the diverse and varied ways this can be included in economy-energy-environment models.

2. Aim of the project

The IMCP aims to look at the impact of endogenous technological change on the economics of stabilising carbon dioxide emissions at different levels. With its special focus on endogenous technological change it is complementary to model comparisons of the Stanford Energy Modelling Forum (EMF). This paper compares and analyses results from a broad range of economic models paying especial attention to the following questions: First, what are the impacts of the different mitigation options on macroeconomic costs under different stabilisation scenarios in different regions? Second, how and why do time-paths of emissions constrained by climate policies differ between different formulations of technological change? Third, what are sign and extent of international spillover effects arising from technology diffusion?

3. The Role of Technological change: a brief modeling survey

Environmental and climate policy interventions create constraints and incentives that affect the process of technological change. Imposition of climate control instruments can stimulate invention and innovation processes. The invention and innovation practices are carried out primarily in private firms through increased research and development (R&D). Technological innovations can become widely available by technological diffusion processes. The induced innovation hypothesis recognizes R&D investments as profit-motivated investments stimulated by relative price changes. Climate policy measures that increase the price of fossil fuels augment the market for low carbon technologies. This effect creates incentives for increased R&D expenditures in the sectors affected by climate change. Increased R&D expenditures accelerate technological change that lowers the costs of low carbon technologies. These effects reduce compliance costs and can lead to increased profits (Porter and van der Linde 1995). However, investment in R&D could also "crowd out" other investments (Gray and Shadbegian 1998). Which could reduce the profits of firms. Econometric tests confirm these ambiguous results. Jaffe and Palmer (1997) find that a carbon tax reduces aggregate R&D causing a decline of knowledge accumulation and a decrease in the rate of technological progress, which results in a deterioration of income and output. Other analyses conclude that environmental policies can have a strong positive feedback on innovation and may induce beneficial economic outcomes (Popp, 2001 and 2002).
In economy-energy-environment models, the representation of technological changes is an important

source of uncertainty in determining the economic costs of climate policy strategies (see Jaffe et al. 1995 and Jaffe 2000). Many of the models applied to climate change analysis have treated technological changes as "exogenous", i.e. technological changes are defined as assumptions fed into the model, rather than emerging as part of the economic response to scarcities within the model.

Economy-climate models that incorporate technological change endogenously in this sense determine technological innovations either by investment in R&D as “induced technological progress”, integration of spillovers from R&D, or by including technological learning processes, particularly scale-economies and “learning by doing” phenomena. Numerous modelling approaches investigate the economic effects of technological change. On a micro, or bottom-up, scale different kinds of technologies are assessed in detail. On a macro, or top-down, scale aggregated economic feedback effects of technological progress are evaluated. In top-down models, technological progress is mostly represented as an innovation which produces the same amount of output (GDP) with smaller amounts of input factors. This implies an increase in input factor productivity. In contrast to an exogenous representation, induced technological progress endogenously triggers increased productivities by different sources such as investment-induced technical progress or R&D-induced technological progress. Modelling results confirm that excluding endogenously determined technological responses leads to an overestimation of compliance costs (Loeschel 2002, Kemfert 2005).

As initial installations of technological innovations are very often expensive, costs decline over time with increasing experience. One representation of endogenous responses in technology-rich models is through ‘experience curves’. These describe cost reductions as a function of accumulated experience in production. Many applied modelling concepts, including bottom-up modelling concepts with a detailed representation of energy technologies, apply learning curves as a meaningful description of technological changes (Grübler et al. 1999, Gerlagh and van der Zwaan 2003, or Azar and Dowlatabadi 1999). Dowlatabadi (1998) finds that emission abatement costs decline substantially if technological change is induced by technological progress, and when learning-by-doing is considered. Gerlagh and van der Zwaan (2003) find that the learning by doing effects that make cheaper non-carbon technologies available induce positive economic impacts and reduce the costs of climate policies.

Some models that incorporate induced technological change by investment in R&D, but also increased opportunity costs, do not find large impacts on abatement costs (Goulder and Schneider 1999, Nordhaus 2002, and Buonanno et al. 2003). Buonanno et al. (2003) introduce technological change into the RICE model. The model comprises one R&D sector, whose accumulated stock has two effects: it increases total factor productivity and decreases the carbon intensity of the economy. In contrast to Nordhaus’ R&DICE, R&D investments not only reduce carbon intensity but also create an external effect increasing the total productivity of the whole economy. Therefore, economic growth and emissions can only be decoupled if the parameters are chosen in a way where the reduction in carbon intensity overcompensates the growth-enhancing effect of R&D investments. Popp (2004) shows that induced technological change significantly raises the benefits of a specific climate policy strategy, but does not largely reduce the costs. He finds that a backstop technology has a greater potential to reduce the costs of climate protection than the improvement of energy efficiency because the R&D investments needed in the latter case crowd out the R&D investments in other sectors. Therefore, the net impact of induced technological change on the macro-economic mitigation costs is not substantial. However, these results are derived using an exogenous time path for total factor productivity. Many models that include learning-by-doing find large welfare gains from induced technological change (Chakravorty et al. 1997, Goulder and Mathai 2002, Manne and Richels 2005, Gerlagh and van der Zwaan 2003). This result is confirmed by many bottom-up energy system models – learning-by-doing within the renewable energy sector reduces the costs of meeting specific concentration targets (Manne and Barreto 2004, Kypreos and Barreto 2000). Edenhofer et. al. (2005) have derived the opportunity costs of R&D investments in an endogenous growth framework incorporating different energy sectors and a sector for resource extraction. It turns out that the contributions of different mitigation options to achieving climate protection goals differ very much. Moreover, induced technological change reduces the macro-economic mitigation costs substantially.

4. Method of model comparison

The models participating in this comparative study have in common that they incorporate technological change in innovative ways, and that they allow an assessment of macro-economic costs of global carbon dioxide mitigation. At the same time, these models cover a wide range of model types. We differentiate four models types that we characterise in the following way:

1. **Econometric models** determine economic interlinkages based on different economic theoretical concepts. They are based on time series data. This class is represented by the Cambridge Econometrics' E3MG model, of which the main features are Keynesian disequilibrium macroeconomic economic structure estimated in time series data using Engle-Granger cointegration, and input-output structure for each region. E3MG differentiates 20 world regions, 41 industrial sectors, 28 consumption categories, 11 fuels, and 17 fuel users.
2. **Endogenous Economic Growth Integrated Assessment Models.** Economic growth is a driving force of GHG emissions. Endogenous growth theory views long-term dynamics of technological change as an outcome of endogenous investment decisions. Early Integrated Assessment Models (IAM) in this framework were highly aggregated models without technological detail. Recently, Endogenous Growth IAM have begun to incorporate technological dynamics by disaggregating selected sectors.
3. **Computable General Equilibrium models** (CGE) divide the economy into distinct, interdependent sectors. Households and firms within these sectors independently try to optimise their welfare and their profits, respectively. Within CGE models an equilibrium is calculated at each point in time, which guarantees not only that all markets are cleared but also that a Pareto-optimum is achieved. Sectoral resolution and the dynamics of relative prices are the main strengths of CGE models.
4. **Energy System Models** derive a cost-minimal sequence of energy technologies for an exogenously given energy demand using linear programming. In more advanced versions the energy technologies are improved by learning-by-doing. The main advantage of this approach is that technological change is based on an engineering assessment of different technologies.

The project also outlines features of technological change which are not captured by the participating modelling teams so far. A first step in this direction is the following classification of endogenous technological change: Table 1 comprises a list of modelling teams, modelling types and features of technological change.

1. **Learning-by-doing** generally means that an activity improves its own efficiency. The underlying assumption is the existence of learning curves, i.e. rising efficiencies or declining costs are a function of accumulated experience. Often, investment costs are modelled to be decreasing with cumulative investments, or efficiency parameters are modelled to increase with cumulative activity. Learning-by-doing can work within and between sectors but also across national boundaries. International spillovers induced by learning-by-doing are just starting to be seen as a potentially positive feedback. For example, renewable energy technologies may have large global benefits if their learning-by-doing potential is transmitted in developing countries by foreign direct investments.
2. **Learning-by-searching** describes a specific activity leading to innovations. In contrast to learning-by-doing it is assumed that such an effort is required for technological progress, or that innovation can be sought independent of other activities. Learning-by-searching may be implemented as research and development (R&D) investments which in the end increase an efficiency parameter or decrease investment costs. Learning-by-searching is often incorporated in models via so-called double factor learning curves improving efficiency parameters of a specific technology or sector. They can also diffuse across national and regional boundaries.
3. **R&D investments:** There are also R&D investments at a macro-economic level where the overall efficiency parameters in the production function are determined by R&D investments. In general this R&D investments have the potential to improve labour, energy and capital productivity.

4. **Path dependent investments:** Technological change is path-dependent if initial conditions determine the choice of long-term technological trajectories. The change to more efficient technological trajectories would induce prohibitive costs. Such a "lock-in" can be overcome if "lock-out options" are available which reduce the costs of transition through path-dependent processes.
5. **Externalities from capital accumulation:** Investment externalities describe capital-embodied technological change, i.e. by purchasing new equipment the inherent technological progress becomes available, leading to an increased productivity. This is often modelled by letting investments cause improvements of efficiency parameters in the production function.
6. **Vintages of capital stock:** Technological progress makes increasingly better equipment available for investments at later dates. This motivates differentiating the age-structure of capital stocks, where different vintages of capital stock differ in efficiency parameters.

Modelling teams have been asked to calibrate their models to a given baseline; for this purpose, the Common POLES/IMAGE (CPI) baseline was selected. It was agreed to run CO_2 concentration scenarios at stabilisation levels of 450, 500, and 550 ppm CO_2. Current debate about climate policy targets often includes the target of a maximum 2°C increase of the global mean temperature relative to the pre-industrial level. The European Union, for example, has adopted the 2°C target. We would like to stress that meeting this restriction is a greater challenge than 450 ppm CO_2 stabilisation: Simulations under a 2°C warming constraint show maximum concentrations below 450 ppm CO_2. Running simulations that keep a 2°C constraint requires the integration of a climate module that translates GHG concentrations to global mean temperature. The technical effort therefore goes well beyond the task of running CO_2 stabilisation scenarios. Alternatively, stricter CO_2 concentration scenarios than 450 ppm could be used to estimate the effect of a 2°C target on the economy. Extensions of this model comparison exercise that heed this issue are under preparation.

In order to assess the impact that the presence of endogenous technological change has on model output, these scenarios were run with and without endogenous technological change enabled. From the multitude of model output of the different models, we asked modellers to report the following key values: gross world product, carbon dioxide emissions and concentrations, marginal costs of emissions and of fossil energy, energy consumption, and investments related to technological change. Where possible, we asked to distinguish different energy sources, world regions, and to report other GHG.

Preliminary results from those models able to meet the first deadline include the following findings.

Previous model comparison exercises have shown that CGE models tend to calculate higher mitigation costs than energy system models or economic growth models (Loeschel 2002); we find that this result still holds when technological change is endogenised. Also, the presence of endogenous technological change seems to have only little impact on macro-economic mitigation costs in some models, whereas in other models it has a substantial impact. In this research project we try to identify the crucial economic mechanisms driving the different impacts of technological change on mitigation costs, investment dynamics, and other crucial macro-economic variables.

It is desirable to identify the contributions that different carbon mitigation options have in achieving an overall mitigation target, and to assess the role of technological change in a mitigation effort. Kaya's identity provides a set of indicators that pinpoint the different ways taken by models to meet a given target, namely the decomposition of carbon dioxide emissions into GWP, its energy intensity, and carbon intensity of the energy (Figure 1).

While in some models mainly energy consumption and GWP are reduced in order to achieve emission reductions (even in the case of endogenous technological change), we find that in other models the reduction of carbon-intensity is predominant. Here, reduction of carbon-intensity is mainly triggered by the introduction of backstop technologies, and the transformation of the fuel mix in general.

This analysis can be taken to a more detailed level by extending the decomposition analysis to features of technological change. To do so, identities similar to Kaya's identity have to be derived, e.g. decomposing carbon intensity reduction in effects of increasing the share renewable energy, capturing and sequestering CO_2, and switching from coal to gas. In IMCP we try to improve on comparing highly aggregated variables like GDP losses because at high levels of aggregation structural changes are not resolved which are crucial in assessing the impact of technological options and in designing efficient climate policies.

5. Scientific challenges of IMCP

1. **Improving model comparability:** It is well-known that the chosen baseline effects mitigation costs, shadow prices, and investment trajectories in a major way. The IMCP seekes to harmonize baselines and scenarios among the models. Furthermore, a reasonable set of indicators has to be developed which captures the impact of endogenous technological change on crucial parameters.
2. **Harmonizing concentration targets:** There are different ways to restrict carbon dioxide emissions in model simulations. The IMCP runs concentration stabilisation scenarios, which may need to be phrased as CO_2 only, CO_2 equivalent, or cumulative CO_2 emission targets depending on the model. Additionally, due to differences in the carbon cycle mode, the same concentration target may appear more restrictive in some models than others. However, the straightforward solution of using the same carbon cycle model may not be feasible because of implementational issues.
3. **Incorporating further aspects of Endogenous Technological Change:** As is evident from Table 1, few models incorporate any endogenous technological change features beyond learning-by-doing. The IMCP aims to debate which type of technological change to incorporate in order to match empirical stylised facts of economic growth, such as vintages, externalities induced by physical and human capital accumulation.
4. **Calibration and empirical validation of the models:** Applied models are based on stylized assumptions about key parameters such as discount rate or Armington and substitution elasticities. Especially the incorporation of endogenous technological change takes into account only few empirical assessments of concrete case studies. We aim at estimating the elasticities and key factors that drive endogenous technological changes in diverse countries of the world.

There is consensus that mitigation costs depend critically on the assumptions about technological change. The IMCP intends to analyse the influence of crucial parameters of technological change on important variables such as investments, emissions etc. in a quantitative way. Based on this modelling comparison exercise, empirical studies could be conducted in order to validate models. This effort is worth to be undertaken because most these models are heavily used as support systems for decision makers.

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Figure 1: Contributions to cumulative CO_2 reduction 2000-2100. This Figure shows the cumulative amount of CO_2 mitigated in the period from 2000 until 2100 in the 450 ppm CO_2 concentration scenario with technological change, relative to the baseline. A decomposition analysis on the basis of Kaya's identity was used to attribute CO_2 reduction to the effects of reductions in carbon intensity, energy intensity, and gross world product.

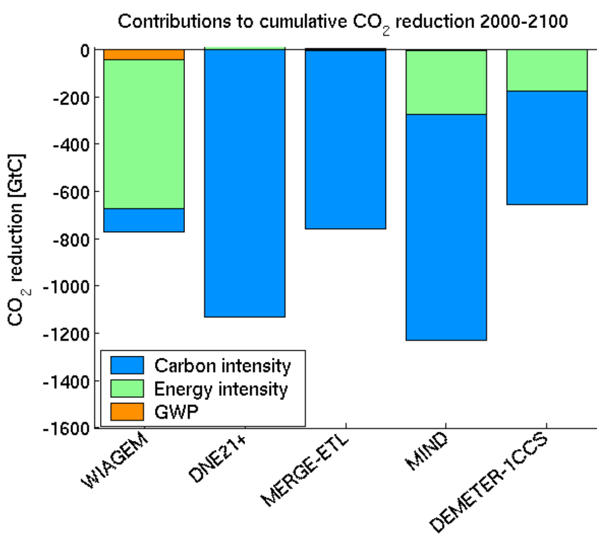

Table 1: This table lists the modelling groups participating in IMCP, and the features of technological change implemented in these models.

Model	Group	Type	Learning-by-doing	Learning-by-searching	R&D invest-ments	Path dependent investments	Externalities from capital accumulation	Vintage capital
E3MG	Cambridge	Econometric	Y	N	Y	Y	N	N
GET-LF-E	Chalmers	ESM	N	Y	N	N	N	N
worldscan	CPB	CGE/IAM	N	N	N	N	N	N
WIAGEM	DIW	CGE/IAM	N	N	Y	N	N	N
AMIGA	EPA	ESM/IAM	Y	N	Y	Y	Y	Y
FEEM-RICE	FEEM	Growth-IAM	Y	Y	Y	N	N	N
MESSAGE	IIASA	ESM	Y	N	N	N	N	N
PAGE	Hope	IAM	N	N	N	N	N	N
MERGE-ETL	PSI	Perfect foresight IAM	Y	Y	N	N	N	N
GEM-E3	MERIT	CGE	N	N	N	N	N	N
PACE	ZEW	CGE	N	N	N	N	N	N
AIM	NIES	CGE/IAM	Y	N	N	N	N	N
DNE21+	RITE	ESM	Y	N	N	N	N	Y
IMACLIM-R	CIRED	Growth	Y	N	Y	N	N	N
MIND	PIK	Growth	Y	N	Y	N	N	Y
IMAGE	RIVM	CGE/IAM	Y	N	Y	N	N	N
DEMETER-1CCS	IVM	Growth-IAM	Y	N	N	Y	Y	Y
DEMETER-2E	IVM	Partial-equ.-IAM	Y	Y	Y	Y	Y	N
ENTICE	Popp	Growth-IAM	Y	Y	Y	N	N	N
FUND	UHH	IAM with Solow growth model	Y	N	N	N	N	N

Modeling Endogenous Technological Change

A reflection for emission scenario builders

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1. Introduction

New ways of modeling endogenous technological change have been developed in endogenous growth theory. Insights from this literature can be used to incorporate endogenous technological change in economic climate change models. Moreover, merging growth models and climate change models, we might strengthen the model link between climate policy and development. We argue that the endogenous growth insights differ markedly from the environmental economics insights on technological change.

2. Partial abatement models versus endogenous growth

In the textbook case, technological change in the context of environmental issues is modeled as an shift in the marginal abatement cost curve. Technological change reduces the cost of reductions in emissions (cf. Goulder and Mathai 2000). This insight from partial equilibrium model does not generally carry over to general equilibrium models with endogenous technological change.

At the other extreme, (endogenous) technological change plays a key role in growth theory. In general equilibrium growth models, technological changes drives long-run per capita growth. When introducing environmental issues in standard endogenous models (Romer, 1990), a reduction in pollution generally crowds out investment in productivity improvements. As a result, the cost of reducing emissions is larger when technological change is endogenous than when technological change is independent of investments and profit incentives (Smulders 1998).

The contrast between the two results stems from the completely different nature of technological change in the partial abatement models and the endogenous growth models. In the former, technological change reduces the cost of "restauration activities" that do not affect production decisions. Moreover, what is called technological change should better be labeled diffusion, since the supply of new technologies is not modeled. In endogenous growth models, technological change reduces the cost of production by increasing the productivity of production factors, including polluting input factors like energy. Thus, technological change increases, rather than decreases, the cost of reducing polluting inputs.

The two results are extreme. We generalize the general equilibirum models with endogenous technological change to find how robust the finding is that endogenous technlogical change increases the cost of emissions reduction policies.

3. The degree of endogeneity of technological change

Conventional models assume completely exogenous technological change. Some recent models have introduced the notion of induced technological change: price changes might change the path of technology. Endogenous growth models assume all technological change stems from profit maximizing innovating firms.

As a generalization, we considers a model in which technological change stems from both exogenous sources as endogenous investments. Changing the relative weight of endogenous technological change in total technological change, we find that the larger this weight, the more emission reduction policies should be undertaken early on to minimize the cost of climate change. Thus, frontloading of abatement becomes more important when endogenous technology plays a larger role (Smulders, 1998). In the partial equilibrium model the opposite result – optimal backloading of abatement – is found (Goulder and Mathai, 1998).

4. Modeling issues

To endogenize technological change, in market economy models, learning by doing (LbD) or Research and Development (R&D) can be modeled. R&D modeling requires:

- imperfect competition. Firms must have the incentive to increase profits through innovation
- knowledge spillovers. Innovators generally cannot capture the full returns to R&D because of the non-rivalness of knowledge that is generated by R&D.
- taking into account multiple externalities and distortions (at least with respect to the environmnet and to innovation).

LbD is mostly modeled through learning curves: a larger scale of (cumulative) activity speeds up cost reductions (technological change). Often it is argued that LbD is simpler to model (e.g. Galeotti, 2004). For example, by linking cost reductions to sector-wide activity levels, individual firms do not need to make monopoly profits and the sector can be modeled as being fully competitive. However, when thinking about optimal or cost-reducing emission reduction, an investment cost is still involved: cost reductions can only be realized by increasing the scale of one sector at the cost of learning in other sectors.

Technological change may occur in various dimensions: some innovations reduce thae cost of energy-intensive technologies, other innovations induce energy saving. Hence, the direction (or bias) of technological change should be taken into account and should be endogenized. Relevant dimensions of technological change are abatement versus integrated technology; and diffusion versus innovation.

A new workhorse general equilibrium model for directed technological change is the model by Acemoglu (2002). He models directed technological by allowing innovation to affect factor augmentation levels. In the context of climate change models, innovators develop new (intermediate) goods or production processes in energy-intensive sectors or in energy-extensive sectors. For example, the economy's production function might be given by $Y = F (A_M M, A_E E)$, where $F(.)$is a CES production function, M and E are man-made and energy inputs, respectively and A_M and A_E are factor augmentation evels, which are endogeously determined by innovation efforts.

Leaving out one or more of the possible directions of technological change (by treating one of the factor augmentation levels as exogenous) biases the results. For example, if in the example above A_E is endogenous and A_M is exogeous, a cut in emissions E might increase the rate of return to innovation (if substitution is poor – with good substitution the rate falls). However, if A_E is exogenous and A_M is endogeous, a cut in emissions E always decreases the rate of return to innovation. This example also shows that the interaction between innovation and substitution is an important modeling issue.

5. Directed technological change

A policy of emissions reduction changes the relative incentives to innovate in the sectors and shifts the direction of technological change. Depending on externalities, there is now a possibility that the return to innovation goes up such that innovation is crowded in (Smulders and De Nooij, 2003, cf. Goulder and Schneider 1999). Nevertheless, the overall cost of emissions reduction is larger with directed technological change than with exogenous technological change.

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Endogenous Technological Change in Long-term Emissions and Stabilization Scenarios

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Technology is the broad set of processes covering know-how, experience and equipment, used by humans to produce services and transform resources.[2] Technological change is a central issue in addressing climate change. The character of technology employed by humans affects both the emissions of greenhouse gases and the cost of limiting those emissions. The state of technology makes an enormous difference to the cost of achieving any environmental goal. The more stringent the environmental goal, the greater is the value of technology in meeting that goal.

As a consequence, the determinants of change in technology have generated renewed interest. Unfortunately, the present state of knowledge is such that there is no simple answer to the question, what are the mechanisms by which technology changes? This interest has generated a recent literature that has explored the relationship between alternative mechanisms by which technology might change and factors such as the emissions pathway, policy portfolio, and the cost of meeting an environmental goal. That literature has produced a variety of results, not all of which are consistent.[3]

Technology in use is highly heterogeneous. This heterogeneity reflects a variety of factors ranging from the history of technology deployment and the vintage of devices in existence to imperfections in institutions and information transfer to variation in factor endowments from place to place. At any point in time there is a significant difference between technology that is deployed and the best technologies that could be constructed and deployed based on existing knowledge (the "technological frontier"). This distinction is real, but frequently blurred in models. The focus of this paper is on the forces shaping the technology frontier and largely ignores the issue of technology deployment and diffusion and its associated voluminous literature.[4]

There is a wide array of factors that have been identified as influencing the technology frontier including research and development (R&D), learning, and spillovers[5]. R&D includes both basic scientific research and applied research. Basic scientific research is the foundation on which applications are built[6]. In contrast applied research refers to those activities through which basic knowledge is transformed into technology options. R&D

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[2] See J. Edmonds and J. Moreira. 2003.

[3] For example Grubb (1997) concluded, "… policies that act to constrain CO_2 emissions will tend to create incentives in energy markets to turn the bulk of corporate energy R&D away from improving fossil fuel technologies towards developing and deploying lower carbon technologies." in contrast, Nordhaus (2002) concluded, "…that we should not look to regulatory stringency or high emissions taxes as a way of forcing inventors to solve our global environmental problems. Popp (2002) concludes that, "…the effect of induced innovation on [optimal] emissions and mean global temperature is small." Goulder and Mathai (1999) concluded that, "When knowledge is gained through R&D investments, the presence of ITC justifies shifting some abatement from the present to the future. However, when knowledge is accumulated via learning-by-doing the impact on the timing of abatement is analytically ambiguous." And Smulders (1997) writes "…the introduction of endogenous technological change has nontrivial implications for optimal environmental policy. The numerical calculation in this paper show that the impact of endogenous technological change on short-run pollution reduction policies may be large. If half of technological change is endogenously generated, first-period pollution reduction should be 16 to 19 percent higher than when technological progress is completely exogenous."

[4] See for example, Metz et al. (2000) for an assessment of this literature.

[5] It is worth noting that we do not consider economies of scale as a source of technological change, but rather a characteristic of either the technology or the market. These characteristics can have an important influence on technology deployment. For example, in the automobile manufacturing sector scale matters. As a consequence, small manufacturing production runs are associated with high unit costs, while large production runs are associated with lower costs.

[6] Stokes (1997) makes the distinction between two types of basic scientific research: curiosity driven basic science research ("Bohr's Quadrant") and basic research motivated by potential use ("Pasteur's Quadrant").

is funded by both the government and the private sectors and is conducted by industry, government, universities, not-for-profit companies, and research consortia.

A great deal of attention has been paid to learning-by-doing (or using) in recent studies. But, that literature has not always been careful in distinguishing between **learning-by-doing**, which refers to the observation that the more an individual or organization repeats a task, the more adept or efficient it becomes at that task, and **experience curves**, which refers to the statistical relationship between cost and cumulative production.[7] There is a well established literature that documents the causal relationship between task repetition and efficiency of production. Experience curves, on the other hand, are a reflection of all effects by all factors that shape both cost and technology deployment.

The effect of activities undertaken in another domain on technology is referred to as a spillover. Many examples exist. The development of advanced turbine designs in the aerospace industry made the high efficiency natural gas combined cycle turbine possible. Developments in sensors and computational capabilities made a marketable hybrid gasoline-electric vehicle possible. The development of advanced computational capabilities combined with the development of magnetic resonance imagery led to the development of 3D seismic imagery, which combined with directional drilling, greatly expanded oil and gas reserves. It is important to note that spillover effects make technology advance possible, but generally require alterations to deploy in the receiving sector. Spillovers are international[8], interindustry and/or intraindustry in origin. The literature on spillovers also distinguishes between spillovers in knowledge, and "rent" spillovers, that is, spillovers strictly of economic benefits that occur indirectly through market forces.

Both the public and private sectors participate in the process of technology development. In general we treat private sector actions as growing out of the competitive process and framed by markets and tempered by institutions and market conditions. We treat government activates as affecting market conditions and institutions. Government policy can affect R&D directly through support for basic research and through applied research.[9]

A central issue is the relative contributions of various forces to shaping technological change. This issue has two facets, historical and prospective. The historical component of the problem is determining the relative contributions of various factors for any historical change in technology. The prospective component of the problem is establishing the relative contributions of various factors for future technologies. Both are complicated by the question of extra sectoral effects. That is, what effect did an improvement in technology have on technology in other sectors? This is particularly pertinent when one contemplates a technology policy that would increase the rate of technological change in a specific sector. One must also ask to what degree that policy altered the rate of technological change in other sectors. Government policy can affect the rate of technological change through various pathways including direct government sponsored R&D including support for basic and/or applied research, and indirectly through policies that affect institutions and markets, such as patent law, taxes, regulations, or technology deployment activities.

There is a substantial literature on the sources of technological change including literatures on productivity and R&D[10], statistical experience curves[11], general purpose technologies[12], technology opportunity[13], environmental regulation and environmental technology

[7] The relationship between cumulative production and declining costs has been variously termed the learning curve, progress function, and experience curve, depending on the level of analysis and how it is interpreted (Dutton and Thomas 1984). Here we use the term “experience curve” to limit confusion with learning-by-doing.

[8] The distinction between international transfer of technology and international spillovers is somewhat vague.

[9] Examples include the development of technologies for the measurement, monitoring and verification of phenomena as well as support for technology development.

[10] See for example, Griliches (1992), Nadiri (1993), Australian Industry Commission (1995).

[11] See for example, Christianssion (1995), McDonald & Schrattenholzer (2001).

[12] See for example, Bresnahan & Trajtenberg (1992), Helpman (1998).

[13] See for example, Klevorick, et al. (1995).

advance[14], and "demand-pull" versus "technology push"[15]. While this literature has not produced a simple mechanism to forecast technological change, it has produced many insights. It is clear, for example, that induced environmental innovation is a reality. But, technology also advances as a function of sources largely unresponsive to environmental policies. This literature is unable to determine whether own-industry or extra-industry sources of technological change are more important, or whether learning is any more or less important than R&D. However, the literature does show that there are strong interactions between different modes of technological advance. For example, spillovers and R&D interact strongly. Many instances exist in which technological advance outside the industry required additional R&D to enable its adoption.

One of the most important findings is that the "optimal" or "right" technology policy is unlikely to be a simple prescription. For example, there is little evidence that technology "Push" policies, which directly influence technological advance (e.g., publicly funded R&D), or technology "Pull" policies, which alter private incentives and ability to innovate (e.g., environmental regulation, patent laws, anti-trust regulation), are either dominant strategies.[16] Furthermore, the literature suggests that spillovers are strong and that the maintenance of a strong technological base for society is important to any technology strategy. Thus, a strong educational system, support for basic sciences, including both fundamental scientific research motivated by curiosity and fundamental scientific research motivated by potential use, and the institutions to encourage technology development such as patent law, are potentially central elements in a technology strategy to address climate change.[17]

While research indicates that the processes of technological advance are varied and complex, energy-economy model representations of technological advance tend to be simple and mechanistic. Ironically the simplicity in model representation is an outgrowth of the complexity and uncertainty surrounding real world processes.

The role of technology in any given model will be shaped by the character of the model. Several implications flow naturally from this point. First, and most obvious, technologies that are not included in the model cannot play a role. A wide array of technologies, such as for example, hydrogen, carbon dioxide capture and storage, combined heat and power, and biotechnology, has been identified as potentially contributing to the future global energy system, particularly in the presence of policies to stabilize greenhouse gas concentrations. Yet many models do not consider these technologies explicitly. While this is most apparent where advanced energy technologies are concerned, it is also the case in other more familiar domains such as energy end-use technologies. Many models represent the use of energy in buildings, industry and transport without specific reference to technology. Yet, changes in energy intensity in scenarios account for a larger change in potential energy use than expanded energy supply. Thus, an obvious source of potential insight lies in an enhanced representation of technology in energy end-use to supplement representations of energy supply technologies. Even many energy supply technologies are represented crudely and analytical insights could be gained by their improved characterization.

Models are also not always careful in distinguishing between best available technology and technology in use. This is a common problem when the vintage of plant and equipment is not explicitly recognized. Physical capital stocks embody a specific technology regime and its character places limits on technological change. The degree of flexibility available at the time of investment in new plant and equipment is significantly greater than afterward.[18] Furthermore, because the capital cost of a technology is a sunk cost, existing plant and equipment

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[14] See for example, Jaffe & Palmer (1996), Lanjouw & Mody (1996), Brunnermeier & Cohen (2003), Newell, Jaffe, & Stavins (1998).
[15] See for example, Mowery & Rosenberg (1979), Rosenberg (1982), Mowery & Rosenberg (1989), Utterback (1996), Rycroft & Kash (1999).
[16] See, for example, Norberg-Bohm (2000) and Norberg-Bohm (2002).
[17] See, for example, Nelson (1993)
[18] The ability to retrofit existing plant and equipment increases technology flexibility somewhat.

can continue to operate long after the point in time when similar units cease to be chosen for deployment as new plant and equipment. Thus, the availability of older vintages of plant and equipment places limits on the penetration of new vintages of technology.

Many models of energy and greenhouse gas emissions place the mechanisms of energy technological change outside the model. That is, the advance of energy technologies is determined exogenously. In such models, technologies change either at a prescribed exogenous rate or as discrete changes over time. More recently studies have begun to consider the induced response of technological advance to government policies. Some studies have substituted experience curves for an exogenously specified description of technology and technological change over time.[19] Experience curves model the cost of supply as a simple function of cumulative deployment. This model is based on observations of a statistical relationship between production cost and cumulative deployment, as for example in Figure 1. As noted earlier, this relationship is frequently confused with learning-by-doing, which is the relationship between repetition of a task and efficiency. Experience curves are a statistical relationship and as such reflect all factors that affect cost and all factors that affect deployment. It is conventional to attribute the entire decline in the cost of production to cumulative deployment. Soderholm and Sundqvist (2003) warn that this can lead to attribution problems. For example, Figure 2 shows experience curves derived from a model run using the MiniCAM modeling framework, described in Edmonds et al. (2004), which exhibit a negative correlation between the log of technology cost and log of cumulative production consistent with the experience curve formulation, even though cost was determined by an exogenous rate of technological change.

Researchers have begun to develop more sophisticated representations of technology change in energy-economy models such as for example, two-factor experience curves, which incorporate direct R&D investment along with technology deployment.[20] While two-factor experience curves reflect a realization that there is more to technological change than merely cumulative deployment, they ignore key features such as spillovers. Manne and Richels (2002) explored the implications of an induced technological change model with both experience curves and spillover effects and show that including spillover effects can have important implications for key analytical results.

Even these efforts have only begun to scratch the surface of endogenous technological change. A sense of the richness of the phenomenon can be gleaned by examining the influence diagram developed by Clarke and Weyant (2002) to describe the many forces shaping technological change, Figure 3.[21] No modeling system presently in use comes close to incorporating the full richness of induced technological change described in Figure 3. They remain simple compared with the phenomenon they attempt to describe.

Modeling results have shown themselves to be highly contingent on both the form of the simple model employed and the parametric values employed to enliven them. It is therefore not surprising that the literature derived from simple models of endogenous technological change should generate diverse and sometimes conflicting results. Any simple deterministic model of technological change employed in the context of general energy-economy interactions will likely lead to incomplete or erroneous implications at some point. The challenge then is to move the state-of-the-art toward a more complete and sophisticated representation technology and technological change in analytical models.

[19] This literature is reviewed by Clarke et al. (2004) and McDonald, A. and L. Schrattenholzer (2001).

[20] This is sometimes referred to as "two-factor learning curves", but is more accurately described as "two-factor experience curves." See for example Barreto (2001), Bahn and Kypreos (2003) and Soderholm and Sundqvist (2003).

[21] The reader interested in understanding the details of this figure is directed to Clarke and Weyant (2002). Its purpose here is simply to convey the richness and complexity of the phenomenon of endogenous technological change.

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Figure 1: Experience Curves for Various Technologies Source: Grübler, et al. (1999), p.254.

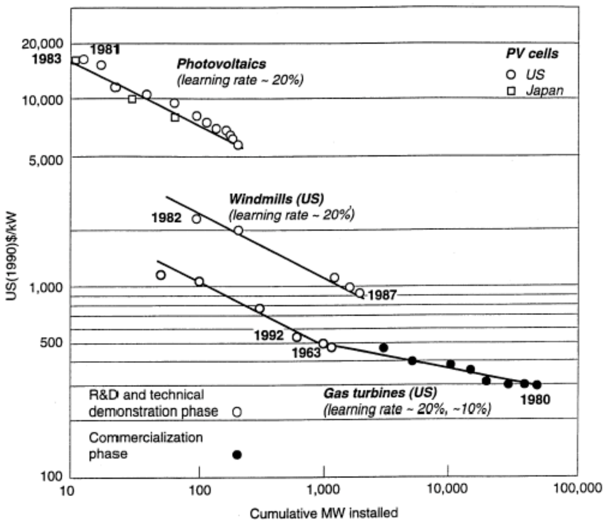


Figure 2: Experience Curves for Three Technologies Derived From a MiniCAM Scenario

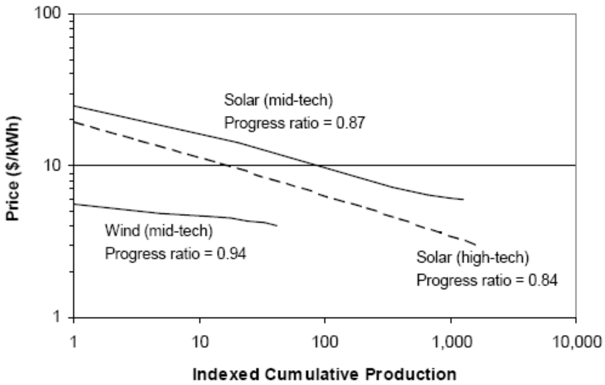
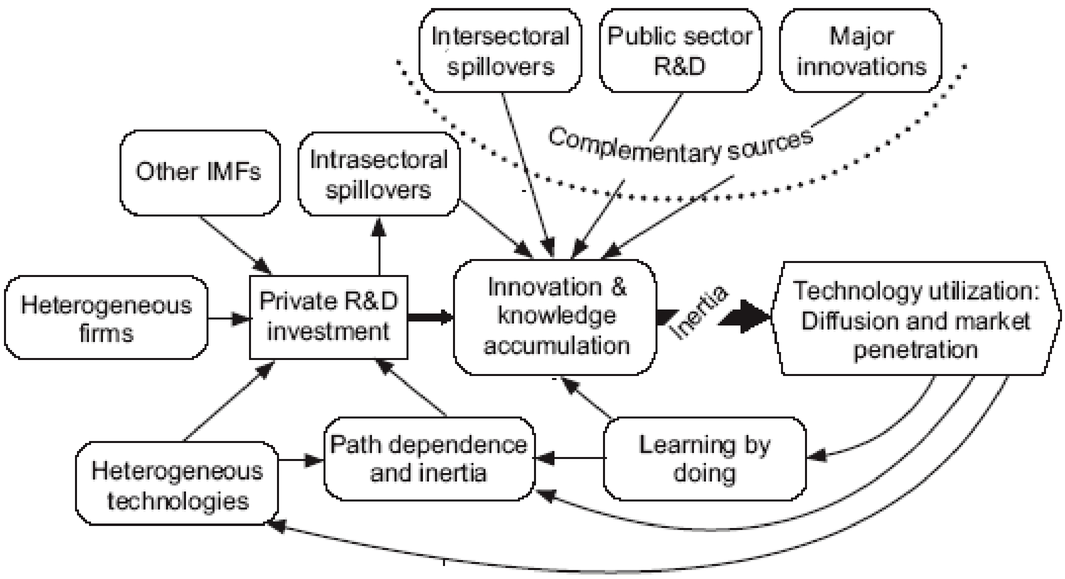


Figure 3: A More Complete Framework for Interpreting and Analyzing Technological Change. Source: Clarke and Weyant (2002), p.26.



Multigas scenarios to stabilise radiative forcing

Detlef van Vuuren, Francisco DelaChesnaye,
John Weyant

1. Introduction

Most literature on mitigation scenarios has concentrated on CO_2. Clearly, CO_2 is the most important greenhouse gas in terms of its contribution to increased radiative forcing. However, taken together the non-CO_2 gases contribute to about 25% current greenhouse gas emissions. One reason for the limited number of so-called 'multigas studies' is that consistent information on reduction potential for the non-CO_2 gases has been lacking. Available studies exploring the impacts of including non-CO_2 gases nevertheless find that major cost reductions can be obtained through the relatively cheap abatement options for some of the non-CO_2 gases and (more generally) the increase in flexibility (e.g. (Hayhoe et al. 1999; Reilly et al. 1999; Tol 1999; Blok et al. 2001; Jensen and Thelle 2001; Manne and Richels 2001; Lucas et al. 2002; Van Vuuren et al. 2003)) or indicate important advantages in terms of avoiding climate impacts (Hansen et al. 2000).

For 'CO_2-only' stabilization, a large range of studies, using different approaches, allows for a reasonably good understanding of mitigation potential and the associated range of costs across a wide range of climate targets (as a function of a wide range of assumptions and modelling approaches) (see Hourcade and Shukla (2001)). A similar situation has not existed for multi-gas stabilisation, as the number of individual studies were rather low, methodologies have not been compared and studies have hardly assessed multiple stabilisation targets. The context of a large modelling comparison study (EMF-21) and the data that has been collected in this context on marginal abatement costs for non-CO_2 (Kyoto) gases has provided an opportunity for change.

2. Methodological questions in multigas analysis

The multi-model study performed by EMF-21 was focussed on developing insights into the question about how multigas strategies on climate change differ from 'CO_2-only' mitigation strategies. Three methodological questions directly arise: 1) how to define the stabilisation target for a multi-gas stabilisation scenario; 2) how to allow for substitution among the different greenhouse gases; and 3) how to incorporate abatement of non-CO_2 gases into the modelling framework. Regarding the first question, in the EMF-21 study it was decided on the basis of analogy with CO_2-only (where studies focussed on stabilisation of the CO_2 concentration) to study the stabilisation of radiative forcing. More specifically, a comparison was made of model studies that focussed on stabilising radiative forcing at 4.5 W/m^2 based on a multi-gas versus a CO_2-only strategy.[22] The second and third question were left to individual modellers groups to decide upon. In this paper, we discuss the results of the EMF-21 modelling groups – and finally relate the results to the more methodological questions raised above.

3. Development of emissions without climate policies

All modeling groups provided a reference scenario on development of emissions of the major greenhouse gasses in the absence of climate policy. The results (Figure 1) show that in all cases, CO_2 emissions are projected to increase but the spread in model results is considerable, from 12 to 35 GtC. On average (across all models), CO_2 emissions increase by 1.4% per year during the 21st century. A considerable part of the spread in fact originates in the second part of the century where some models show sustained emission growth – while others show emission growth to slow down or even reverse (mostly by stabilising or declining global population). For most models, the projected emissions increase in CH_4 is considerably less than that of CO_2 for

[22] In addition, some models run a third scenario aiming to reduce the rate of temperature change.

most models. Averaged across the different models, the annual emission increase amounts to 0.6%, leading to a decline of the CH_4 share in total emissions from 18% to 13%. The main reason for the slower growth of CH_4 than those for CO_2 is that emissions mostly originate from the agriculture sector. Activities in this sector are expected to grow less fast than the main driver of CO_2 emissions, energy consumption. Emissions of N_2O are projected to grow at 0.2% annually in the 21st century. Also here, the share to total emissions drops from 9 to 4%. Even more as for CH_4, N_2O emissions originate from activities with clear saturation tendencies. Note that for N_2O, base year emissions of the different models differ substantially. Two factors may contribute to this. First of all, different definitions exist of what should be regarded as human-induced and natural emissions in the case of N_2O emissions from soils. Secondly, some models may not have included all emission sources. In conclusions, without climate policies the baseline scenarios explored project emissions of non-CO_2 gasses to grow – but their contribution to overall emissions to drop.

Figure 1 also compares the EMF-21 results with the IPCC SRES scenarios (Nakicenovic et al. 2000). In general, the range of the EMF-21 coincides well with those from SRES, certainly in the case of the non-CO_2 gasses.[23]

The total emissions growth under these baseline scenarios implies a strong increase in radiative forcing. Reported radiative forcing by the model groups increases from more-or-less 1.7 W/m^2 above pre-industrial now to 6-8 W/m^2 in 2100. This implies that none of the reference scenarios complies with the 4.5 W/m^2 stabilisation target without additional policies in place.

4. Stabilising radiative forcing at 4.5 W/m^2: Multi-gas versus CO_2-only

In order to reach the selected emission profile that leads to stabilisation of the greenhouse gas radiative forcing at 4.5 W/m^2, greenhouse gas emissions (measured in terms of CO_2-equivalents) in the different models need to be reduced by something in the order of 70% in 2100 in comparison to the baseline emissions (these numbers obviously differ strongly depending on the baseline.

In the CO_2-only strategy, by definition the largest contribution in mitigation comes from reducing CO_2 emissions. CO_2 emissions are reduced by about 75% in 2100 compared to baseline Nevertheless, as shown in Figure 2 a small part of the emission reductions are, in fact, achieved through reduction of CH_4 and N_2O, as the systemic changes in the energy system, induced by putting a price on carbon, also reduces these emissions..

In the Multi-gas scenario, less stringent reductions of CO_2 are obviously required. Nevertheless, still a considerable reduction of CO_2 is required given the large share of CO_2 in total emissions (on average, 60% in 2100) It should be noted that the reduction rates are not distributed evenly across the different gases and the contributions of different gasses change sharply over time.

The reduction for CH_4 in time differs notecably among the models. The choice of using GWPs as a basis for substitution among different gasses (as for instance defined in the Kyoto Protocol) plays a major role in this. For those models that base substitution on GWPs, the reduction of CH_4 emissions in the first three decades is already substantial. In contrast, models that do not use GWPs only start to reduce CH_4 substantially by the end of the period. The logic in the latter case is that aiming specifically at the long-term target set in the analyis, early CH_4 reduction does not pay-off given its short life-time. In the first group of models, however, CH_4 emissions are attractive based the available low cost reduction options. Other uncertainties that may contribute to the existing range among different models include the total reduction burden (as a function of baseline emissions), the distribution among different sources, the different methodologies in handling technology development..

[23] The most important difference is noted for CO_2: in the short term 2 SRES scenarios are above the EMF-21 range and in the longer run the B1 is clearly below the SRES range. The latter is caused by the deliberate assumption of radical energy efficiency improvement in B1.

For N_2O, the increased reduction in the multi-gas strategy is not that large as for CH_4. The main reason is that the identified potential for emission reduction for the main sources of N_2O emissions, fertiliser use and animal manure, is still limited. For N_2O, the use of GWPs does not play an important role – given its medium lifetime, which is similar to that of CO_2.

What does this mean for costs? Two concepts of costs have been looked at, the marginal costs of emission reduction and the reduction of GDP growth. Figure 3 shows the value of the required carbon tax in each of the models in the multi-gas case compared to the CO_2-only case. While there are clear differences among the models and in time, on average, the reduction in the marginal costs amounts to 30-60%. Almost all models show a much stronger reduction in the first decades, in which a considerable part of more expensive emission reductions now being replaced by cheaper reductions in non-CO_2 emissions. In the second part of the century, the reduction is reduced to about 30%. Some models, however, show again by the end of the scenario period an increasing cost benefit from the multi-gas strategy as it avoids the steep costs increases involved in deep CO_2 emission reductions. For the second cost indicator, GDP losses, more-or-less the same results can be seen. The cost reduction here is about 30-40%, with again the largest benefits occurring in the first decades of the scenario period.

5. Conclusions and way forward

EMF-21 performed a multi-model comparison project on scenarios that not only encompass CO_2, but also other major greenhouse gasses. The analysis showed the following results:

- Under baseline conditions, the share of non-CO_2 gasses is expected to be reduced from 25% to 17% (on average).
- A multigas strategy can achieve the same climate goal at considerably lower costs than a CO_2-only strategy. The cost reduction may amount to about 30-50%.
- Under a multi-gas strategy using the 100-year GWPs, the contribution of the non-CO_2 gases in total reductions is very large early in the scenario period (50-60% in the first two decades). Later in the scenario period, the contribution of most gases becomes more proportional to their share in baseline emissions.
- Not using GWPs (but instead determining substitution on the basis of cost-effectiveness in realising the long-term target within the model) implies that reductions in CH_4 are delayed to later in the century.
- Identified reduction potentials for non-CO_2 gasses get exhausted if substantial emission reductions are required. Further research into identifying means to reduce agriculture CH_4 and N_2O emissions and expected technological change is therefore an important research topic.
- Research has focussed on stabilising radiative forcing. However, some publications have indicated that stabilisation of the global temperature can be achieved more cost-effectively by profiles that result in radiative forcing levels that peak and then decline. Further research could focus on such overshoot scenarios.

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Figure 1: Baseline emission development in the EMF-21 scenarios (left) and comparison to the SRES scenarios (right)

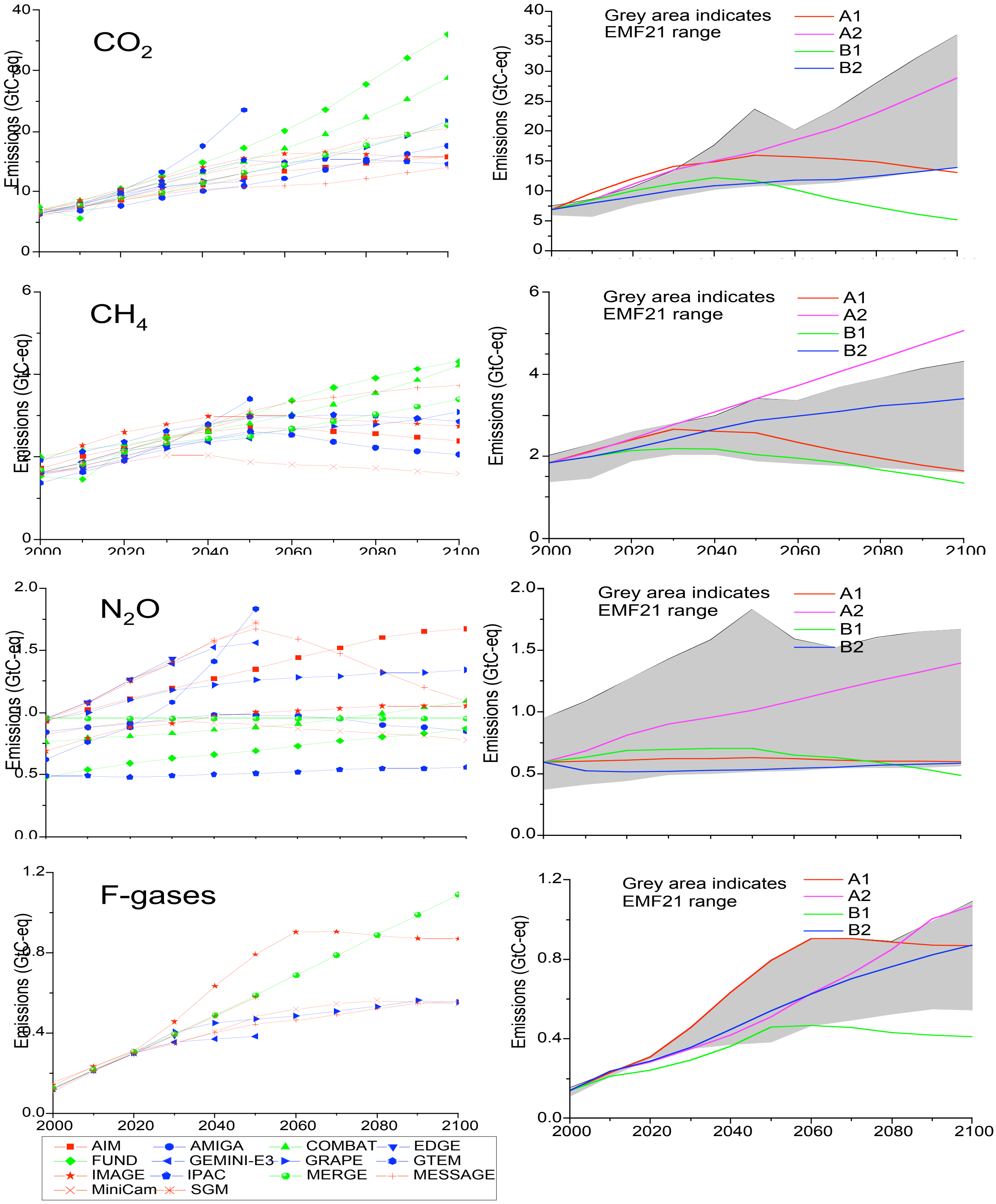


Figure 2: Reduction of emissions in the stabilisation strategies, CO_2-only versus multigas

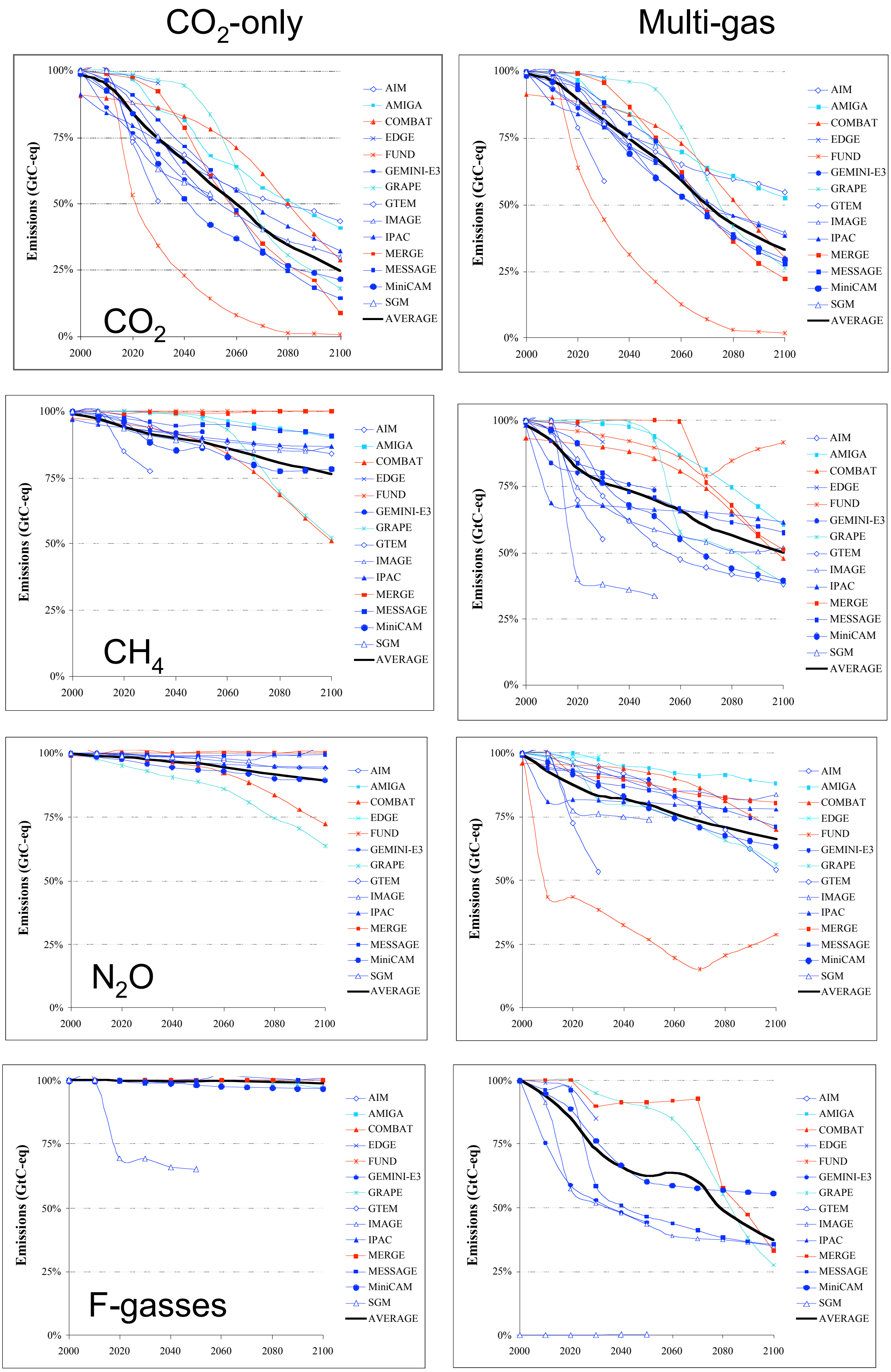
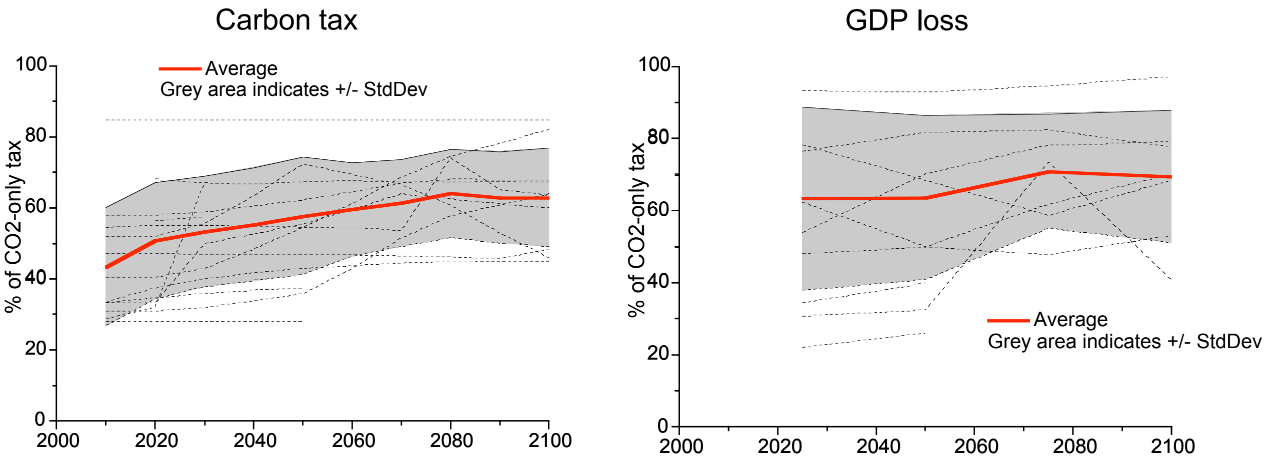


Figure 3: Costs of stabilising radiative forcing at 4.5 W/m², ratio of costs in the multigas case over the CO_2-only case.



Multi-Gas mitigation analysis for Global and China

Kejun Jiang, Xiulian Hu, Zhu Songli
Energy Research Institute

By recognizing the importance of non-CO_2 gases mitigation for climate change abatement, modeling study for multi-gas scenarios was conducted by using IPAC model. This paper presents the study for China and global analysis. The China study is based on the emission scenario study for China and global analysis is part of EMF-21 study for comparing the cost for CO_2 mitigation and multi-gas mitigation. The main objective of this analysis is to evaluate the potential and costs of non-CO_2 greenhouse gas abatement in China and in the world.
For quantifying these gases from various sources, IPAC-emission model was used. Integrated Policy Assessment model for China (IPAC) was a model framework developed in Energy Research Institute, to analyze energy and emission mitigation policies with focus on China.

The study follows the process of EMF 21. Therefore scenarios defined in EMF 21 were used here. There are several scenarios defined by EMF 21. Because of IPAC-Emission model has the capacity to analyze long-term scenarios, three scenarios were picked up from EMF-21 study, that are modeler's reference scenario, and two Long-term climate change, Cost-minimizing Scenarios including CO_2 mitigation only scenario and multi-gas mitigation scenario.

For the CO_2 mitigation only scenario, compared with reference scenario, there will be 55.8% GHG emission reduction by 2100 (see figure 5). GDP loss could be 2.4% by 2100 (see figure 15). Carbon tax need generally increase from US$50/t-C in 2000 to US$350/t-C by 2100 to get larger emission reduction (see figure 5). Because of only reduce CO2 emission in this scenario, by 2100 the share of CO2 in total GHGs will reduced from 73% in 2000 to 60% in 2100 (see figure 7). CO_2 mitigation will have strong impact on energy activities, much more renewable energy have to be utilized after 2050 (see figure 8), this give strong requirement for technology R&D from now.

In multi-gas mitigation scenario, compared with CO_2 mitigation scenario, carbon tax could be lower, started from US$25/t-Ce in 2000 to US$210/t-Ce by 2100 (see figure 25). GDP loss would be 1.8% in 2100, 23% less GDP loss compared with CO_2 mitigation scenario (see figure 15). CO_2 emission shares 71.6% in 2100 in total GHG emissions while it is 60% in CO_2 mitigation only scenario. There are large potential for non-CO_2 emission reduction, especially before 2020. By 2020 there could be nearly 30% emission reduction for non-CO_2 gases, and it would be 35% emission reduction in 2100. Total primary energy demand could have less pressure to reduce CO_2 emission, it could be 8% more energy used in 2100.
If comparing multi-gas mitigation scenario and reference scenario, by 2100, CO_2 takes largest share for the reduction, it accounts for 87% of total GHG reduction; CH_4 accounts for 11%, and 1.2%, 0.3%, 0.02% and 0.1% for N_2O, HFC, PFC and SF_6. If comparing CO_2 mitigation and multi-gas mitigation scenario, CH_4, N_2O,

Figure 1: GHG emission of reference scenario

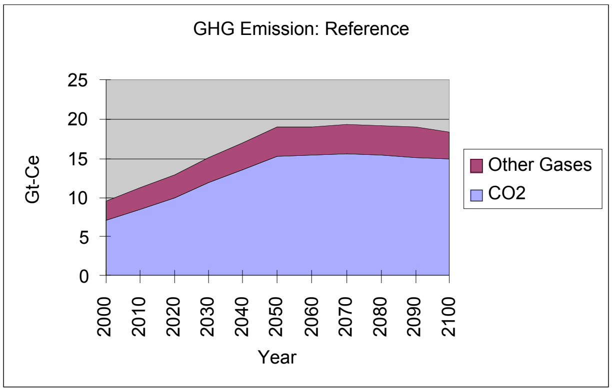


Figure 2: GHG Emission of CO_2 mitigation scenario

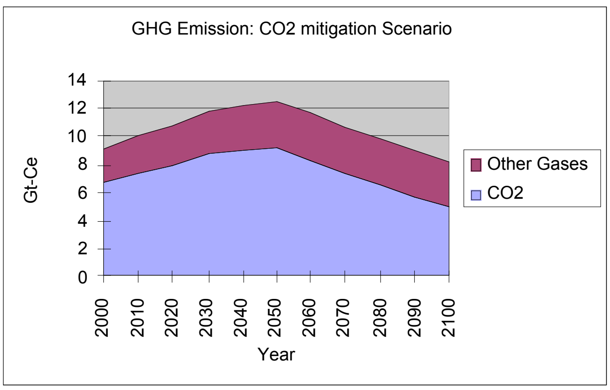


Figure 3: GHG emission of multi-gas mitigation scenario

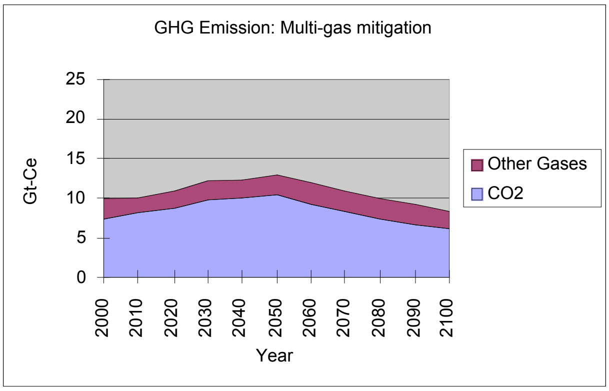
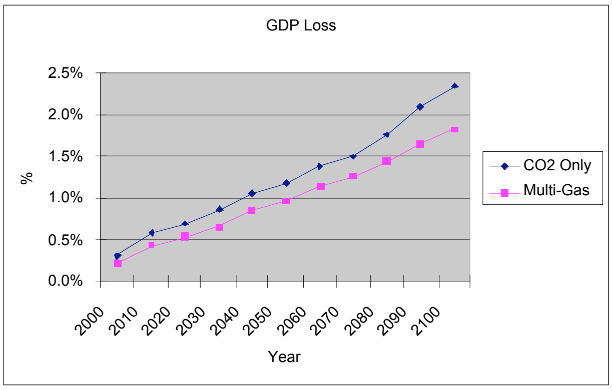


Figure 4: Global GDP loss



HFC, PFC and SF_6 contribute 83%, 10.7%, 3.3%, 0.2% and 2.2% respectively to non-CO_2 gases emission reduction.

Because of large population and catch up with developed countries, developing countries accounts for 75% of total GHG emission in the scenario. In CO_2 mitigation scenario, compared with reference scenario, China and south, south east Asia take largest part of the reduction, together they account for 45% emission reduction.

By comparing the results for different scenarios, it is found that there is quite large potential for non-CO_2 mitigation potential. Multi-gas mitigation policies could have lower cost compared with CO_2 only mitigation policies. In order to reach same mitigation target level of GHG emission, there could be 30% lower carbon tax rate for multi-gas mitigation, and therefore GDP loss could be reduced by 23% in 2100. Multi-gas mitigation could give less pressure for energy system to transform.

Stabilization Metric

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Initial studies on the costs of stabilization focused on atmospheric CO_2 concentrations primarily from the combustion of fossil fuels.[24] More recently, the analyses have been expanded to include non-CO_2 greenhouse gases and terrestrial sequestration. The addition of other trace gases has highlighted problems associated with Global Warming Potentials (GWPs) and has led to the exploration of alternative approaches for making tradeoffs among gases. Most recently, the discussion has been expanded to include what constitutes an appropriate stabilization metric (e.g., concentrations, radiative forcing, temperature change, or impacts). In this note, each of these issues is discussed in turn.

Studies of the costs of stabilizing CO_2 concentrations suggest that mitigation costs are sensitive to a variety of socioeconomic, scientific, technological, and geopolitical factors. Key determinants include:

1. Future emissions in the absence of policy intervention;
2. The behavior of the natural carbon cycle;
3. The cost differential between carbon venting technologies and carbon free alternatives;
4. Technological progress and the rate of adoption of technologies which emit less carbon per unit of energy produced;
5. Transitional costs associated with capital stock turnover which increase if carried out prematurely;
6. The concentration target and route to stabilization;
7. The degree of international cooperation;

The extent to which market mechanisms are employed both internationally and domestically.

Cost-effectiveness studies suggest that the costs of stabilizing CO_2 concentrations in the atmosphere increase as the stabilization level declines. Whereas there appears to be a moderate increase in costs when passing from a 750 to a 550ppmv stabilization level, there is a larger increase when passing from 550 to 450ppmv. The nonlinearity in the abatement cost curve appears to be due to increasing pressure to prematurely retire existing plant and equipment as the ceiling approaches 450ppmv. Different assumptions about the key determinants of costs (as summarized above) can have a strong influence on absolute costs.

Until the TAR, climate policy analyses had focused almost exclusively on CO_2 emissions abatement. This is not surprising, given the importance of CO_2 relative to other greenhouse gases, and both the capabilities of existing models and the paucity of data related to the non-CO_2 greenhouse gases at that time. Nevertheless, it was recognized that a CO_2 emissions only approach can lead to significant biases in the estimation of compliance costs.

Since the TAR, there have been a number of efforts to incorporate multiple greenhouse gases into stabilization analyses. Most notable is the current study organized by the Stanford Energy Modeling Forum (EMF 21)[25], which involved 18 modeling teams from around the world, including participants from Asia, Australia, Europe, and the US. In addition, extensive data gathering efforts were conducted by the USEPA and the IEA Greenhouse Gas R&D Program. The modelers worked closely with those responsible for data gathering to identify data requirements and to ensure that the analyses were based on the best available information.

For its long-term stabilization target, the EMF 21 study chose radiative forcing rather than atmospheric concentrations for a ceiling. Using the latter is problematic since it requires an arbitrary way to make trade-offs among gases. By choosing a ceiling to which

[24] For purposes of the current discussion, the term "cost" applies exclusively to abatement or mitigation costs. It does not include the damages associated with global climate change.
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each gas contributes (i.e., radiative forcing), the trade-offs among gases can be based on the relative prices of each gas as determined by its contribution to the ceiling. This approach, which includes both physical and economic considerations, avoids the methodological problems associated with the use of GWPs.

The results of the EMF 21 study showed that total abatement costs were reduced (in some cases substantially) when multiple greenhouse gases were included in the abatement strategy. Although the focus was on limiting radiative forcing, the models also showed the concentration levels associated with each gas in order to meet a particular target. Differences in results among models were due not only to different assumptions regarding those factors influencing CO_2 emissions abatement costs, but also different assumptions regarding the costs of non-CO_2 greenhouse gas abatement. The results of this effort will be published in a special edition of the Energy Journal in early 2005.

More recently, there has been an effort to extend the analysis further along the causal chain connecting human activities and impacts. Given the current uncertainties in our understanding of the climate system, it is impossible to project with any degree of confidence the effect of a given concentration ceiling on temperature. Or conversely, for a particular temperature cap, the required concentration ceiling is highly uncertain. This calls into question the current focus on atmospheric concentrations.

From a benefit-cost perspective, it would be desirable to minimize the sum of mitigation costs and damages. Unfortunately, our ability to quantify and value impacts is limited. For the time being, we must rely on a surrogate. Some argue that focusing on temperature rather than on concentrations provides much more information on what constitutes an ample margin of safety. Concentrations mask too many uncertainties that are crucial for policy making. This issue is likely to be a major focus of the new EMF 22 study, which will consider alternative long-term climate stabilization scenarios and is scheduled to begin this fall.

Annex III: List of participants

Participant list

IPCC Expert Meeting on Emission Scenarios
12 – 14 January 2005

1. Anthony Adegbulugbe
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NIGERIA

2. Knut Alfsen
Statistics Norway
NORWAY

3. Frans Berkhout
Free University Amsterdam
NETHERLANDS

4. Eduardo Calvo
Universidad Nacional de San Marcos
PERU

5. Timothy Carter
Finnish Environment Institute (SKYE)
FINLAND

6. Wenying Chen
Tsinghua University
CHINA

7. Jan Corfee Morlot
OECD
FRANCE

8. Francisco de la Chesnaye
U.S. Environmental Protection Agency
USA

9. Peter Downes
Treasury/AGO
AUSTRALIA

10. Otmar Edenhofer
Potsdam Institute for Climate Impact Research (PIK)
GERMANY

11. Jae Edmonds
Pacific Northwest National Laboratory
USA

12. Brian Fisher
Australian Bureau of Agricultural and Resource Economics
AUSTRALIA

13. Brian Flannery
Exxon Mobile
USA

14. Arnulf Gruebler
IIASA
AUSTRIA

15. Michael Grubb
Cambridge University
UK

16. Marty Hoffert
New York University
USA

17. Monique Hoogwijk
IPCC WGIII, TSU
NETHERLANDS

18. Jean-Charles Hourcade
CNRS (Centre National de la Recherche Scientifique)
FRANCE

19. Francis Ibitoye
Centre for Energy Research and Development
NIGERIA

20. Henry Jacoby
MIT
USA

21. Kejun Jiang
Energy Research Institute,
CHINA

22. Mikiko Kainuma
National Institute for Environmental Studies
JAPAN

23. Claudia Kempfert
German Institute for Economic Research
GERMANY

24. Reto Knutti
NCAR, Climate and Global Dynamics Division.
USA

25. Jonathan Koehler
University of Cambridge
UK

26. Tom Kram
RIVM
NETHERLANDS

27. Olga Krankina
Oregon State University
USA

28. Emilio la Rovere
Institute for Research and Graduate Studies of Engineering, Federal University of Rio de Janeiro - COPPE/UFRJ
BRAZIL

29. Skip Laitner
U.S. Environmental Protection Agency
USA

30. David Lee
Manchester Metropolitan University
UK

31. Mark Levine
Lawrence Berkeley National Laboratory
USA

32. Martin Manning
IPCC WGI TSU
USA

33. Bert Metz
Co-Chair IPCC WGIII
NETHERLANDS

34. Leo Meyer
IPCC WGIII TSU
NETHERLANDS

35. Monirul Mirza
University of Toronto, Adaptation and Impacts Research Group (AIRG)
CANADA

36. Richard Moss
Pacific Northwest National Laboratory
USA

37. Nebojsa Nakicenovic
IIASA / Vienna University of Technology (VUT)
AUSTRIA

38. Bill Nordhaus
Yale University
USA

39. Joaquim Oliveira Martins
OECD
FRANCE

40. Brian O'Neill
IIASA
USA

41. Donald Pearlman
World Climate Council
USA

42. Tony Peluso
National Resources Canada
CANADA

43. Jonathan Pershing
WRI
USA

44. Hugh Pitcher
Pacific Northwest National Laboratory
USA

45. Shrestha Ram
Asian Institute for Technology
THAILAND

46. Ashish Rana
Reliance Industries Ltd.Energy Research Group
INDIA

47. Sarah Raper
University of East-Anglia Climatic Research Unit and Alfred Wegener Institute for Polar and Marine Research
UK

48. Keywan Riahi
IIASA
AUSTRIA

49. Richard Richels
Electric Power Research Institute, USA
USA

50. Dale Rothman
Macaulay Institute
UK

51. Joyashree Roy
Jadavpur University
INDIA

52. Kenneth Ruffing
OECD
USA

53. Jeffrey Sachs
Columbia University
USA

54. Roberto Schaeffer
Federal University of Rio de Janeiro
BRAZIL

55. Michael Schlesinger
University of Illinois
USA

56. Ronaldo Seroa da Mota
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57. P. R. Shukla
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58. Sjak Smulders
Tilburg University
NETHERLANDS

59. Peter Stone
MIT
USA

60. Rob Swart
RIVM
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