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Leen Hordijk
Director, IIASA

Communicating climate change

Here in Laxenburg we have been enjoying an unseasonable spell of glorious weather, with October temperatures unsurpassed since 1971. Were these temperatures a random “blip” in the seasonal cycle or are they symptomatic of global warming? I ask this question because, in spite of the meticulously peer-reviewed findings of the Intergovernmental Panel on Climate Change that climate change does indeed exist, that it is caused by greenhouse gas emissions resulting from human activities, and that it will—if unmitigated—inflict irreparable damage on human life and ecosystems, the public debate continues as to whether we should actually take climate change seriously or whether it even constitutes scientific certainty.

Irrespective of whether the warm Laxenburg fall is due to good luck or global warming, this issue of *Options* will, I hope, leave no doubt in the minds of readers about either the existence of climate change or the intensive efforts at IIASA to find explanations for and solutions to the mounting global threat. But what of the naysayers, such as Senator James Inhofe of Oklahoma, who in September 2006 argued from the floor of the U.S. Senate that the threat of global warming was exaggerated by “the media, Hollywood elites, and our pop culture”? How should we respond to denial? How also should we respond to the “doubters,” those “middle-of-the-road” journalists and public figures who take a Pascal’s Wager type of approach to climate change—if we’re wrong but we act, then the worst that can happen is an energy-efficient world. If we’re wrong and we don’t act, then the consequences will be devastating... So, just to be on the safe side, let’s act.

While politicians and vested interests, such as oil companies, are frequently lambasted by the pro-climate change lobby for undermining public belief in global warming, perhaps we scientists also have to take some blame for failing to win hearts and minds to this most worthy cause. After all, who, but a scientist, must use such impenetrable, guarded, and conditional language when talking about the threats of climate change? Of course, within the scientific community, the issues, and the necessary caveats involved, are perfectly understood. But the public, with the democratic power to make or break governments, is left somehow unsure.

A year ago, we decided to “revamp” *Options* with a view to providing an informed public with robust scientific information in a format that was, as far as possible, enlightening, useful, and jargon-free. From your personal comments and e-mails to me, I am convinced that we are achieving this goal and that we are making the complex scientific work carried out at IIASA available to a wider and often influential audience.

I hope you find this issue on climate change both worthwhile and stimulating. I look forward to receiving your comments on *Options* and on IIASA’s work in general.

About IIASA

IIASA is an international scientific institute that conducts policy-orientated research into problems that are too large or complex to be solved by a single country or academic discipline.

IIASA’s scientists research

- energy and technology;
- environment and natural resources; and
- population and society.

IIASA produces

- data, models, and research tools;
- refereed scientific literature; and
- policy-relevant information.

IIASA helps

- countries make better-informed policy;
- develop international research networks; and
- support the next generation of scientists.

IIASA is funded and supported by scientific institutions and organizations in the following countries:

Austria, China, Czech Republic, Egypt, Estonia, Finland, Germany, Hungary, Japan, Netherlands, Norway, Poland, Russian Federation, Sweden, Ukraine, United States of America

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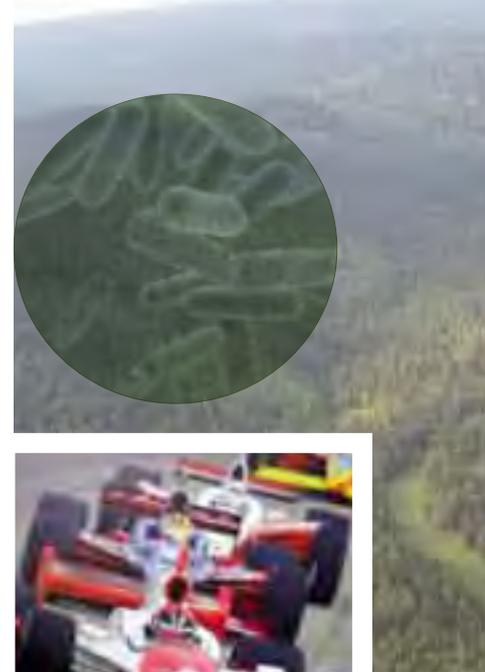
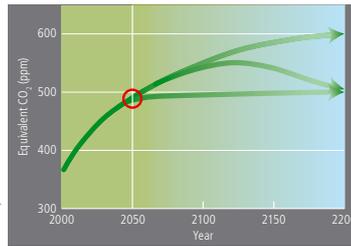
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Nobel laureate's planet-saving technology

Like the chameleon, which changes its skin color to adapt to new surroundings, humans will have to adapt to our changing climate. Unlike the chameleon, we can also transform our activities to reduce how much our climate will actually change. This *Options* highlights how the world can both adapt to and mitigate climate change. (Photo: CiN/Michael O. Fry)



IMMIGRATION

China towns

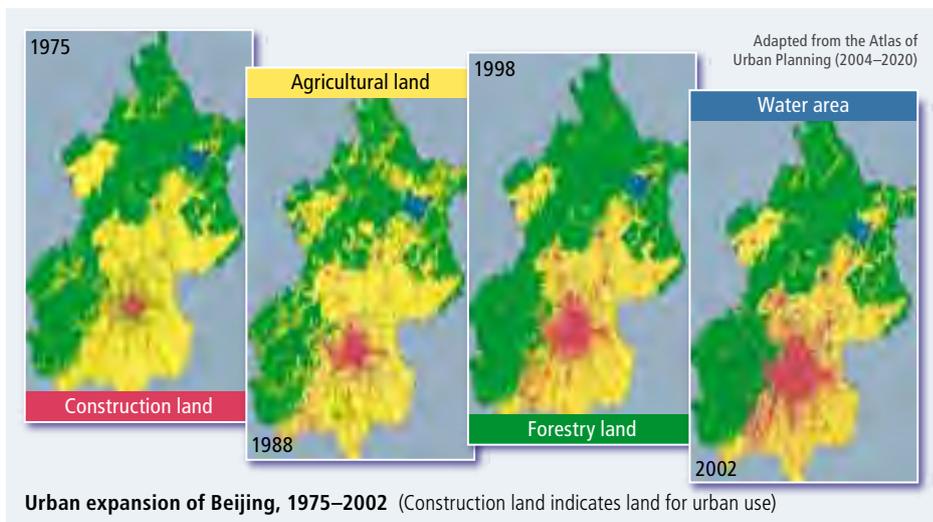
“Metropolitan Trends and Challenges in China,” the first output of a joint ongoing IIASA and Beijing University project, “Regional Urbanization and Human Capital Projections for China,” was published in October. The report, which emphasizes demography, considers the significant regional variations that have emerged in urban growth during China’s transformation from a rural to an urban economy, in particular, the large divide between the coastal mega-urban regions of Shanghai, Beijing, and Guangdong and the less-prosperous inland regions.

The report notes that Shanghai, Beijing, and Guangdong—the most socioeconomically advanced regions in China—will continue to be engines of strong economic growth until 2030, presenting a strong challenge to regional and national development in China. There will be labor force migration to meet the expected economic growth in the mega-urban regions, which will slow the fast population aging of all three regions. The proportion of the population with higher education will also be greater there during the next three decades, compared with the rest of China.

According to the IIASA/Beijing University research, irrespective of whether Beijing and Shanghai apply a limited or liberal migration policy, both cities will figure among the ten largest urban agglomerations in the world in the coming decades, ranked by population size. These projection results are much higher than the United Nations projections for Beijing and Shanghai, which do not take the migration factor into account.

The growth of Chinese mega-urban regions will have knock-on effects at the global level, the report suggests. Of all the East Asian mega-urban regions, Beijing, Shanghai, and Guangdong are among the best-placed to become centers for the control, coordination, and servicing of global capital and, in turn, central poles in the hierarchical organization of labor and migration flows.

Cao G-Y, Zheng X-Y, Nilsson S, Pang LH, & Chen G (2006). *Metropolitan Trends and Challenges in China: The Demographic Dimension*. For more information, or to obtain a copy of the report, contact Gui-Ying Cao: cao@iiasa.ac.at

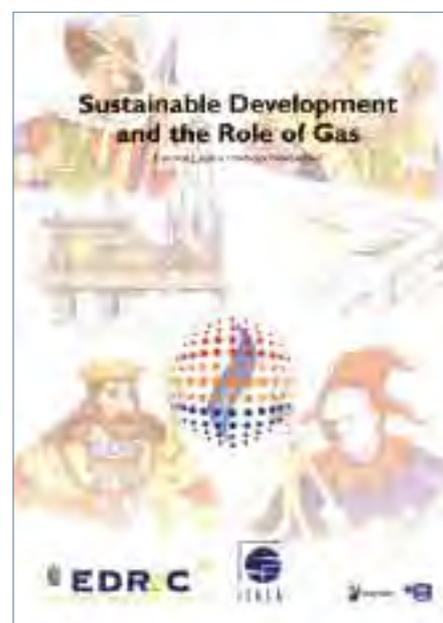


FUTURE FOR NATURAL GAS

Gas is greener

Clean, abundant, efficient, and cost-effective, natural gas is uniquely positioned to lead the way to decarbonization and bridge the period until sustainable energy systems are available on a commercial scale. IIASA’s Professor Nebojsa Nakicenovic is co-author of a report that explores the role of natural gas in the transition to more sustainable production and use of energy. The report, which stemmed from a major study presented at the 2003 World Gas Conference in Tokyo, was launched at the 2006 World Gas Conference in Amsterdam at a panel session conducted by Ged Davies. The report presents four different storylines that take account of the possible threats and opportunities to the international gas sector in the next four decades and studies ways of addressing them.

In the “security of supply storyline,” societies fail to substantially decouple energy use from strong economic growth, and security rather than sustainability dominates the international economic and political discourse. The “coal, oil, and nuclear storyline,” has low concerns about sustainability, assuming that technological advances will solve the environmental and safety problems arising from coal and nuclear utilization. In the “underinvestment storyline,” even if concern for climate issues is high, political and market uncertainties will prevent policy makers from establishing a clear and convincing climate strategy. Finally, the “green,” future-oriented “transition storyline” is driven by air quality



and technological innovation, with natural gas in combination with renewable energy sources bridging the transition to energy sustainability on a commercial scale.

According to the report, however, issues such as security of supply, possible political lobbying by suppliers of competing energy sources, and underinvestment by gas industry players need to be tackled before the full transition potential of natural gas is realized.

The full report, *Sustainable Development and the Role of Gas*, by Professor Catrinus Jepma, Scientific Director of the Energy Delta Research Center, University of Groningen, the Netherlands, and Professor Nebojsa Nakicenovic, Professor of Power Systems and Energy Economics, Vienna University of Technology and IIASA, can be obtained by contacting Katalin David: david@iiasa.ac.at

DISASTER RISK MANAGEMENT

Insuring the poorest

“Disaster Insurance for the Poor? A Review of Microinsurance for Natural Disaster Risks in Developing Countries” is an in-depth report presented by two IIASA scientists at the Sixth DPRI-IIASA Forum on Integrated Disaster Risk Management in Istanbul in August. The Provention-supported study, by Reinhard Mechler and Joanne Linnerooth-Bayer of IIASA’s Risk and Vulnerability Program, analyzes the case for disaster microinsurance for the world’s poorest people.

This review of implemented microinsurance schemes not only demonstrates the potential of disaster microinsurance programs as a



means of protecting the poor against the consequences of natural disaster shocks but also reveals the significant challenges of making this protection viable. ■

The full report can be downloaded from: www.proventionconsortium.org

GREENHOUSE GAS EMISSIONS

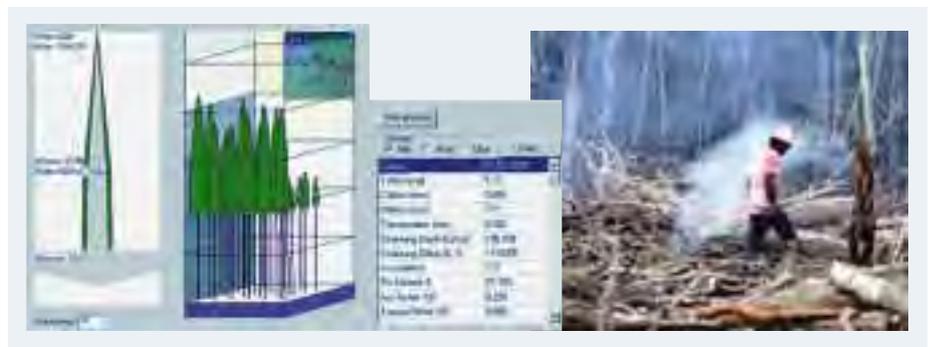
Filling sinks

The importance of the role of land use, land use change, and forestry in international efforts to reduce greenhouse gas emissions has gained importance as countries seek the most efficient and effective ways of reducing emissions while allowing for necessary economic growth. July 2006 saw the finalization of the project, the Integrated Sink Enhancement Assessment (INSEA), a series of projects designed to develop a scientifically sound analytical tool to assess the economic and environmental effects of enhancing carbon sinks and

greenhouse gas abatement measures on agricultural and forest lands.

The INSEA findings, which are expected to be made known in the next two years, will have wide implications for policy makers. Several INSEA projects, for instance, focus on the influence of scale and cost on mitigation measures, while others use innovative approaches to addressing the use of bioenergy as an alternative to fossil fuels. ■

See pages 22–23 of this *Options* and www.insea-eu.info for related information



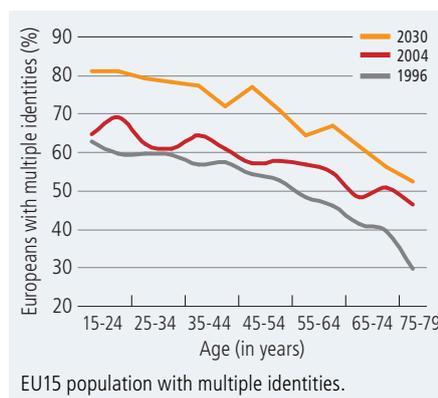
POPULATION

European identity on the rise

Although 54.87 percent of French voters voted *non* in the 2005 European Constitution referendum, the French are among the most European-minded of all European Union (EU) inhabitants. And the younger generations of Europeans, in addition to their national identities, have a greater sense of European identity, which is expected to lead to a higher overall prevalence of European identity in the future.

These are some of the results of research, carried out by IIASA’s World Population Program and the Institute of Advanced Studies, which applied demographic age–period–cohort models to the rather “soft” question of European identity. A research paper on the issue of the growth of European—as distinct from national—identity was recently published in the magazine *Science*.

Contrary to popular belief, the development of a European identity does not have to be accompanied by a decline in national identity. European integration has established a new context with which people are able to identify, that opens



up the possibility of multiple identities. This is important because in the political science literature, identity is often seen as a necessary precondition for the stability and legitimacy of a political system.

The statistical analysis carried out by IIASA researchers was based on comprehensive individual-level data on identity collected over several years from responses to the Eurobarometer (EB) survey. The IIASA research asked: How does the sense of European identity differ by age, sex, and

country of residence? How has it changed over time and how much has it changed along cohort (generational) lines? What are the implications of the trends observed for the prevalence of European identity in coming decades?

The analysis finds a strong and significant positive cohort effect. Applying this effect to population projections, the study finds, for instance, that in the 30–44 age group, those who have some European identity will outnumber those with a strictly national identity by more than three to one in 2030. While very strong country differences are likely to persist, the older, more nationally oriented cohorts will naturally be replaced by younger, more European-minded cohorts, which will bring significant changes in the pattern of European identity. These long-term “tectonic shifts” in European identity, say IIASA researchers, are likely to have major and enduring consequences for the future of Europe. ■

Lutz W, Kritzinger S, & Skirbekk V (2006). The Demography of Growing European Identity, *Science* 314:425.

MODELING UNCERTAINTY

Skunks sought

The Greenhouse Gas Initiative (GGI) has invited proposals on small-scale exploratory projects—so-called Skunk Projects—on the topic of climate change and uncertainty. The purpose of this initiative is to explore a variety of approaches to uncertainty related to GGI work and to intensify cross-program cooperation at IIASA.

Preference is given to proposals that explore novel concepts of modeling key uncertainties and their implications for potential climate change response strategies. So far research has been conducted to estimate attainability domains of simple climate–economy models and on the problem of optimal stochastic control of greenhouse gas emissions that have the potential to induce abrupt climate change.

Proposals for Skunk Projects are open to all researchers at IIASA as well as to outside researchers. To date, Skunk Projects have been proposed only by IIASA staff. Proposals should document the research idea in a one-page research statement for oral presentation at a GGI seminar. If considered relevant to GGI work, the Skunk project will be funded by GGI for a maximum three-month period, with the possibility of an extension. Skunk Projects should aim to culminate in a publishable paper. ■

IIASA's Greenhouse Gas Initiative
www.iiasa.ac.at/Research/GGI



EUROPE'S GREENHOUSE GASES

The nitrogen challenge

IIASA's Forestry Program is taking part in the NitroEurope (NEU) project, the main aim of which is to assess the overall effect of nitrogen on the European greenhouse gas balance. The €27 million project, which is funded by the European Commission, will run until 2011.

Although excess nitrogen contributes substantially to issues such as changes in the carbon cycle, global warming, water quality, acid rain, biodiversity loss, and air pollution, the issue has received little attention from the scientific community until now.

The integrated program, which combines field measurements and computer modeling, will develop the scientific basis to support European countries and the EU in negotiations under several United Nations conventions, in particular those on climate change, air pollution, and biodiversity. ■

NitroEurope project
www.neu.ceh.ac.uk

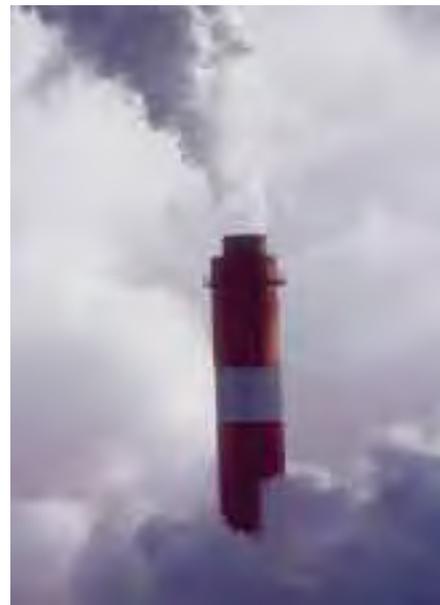


SOIL AND WATER

Microbe modeling

IIASA's Forestry Program is a driving force in MICDIF, a microbial project linking microbial diversity and functions across scales and ecosystems, which, if funded, will start at the beginning of 2007. The aim of the project is to increase the understanding of microbial processes in soil and water and to use this knowledge to predict larger-scale ecosystem processes and how they respond to climate and other environmental factors. IIASA modelers will integrate and interpret the substantial experimental work performed by some of Austria's leading experts in microbial ecology, biology, and chemistry at Vienna University and the University of Natural Resources and Applied Life Sciences (BOKU) in Vienna. ■

IIASA'S Forestry Program
www.iiasa.ac.at/Research/FOR



AIR POLLUTION

Climate strategies

IIASA's Atmospheric Pollution and Economic Development (APD) Program is to head the Consortium for Modelling of Air Pollution and Climate Strategies (EC4MACS), composed of integrated assessment modeling teams from across the European Union (EU). The Consortium includes teams modeling energy, agriculture, transport, atmospheric processes, health and ecosystems impacts, and benefit assessments. The project will prepare and maintain modeling tools for air quality and climate policy development for reviews of the Clean Air for Europe and the European Climate Change Programme in 2011.

The €4.5 million EC4MACS project, funded by the European Commission under LIFE (The Financial Instrument for the Environment), one of the spearheads of EU environmental policy, will run from 2006 to 2011. ■

IIASA's Atmospheric Pollution and Economic Development Program
www.iiasa.ac.at/rains





EUROPE'S WATER

Freshwater futures

IIASA is a partner in the four-year, €10.2 million European Commission-funded project, "Water Scenarios for Europe and for Neighbouring States" (SCENES). Personnel from IIASA's Risk and Vulnerability Program will lead a stakeholder-driven process to develop and analyze a set of comprehensive scenarios of Europe's freshwater futures up to 2025. The scenarios will cover all of "Greater" Europe, reaching to the Caucasus and Ural mountains and including the Mediterranean rim countries of North Africa and the Near East.

IIASA's World Population and Land Use and Agriculture Programs will contribute to quantifying the key drivers of change as input to scenario development. These scenarios will provide a reference point for the long-term strategic planning of European water resource development, alert policy makers and stakeholders to emerging problems, and allow river basin managers to test regional and local water plans against the uncertainties and surprises that are inherent in a longer-term strategic planning process. ■

IIASA's Risk and Vulnerability Program
www.iiasa.ac.at/Research/RAV

WATER AND GLOBAL CHANGE

Water watch

IIASA is coordinating the "Population and Land-Use Change" work block in the new European Commission-funded project, WATER and global CHange (WATCH). The project brings together the hydrological, water resources and climate communities to investigate the current and future global water cycles and related water resources.

The aim of the research project is to provide comprehensive quantitative and qualitative assessments and predictions of the vulnerability of water resources, as well as water-climate-related vulnerabilities and risks for the twenty-first century. ■

<http://vague.eurecom.fr/initiatives/foi060732/proj798674>



FISHERIES MANAGEMENT

Fisheries-induced evolution

IIASA's Evolution and Ecology Program is to head a €1.8 million research project, funded by the European Commission, to investigate fisheries-induced adaptive changes in exploited fish stocks. The project, "Fisheries-induced Evolution" (FinE), will focus on European and North American fish populations that are of particular relevance to fisheries management in the European Union (EU). It endeavors to unravel the underlying mechanisms of evolutionary change ranging from the phenotypic to the genetic level, to evaluate their consequences for population and fisheries dynamics, and to provide recommendations for evolutionarily enlightened management. Due to start next year, the FinE initiative is scheduled to operate until 2009.

Today, fishing is the dominant source of mortality in most commercially exploited fish stocks. According to the United Nations Food and Agricultural Organization (FAO), world capture fisheries have reached a ceiling, with three stocks out of four being maximally exploited or overexploited. As all fish species were genetically adapted to the environmental conditions they experienced prior to intensive exploitation, the current, drastically altered, conditions cannot possibly leave their life-history patterns unaffected. In other words, fishing not only decreases the abundance of fish, but also changes their genetic composition.

IIASA was chosen to head the international FinE research consortium based on its past and present work on fisheries-induced evolution. In particular, IIASA's innovative and persistent focus on this topic, accompanied by the efforts of collaborators worldwide, was a key factor in the European Commission's decision to highlight the need for enhanced scientific understanding of fisheries-induced evolution in its Sixth Framework Programme. The FinE consortium, comprising 18 different national teams, will bring together fisheries scientists, population and evolutionary ecologists, quantitative and population geneticists, evolutionary modelers, and resource economists from across the EU to approach this complex topic from different, mutually complementary, angles. Such a multidisciplinary approach to the integrated assessment of causes, consequences, and potential remedies of fisheries-induced evolution is needed for the responsible management of Europe's living aquatic resources. ■

IIASA's Evolution and Ecology Program
www.iiasa.ac.at/Research/EEP

FORTHCOMING BOOK

Climate negotiations

How to cope with stumbling blocks

IASA's Processes of International Negotiation (PIN) Network has just completed a book project that investigates international negotiations on climate change. *Strategic Facilitation of the Climate Talks—How to Cope with Stumbling Blocks* will be published next year.

The latest PIN book differs from other works on climate change in that it focuses purely on multilateral climate change negotiations, as opposed to the issue of climate change itself, the interpretation of international agreements, or bilateral talks. It will thus have a broad appeal not only for academics and university students but also for practitioners, engaged directly and indirectly in international climate negotiations such as policy makers, diplomats, and experts.

In this, as in all PIN book projects, international experts (academic analysts and practitioners) joined forces. In this case, they were asked to look at key themes and issues pertaining to climate change negotiations. These issues include the importance of leadership, the failing negotiation capacity of weak countries, the role of non-governmental organizations (NGOs), the management of scientific knowledge and information, and the linkages between fundamental uncertainty problems, the verification system, and the prospects for future binding commitments to further reduce greenhouse gas emissions.

The book's key concept of strategic facilitation concerns actions with a long-term impact that non-Parties undertake or suggest in order to support the climate negotiation. Strategic facilitation is "operationalized" as coping with the stumbling blocks that represent persistent obstacles in the climate talks.

Stumbling blocks arise in several quite different dimensions of the climate negotiation: (1) the climate issue as it has been framed and constructed for negotiation purposes; (2) the actors participating in the negotiation; (3) the process of negotiation; and (4) the institutional setting in which the process unfolds. This categorization makes it clear that facilitation measures need to be designed in many different ways depending on the character of the stumbling block in question.

Moreover, the climate issue has certain inherent properties that, together, represent a major stumbling block. One such factor is the extreme values (financial assets, a preserved environment, or good health) that are at stake in negotiations with respect both to unmitigated climate warming and the mitigation and adaptation measures proposed. A second example is the complexity of the uncertainty problems pertaining to most of the key aspects of the climate problem: their causes, future manifestations, expected disastrous consequences, as well as the effectiveness of proposed counter-measures. A third example is the immeasurability problem involved in systematically comparing certain short-term mitigation costs with uncertain long-term mitigation benefits.

The leadership problem in the climate talks is a telling example of actor-related stumbling blocks. No single state or coalition of nations is willing or able to perform the kind of driving leadership role that has often been a precondition for successful multilateral



Former US President Bill Clinton and Canadian Premier Paul Martin at the 2005 Montreal UN Climate Change Conference. A forthcoming IASA book examines how countries can overcome persistent obstacles in climate negotiations.

negotiation. This leadership problem has been exacerbated by United Nations procedural rules for the election of chairpersons in contact groups and other negotiation bodies, with some chairs lacking the necessary competence to perform their roles effectively and constructively.

The dilemma of whether to increase the participation of weak countries and some categories of NGOs in negotiation groups, while at the same time preserving the effectiveness of the groups in question, is an example of process-related stumbling blocks. As is the lack of a precise, accepted, long-term, absolute mitigation objective: something that has seriously impeded bargaining on greenhouse gas emissions.

An important institutional stumbling block concerns the expected difficulties that the Intergovernmental Panel on Climate Change and other institutions for knowledge management will experience in coping with the increasing inflow of social scientific knowledge and information resulting from the planned upgrading of the adaptation objective. These will bring the negative consequences of climate warming more into focus in the negotiation.

The final analytical part of the new PIN book contains suggestions as to how stumbling blocks, once identified, can be reduced in importance by facilitation measures targeting the climate issue, negotiating parties, and critical attributes of the negotiation process, as well as through institutional design or redesign of negotiation bodies. ■

Further information IASA's Processes of International Negotiation (PIN) Network at www.iiasa.ac.at/Research/PIN

Gunnar Sjöstedt is a member of the PIN Steering Committee and Project Coordinator of the forthcoming publication, *Strategic Facilitation of the Climate Talks—How to Cope with Stumbling Blocks*.

FISH & CLIMATE CHANGE

Herring in warming waters

Climate change may cause herring to reproduce less often

As fish grow, they add new, thin layers (known as rings) to their scales and bones. These layers are relatively thick when feeding is active and growth is fast, but even during winter, when little or no growth occurs, very thin layers are laid down. Through this process, individual fish create personal archives that contain a great deal of information on their life. For example, fish are often aged based on the number of winter zones in their scales or otoliths. However, other information is sometimes also retrievable, such as the number of times an individual has spawned and the type of water mass it was in at the time of laying down a ring.

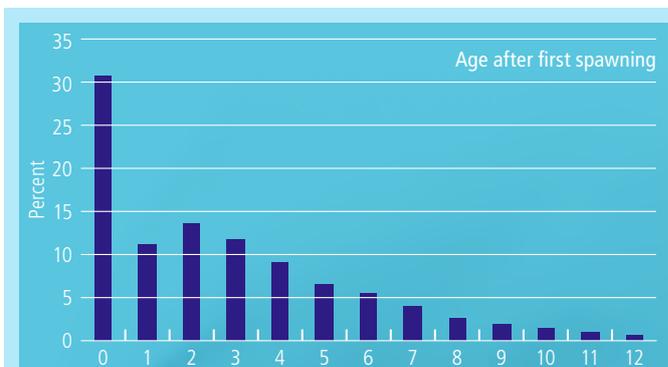
The Norwegian Institute of Marine Research in Bergen has collected and measured scales from the so-called Norwegian spring-spawning herring since the mid-1930s. These herring are key players in both coastal and open ocean ecosystems in the Norwegian and Barents Seas. This bounty of the ocean has also supported the livelihoods of coastal communities since ancient times. Although the stock collapsed to economic extinction in the late 1960s, it has since recovered and is again one of the main pillars supporting fishing industries in the northeast Atlantic.

Reading and measuring herring scales gives the age of an individual, its age at first spawning, and its annual growth. From these data we know that marked changes in growth and maturation have taken place over the last eight decades in this important stock.

Our novel way of looking at the herring scale data has revealed an unexpected phenomenon. Normally, it is assumed that long-lived, repeatedly spawning fish such as herring, once matured, return to spawn annually. However, scale data suggest that almost one in two adults may skip their second spawning migration. At first sight, skipping spawning opportunities sounds like a foolish thing to do. But herring in this stock are undertaking long and strenuous spawning migrations, and it is possible that some individuals need an additional feeding season to build sufficient energy reserves for the second spawning. Indeed, our analyses suggest that skipped spawning is more frequent after a year in which first-time spawning herring had low body condition and small body size.

Frequency of skipped spawning is also modulated by temperature: there is a negative correlation between temperature and frequency of skipped spawning in the following spawning season. This is probably caused by better availability of prey in cooler years. Thus, climate change may make skipped spawning more frequent and negatively impact the reproductive potential of the stock.

Curiously, the overall effect of the warming climate may still be positive. Earlier research has shown that successful year classes are more likely under warm conditions, probably because of the better survival and growth of herring larvae and young in the Barents Sea. During the last decade, the number of strong year classes has been unusually high. This example illustrates some challenges to species' predicted response to changing climate. ■



Number of years since individual herring first spawned The reducing proportion of herring alive each year after their first spawning reflects the mortality of the fish as it ages. The data comes from the spawning grounds, and the dip at year 1 suggests that not as many herring as expected are returning to spawn in the year after they first reproduced. *Source:* Institute of Marine Research, Bergen.



Increases in the number of herring each summer Most year classes have been strong during the present warm period confirming that strong year classes are usually born in warm years. *Source:* International Council for the Exploration of the Sea.

Further information Engelhard GH & Heino M (2006). *Climate Change and Condition of Herring (Clupea Harengus) Explain Long-Term Trends in Extent of Skipped Reproduction*. IIASA Interim Report IR-06-008. Available at www.iiasa.ac.at/Admin/PUB/Documents/IR-06-008.pdf.

Dr Mikko Heino is a research scholar with IIASA's Evolution and Ecology Program, a scientist at the Norwegian Institute of Marine Research, and a professor at the University of Bergen, Norway. **Dr Georg Engelhard** is a scientist at the Centre for Environment, Fisheries & Aquaculture Science (Cefas), Lowestoft, UK.

October 2006 saw many of the world's leading experts on climate change mitigation gather in New Zealand. These were members of the Intergovernmental Panel on Climate Change's (IPCC) Working Group III, which studies how the world can lessen climate change. From eight in the morning until nearly midnight, they discussed and responded to government and expert review comments on their second draft of the forthcoming Fourth Assessment Report. IIASA scientists Nebojsa Nakicenovic, Arnulf Grubler, and Keywan Riahi participated in the October meeting.

IIASA's researchers have played important roles in the IPCC's reports into climate change since the Panel was established in 1988. The IPCC's reports are widely recognized as the most important source of scientific, technical, and socioeconomic information about climate change, its impacts, and the possible response options.

Work at the IPCC is currently focused on producing the Fourth Assessment Report which is due out in 2007. Seven IIASA scientists are lead authors, and one is a coordinating lead author. They are writing chapters on, among others, mitigation, impact of climate change on food, and new methodologies to assess impacts and vulnerability (see box, far right).

Only last year, the IPCC published its *Special Report on Carbon Dioxide Capture and Storage*, and IIASA scientist Keywan Riahi was lead author for the chapter on costs and economic potential. In addition, IIASA hosted the first workshop of the special IPCC Task Group on New Emissions Scenarios in July 2005.

Since 1988 the IPCC has successfully provided independent scientific advice on the complex issue of climate change, and this has informed decisions taken by the international community to tackle this global problem. The success of the IPCC stems partly from its relationship with the United Nations Framework Convention on

POLICY-RELEVANT RESEARCH

Informing the international community

IIASA and the Intergovernmental Panel on Climate Change



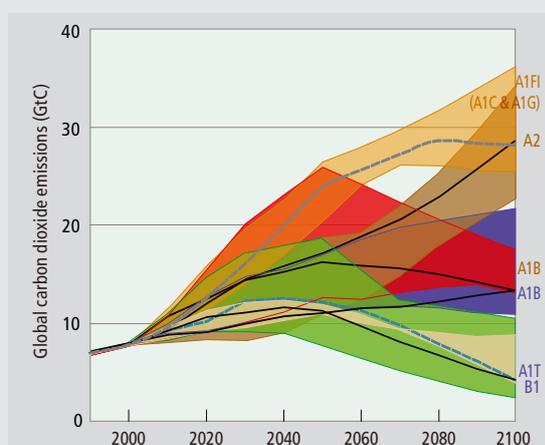
Emissions scenarios: Calculating alternative images of the future

The cutting-edge *Special Report on Emissions Scenarios* (SRES) has been used extensively since it was published by the Intergovernmental Panel on Climate Change (IPCC) in 2000.

Emission scenarios are crucial to climate research. When determining how the climate may change we need to know how greenhouse gas emissions in the atmosphere may change over time. Such forecasts are loaded with uncertainty, dependent as they are on assumed changes (over decades) in both natural and anthropogenic emissions; these, in turn, are dependent on assumptions regarding socioeconomic, demographic, and technological change.

Work on SRES began in 1996, with IIASA's energy economist Professor Nebojsa Nakicenovic as coordinating lead author. Nakicenovic marshaled a huge international effort over four years to produce the SRES: Dr Mike Hulme, director of the United Kingdom's Tyndall Centre for Climate Change Research, calls it, "essential reading for anyone who is researching in the area of future climate change and its implications." Over 50 scientists from 18 countries wrote SRES, reviewing over 400 global and regional greenhouse gas scenarios, which were used to develop 40 scenarios. This work was then formally reviewed by over 80 experts. SRES also comprised an open process that enabled any research group in the world to comment online and submit their own scenarios.

This huge scientific collaboration addressed uncertainty in two new ways. First, the scenarios were based on a set of storylines (narrative descriptions) of alternative broad development patterns for the twenty-first century. Unlike earlier IPCC scenarios, these storylines described consistent demographic, social, economic, technological, and environmental developments that drive emissions of greenhouse gases due to human activities. Previous IPCC scenarios were based on disconnected quantitative assumptions about future population growth, GDP per capita, and energy intensity. Second, the SRES process included six different models for creating quantitative interpretations of each of the storylines. These two approaches made SRES unique in being the first study to combine qualitative and quantitative approaches to developing emissions scenarios.



Global carbon dioxide emissions Global carbon dioxide emissions (GtC/yr, standardized) from all sources for the six SRES scenarios from 1990 to 2100. Each colored emission band shows the range of the scenarios within one group that share common global input assumptions for population and GDP.

Climate Change (UNFCCC), an international treaty that considers what can be done to reduce global warming—the IPCC is the essential source of high-quality information about climate change for the 185 countries that have ratified the UNFCCC. The relationship between the two bodies is considered to be a model for interaction between science and decision makers on complex issues.

Scientific integrity underpins the success of the IPCC reports. Each report is prepared by teams of authors, specifically selected for the task, based on their expertise. The authors assess the work of hundreds of scientists and their reports are, in turn, rigorously

reviewed twice by experts. The final reports are accepted at a plenary session, with the summaries for policy makers approved line by line. The reports are policy-relevant but not policy-prescriptive, which makes them highly valuable in negotiations.

IIASA has a long history of involvement with the IPCC. The chairman of IIASA's Science Advisory Committee, Bert Bolin, was the first chairman of the IPCC from 1988 to 1998. IIASA's Nebojsa Nakicenovic was the coordinating lead author of the IPCC's *Special Report on Emissions Scenarios* (see box, page bottom) which was published in 2000. The report produced the most comprehensive and sophisticated scenarios of greenhouse

gas emissions for the twenty-first century and provided the backbone of the IPCC's Third Assessment Report which concluded, based on the emissions scenarios, that the world is committed to temperature increases of between 1.3 and 5.8 °C by 2100.

Nine other IIASA scientists contributed to the IPCC's Third Assessment Report (2001) and nine IIASA researchers also contributed to the Second Assessment Report (1995). When published, these assessment reports were considered the world's most comprehensive scientific reports into climate change. ■

Further information Intergovernmental Panel on Climate Change at www.ipcc.ch



IIASA and the IPCC's Fourth Assessment Report

The IPCC's Fourth Assessment Report will become the most comprehensive scientific assessment of climate change to date when it is published in 2007. Eight IIASA scientists have been selected as lead author or coordinating lead author:

Working Group II: Impacts, Adaptation and Vulnerability

Chapter 2: New Assessment Methodologies and the Characterisation of Future Conditions
Brian O'Neill, Leader of IIASA's Population and Climate Change Program

Chapter 5: Food, Fibre and Forest Products

Francesco Tubiello, Research scholar in IIASA's Land Use Change and Agriculture Program

Chapter 12: Europe

Anatoly Shvidenko, Senior scientist in IIASA's Forestry Program

Chapter 18: Interrelationships between adaptation and mitigation

Ferenc Toth, Research scholar in IIASA's Land Use Change and Agriculture Program

Working Group III: Mitigation

Chapter 2: Framing Issues

Arnulf Grübler, Senior research scholar in IIASA's Transitions to New Technologies Program

Chapter 3: Issues related to mitigation in the long-term context

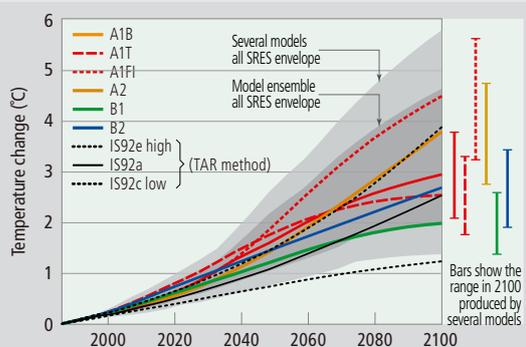
Nebojsa Nakicenovic (coordinating lead author) and *Keywan Riahi*,

Respectively leader and research scholar in IIASA's Transitions to New Technologies Program

Chapter 11: Mitigation from a cross-sectoral perspective

Markus Amann, Leader of IIASA's Atmospheric Pollution and Economic Development Program

In addition, *Keywan Riahi* has been chosen to be in the core writing team for the assessment's synthesis report and *Nebojsa Nakicenovic* is a member of the new Task Force on Emissions Scenarios. ■



Global mean temperature change The six illustrative SRES scenarios underpin the IPCC's Third Assessment Report's conclusion that the world is committed to temperature increases of between 1.3 and 5.8 °C by 2100. Four storylines underpin the scenarios and describe future worlds that are generally more affluent compared to the current situation. They range from very rapid economic growth and technological change to high levels of environmental protection, from low to high global populations, and from high to low greenhouse gas emissions. Source: Houghton, JT et al. (2001).

The book, *Special Report on Emissions Scenarios*, made a huge impact, selling over 3,000 copies and achieving around 500 citations to date (by comparison, academic publishers are normally pleased with sales of 1,000 units, and the average citations for an article in *Nature* are 30 a year).

More important is who is using the research: SRES has served as the basis for research evaluated by the IPCC's Third Assessment Report and will be assessed by the Fourth Assessment Report, the world's most important sources of scientific, technical, and socioeconomic information about human-induced climate change.

The SRES scenarios also underpin individual countries' research into climate change, from the United Kingdom's Hadley Centre and the Finnish Meteorological Institute to New Zealand's National Climate Centre and Japan's Meteorological Agency. SRES also lies behind the work of the many different parts of the climate change research community, from global climate modelers to mitigation experts. And by providing a common set of emissions scenarios, SRES has crucially helped this diverse and international climate research community to produce more directly comparable results.

Climate change has supporters and opponents. Not surprisingly with such an influential study, SRES did spur some controversies at the political and scientific level. For example, whether market exchange rates or purchasing power parities should be used to measure economic growth in emissions scenarios or whether scenarios should each be assigned a likelihood of taking place. Although most of the scientific community supports the approaches used in SRES, these debates can lead to a better understanding of how to avoid dangerous climate change and to advances in scenario analysis. ■

Further information Nakicenovic, N et al. (2000). *Special Report on Emissions Scenarios*, Working Group III of the Intergovernmental Panel on Climate Change, IPCC, Cambridge University Press, Cambridge, UK. Available at www.grida.no/climate/ipcc/emission.

Dealing with uncertainties

What are the best responses to climate change, given that we are not aware of all the facts and probably will not be until it is too late to act?

It is 1896 and Swedish scientist Svante Arrhenius has just painstakingly calculated the potential consequences of a doubling of atmospheric carbon dioxide (CO₂) concentrations. He warns of global warming of 5–6°C due to emissions

from human activities. However, the Swede's work is widely dismissed as too simplistic by his scientific peers.

Move to 2006 and history shows that Arrhenius' science was sound, but his results perhaps on the high side of today's estimates. However, his timeframe was certainly wrong. He estimated that it would take over 2,000 years for the levels of CO₂ in the air to double as a result of industrial emissions. He failed to account for the rapid pace of industrialization in the twentieth century and the huge demographic, economic, and social changes that would see atmospheric CO₂ more likely to double within 200 years of his work rather than 2,000.

Arrhenius was trying to forecast how climate would change in the future. Even today this area is fraught with huge uncertainties. Although progress has been made in the past century, today's scientists still do not fully understand the complexities of the climate system. Nor can researchers accurately predict the long-term development of the socioeconomic drivers of climate change, such as population and energy use. Add to this that climate change takes place over decades and centuries so that causes and effects are separated by generations and one realizes that climate change is probably among the most challenging issues ever to be addressed by the scientific community and humanity as a whole.

To shed light on these uncertainties, IIASA's Greenhouse Gas Initiative (GGI) has carried out a comprehensive integrated assessment study. The initiative combines the expertise of a wide range of disciplines from demographers through engineers to forestry experts to study in a truly interdisciplinary way the climate change research area. The initiative's latest research has just gone to press in a special issue of the journal, *Technological Forecasting and Social Change*.

The Methods

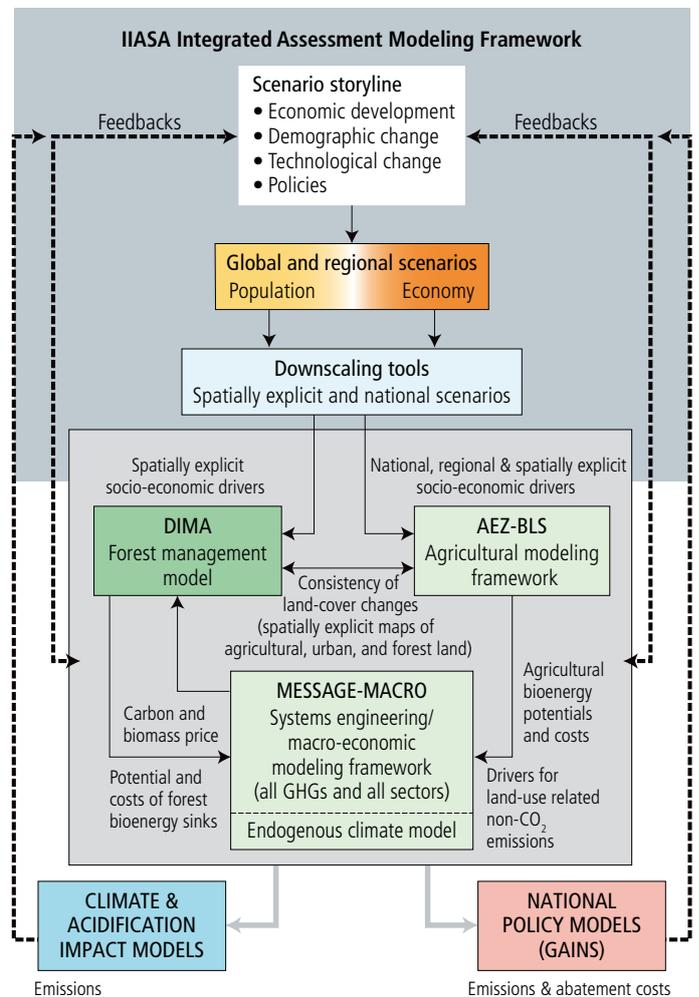
The research is underpinned by a new common analytical framework, the IIASA Integrated Assessment Modeling Framework (see diagram to right). The framework combines a careful blend of rich disciplinary models operating at different spatial resolutions that are interlinked and integrated into an overall assessment framework. The framework covers all greenhouse gas-emitting sectors, including agriculture, forestry, energy, and industrial sources for a full basket of greenhouse gases (GHGs), including CO₂, methane (CH₄), nitrous oxide (N₂O), and fluorinated gases (HFCs, CF₄, SF₆). In contrast to the traditional model integration through simplified "black box" representation of individual components, the IIASA modeling approach encompasses a detailed representation of each of the individual sectors. Integration is achieved through a series of hard and soft linkages among the individual components to ensure internal scenario consistency and plausibility.

To address the uncertainties in GHG emissions and their mitigation options, IIASA's Greenhouse Gas Initiative has taken a new pluralistic approach that combines model sensitivity analysis and probabilistic approaches with scenario-based techniques. The analyses of the different aspects of climate change—from socioeconomic drivers to emissions and related (agricultural) impacts and vulnerabilities—are based on a common set of comparable scenarios. This is in contrast to most of the climate change literature that continues to be plagued by a plethora of different scenarios used in the various assessments, which makes a comparison of model results almost impossible.

Findings: Uncertainties

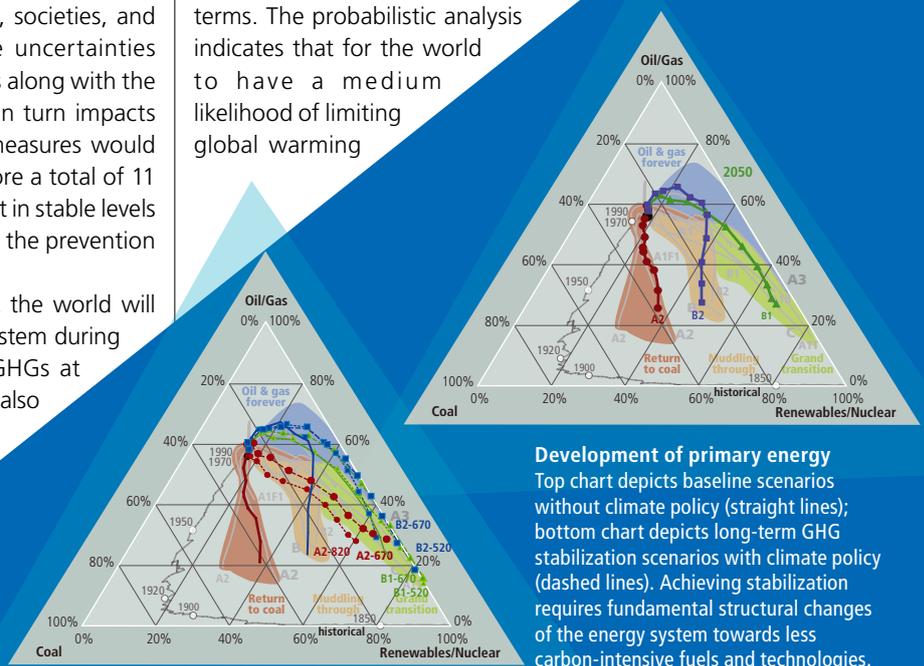
The first paper in the special issue on GGI research by Keywan Riahi, Arnulf Gröbler and Nebojsa Nakicenovic explores exactly these alternative future scenarios for the twenty-first century. The scenarios vary depending on how economies, societies, and populations develop. They thus investigate the uncertainties associated with the drivers of future GHG emissions along with the resulting magnitude of climate change, how this in turn impacts our world, and what the feasibility and cost of measures would be to mitigate the emissions. The researchers explore a total of 11 stabilization scenarios that in the long term will result in stable levels of GHG concentrations in the atmosphere and thus the prevention of dangerous interference with the climate system.

Among many findings, this analysis shows that the world will have to completely restructure the global energy system during the twenty-first century if it wishes to stabilize GHGs at relatively low levels (see triangle charts). The work also breaks new ground in its analysis of robust technology portfolios by arguing that a narrow focus on supply-side mitigation options alone is likely to fall short of harnessing the full synergistic mitigation potential of new technologies that could result from integrating both energy end-use (efficiency) and



supply aspects. This need for measures to reduce demand for energy such as energy conservation and efficiency improvements is echoed in the results of the second paper.

The second paper by Ilkka Keppo, Brian O'Neill, and Keywan Riahi extends the above "upstream" uncertainty analysis "downstream" to the climate change uncertainty chain, connecting changes in human activities to climate change impacts, and it treats a discrete variable, so-called climate sensitivity, in probabilistic terms. The probabilistic analysis indicates that for the world to have a medium likelihood of limiting global warming



to 2.5–3°C above the preindustrial level; it must reduce 45–60 percent of cumulative emissions by 2100 compared with unmitigated scenarios. In addition, GGI researchers conclude that the *rate* of temperature change may be even more difficult to control if most of the mitigation effort is postponed until later in the century. This has important policy implications, as it emphasizes the importance of short-to-medium-term measures as part of a long-term cost-effective climate abatement strategy (see page 26 of this *Options*).

Although long-term climate-policy and modeling studies comprehensively study socioeconomic as well as geophysical sources of uncertainty, it must be noted that they generally assume a “perfect” policy environment, in which both policy instruments and cooperative behavior on the part of individual parties are assumed to operate with perfect efficiency. But what are the implications if countries fail or are simply late to implement policies, or if they are unwilling to join international agreements to combat climate change?

The third paper by Ilkka Keppo and Shilpa Rao presents a systematic sensitivity analysis of climate stabilization scenarios as they are affected by varying delays in the participation by different regions in global emission mitigation efforts. The main conclusion of Keppo and Rao is that nonparticipation in global mitigation efforts results in a hefty economic penalty: mitigation costs increase substantially according to the degree of noncooperative behavior, with the size of the economic penalty depending on baseline emissions, the contribution of the nonparticipating region to the global emissions burden, the stringency of the climate target, and the spatial and technological flexibility assumed in the reorganization of mitigation measures from other regions that need to make up for the “shortfall” in emission reductions due to a region’s noncompliance.

Another important finding is that nonparticipation leads to additional inertia in energy systems and thus to a delayed “technological transition” toward a low-carbon future. This “lagging behind” in technology and infrastructure development is the inevitable long-term economic trade-off entailed by the short-term economic benefits of “free riding” by nonparticipation in globally coordinated mitigation efforts.

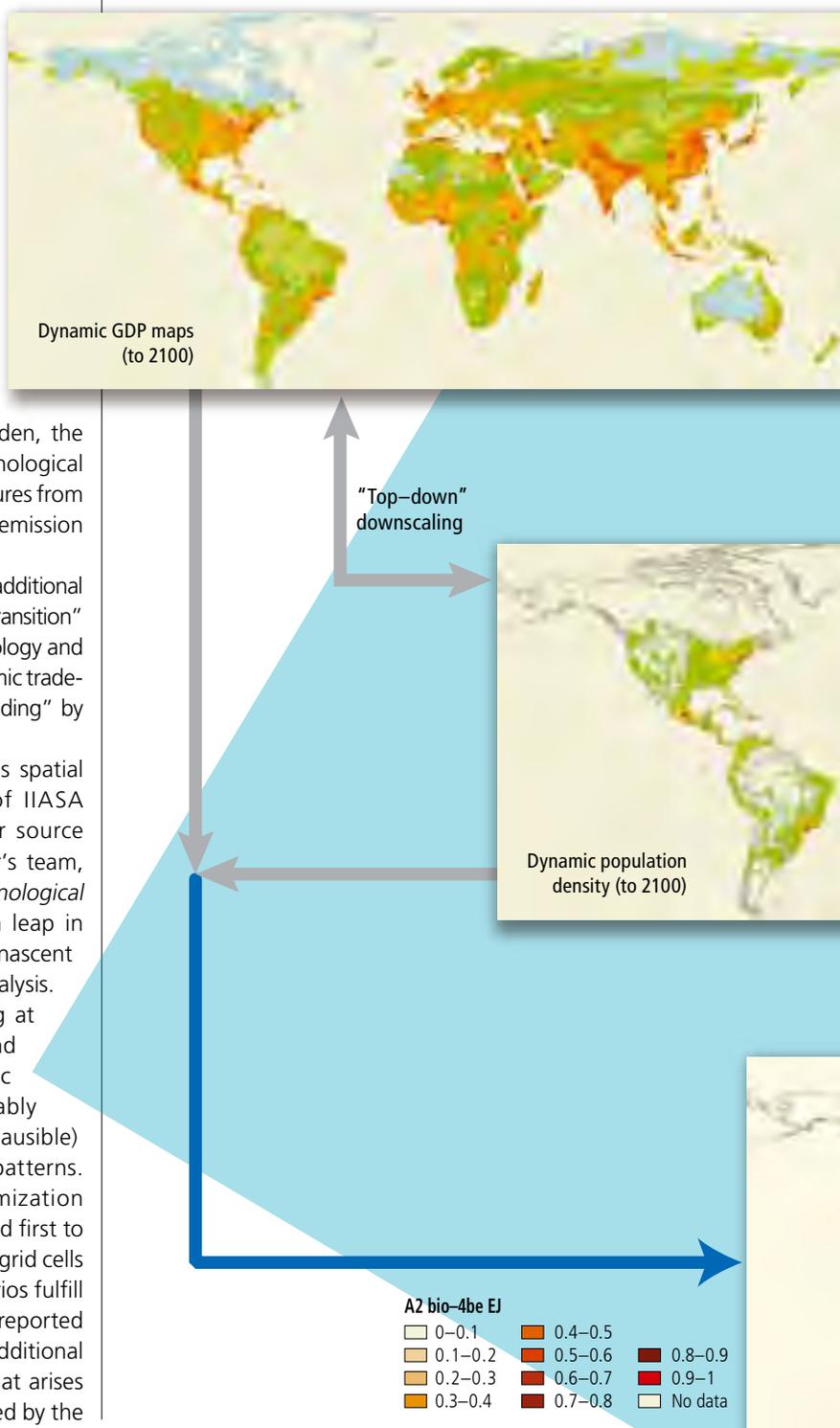
Another important characteristic of climate change is spatial heterogeneity, which is highlighted by the team of IIASA researchers coordinated by Arnulf Grübler as a major source of climate change uncertainty. The research of Grübler’s team, summarized in the fourth paper of the special issue of *Technological Forecasting and Social Change*, represents a quantum leap in both the methodological and empirical aspects of the nascent field of spatially explicit scenario and climate change analysis. The paper not only illustrates the importance of looking at spatial heterogeneity; it also offers new approaches and methodologies for capturing this heterogeneity in dynamic socioeconomic scenarios, which to date have invariably either ignored spatial detail or relied on (entirely implausible) assumptions of uniform proportional spatial growth patterns.

Using a combination of decomposition and optimization techniques, world regional scenario results are downscaled first to the level of 185 countries and subsequently to the level of grid cells at a resolution of 0.5° by 0.5°. The spatially explicit scenarios fulfill a dual role in the integrated scenario uncertainty analysis reported in the special issue. First, they elucidate an important additional uncertainty dimension to the climate change problem that arises from spatial heterogeneity, which is perhaps best illustrated by the

staggering urban growth in developing countries that characterizes invariably all scenarios, despite the vast differences in their assumed population growth and urbanization rates. Second, the scenarios provide important input data for the spatially explicit modeling of land-based GHG emission mitigation options, such as biomass energy and carbon sequestration options (e.g., afforestation) that are reported in the three subsequent papers concluding this special issue (see maps below).

Findings—Food and Forests

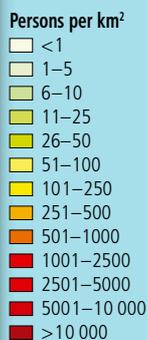
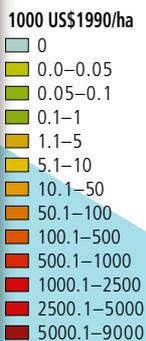
The final three papers in the special issue illustrate the importance of detailed, spatially explicit assessments of climate change. The study by Francesco Tubiello and Günther Fischer suggests that slowing



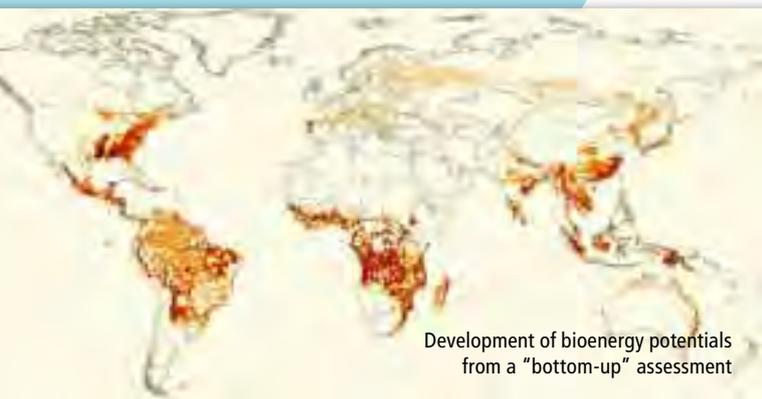
climate change through mitigation measures will have significant positive effects on agriculture compared to an unmitigated climate change. Global impact costs, though relatively small in absolute numbers, were reduced by roughly 75–100 percent; and the number of additional people at risk of malnutrition due to climate change was reduced by 80–95 percent by mitigation. However, there were regional differences, and by the end of the century some regions, particularly temperate-zone developed countries, would be worse off because of mitigation (see page 16 of this *Options*).

The sixth paper by a team of forest experts coordinated by Dimitri Rokityanskiy presents major improvements to the scientific models that explore GHG mitigation options such as biomass energy, afforestation, and avoided deforestation. By integrating changing land prices and competing land uses (agriculture, biomass plantations, or forestry) with models of the biophysical phenomena, the researchers project that forests could absorb up to 30 years of current energy-related emissions by 2100 through afforestation and avoided deforestation. The exact quantities depend on carbon prices and the demand for biomass, which could result in unprecedented land use changes.

Biomass potentials Estimation of biomass potentials derived from spatially explicit dynamic projections of economic and demographic change. Maps illustrate the spatial distribution of Gross Domestic Product (GDP), population, and biomass energy potentials by 2100 (A2 scenario).



Consistency of land-price, urban areas, net primary productivity, biomass potentials (spatially explicit)



Development of bioenergy potentials from a "bottom-up" assessment

The final paper examines how farmers can adapt to climate change by increasing irrigation. IIASA's agriculture experts led by Günther Fischer examine this little researched area. They estimate that by 2080 the world's warmer climate will lead to a 45 percent increase in demand for water to irrigate crops because of an increase in daily water requirements under higher temperatures and extended crop calendars in temperate and subtropical zones. However, the researchers expect irrigation efficiency to increase by some 20 percent, meaning that agricultural water withdrawals would increase by only 25 percent.

The special issue offers far more findings and details on the new methodologies than have been possible to include in this article. It is well worth reading, as it highlights the problems and possible solutions to researching the uncertainties of climate change now and in the future. After all, would Arrhenius have predicted that the once backward and colonially exploited China would now be in the process of surpassing the economic output of the United Kingdom? Or would he have foreseen that the dominant technology of his day—coal fired steam engines—would now be obsolete? ■

Further information Special issue of *Technological Forecasting and Social Change: Integrated Assessment of Uncertainties in Greenhouse Gas Emissions and their Mitigation* (Nakicenovic and Riahi (eds.), in press). See www.iiasa.ac.at/Research/GGI/publications.

Dr Fabian Wagner, Dr Keywan Riahi and **Dr Michael Obersteiner** are coordinators of IIASA's Greenhouse Gas Initiative.

MOVING FROM RESEARCH TO ACTION

What IIASA's Greenhouse Gas Initiative will do next

One of the great challenges in addressing climate change is how to engage stakeholders in time to respond to this threat. Though we already now detect that climate change is taking place, its full impacts are looming only far in the future, and arguably affecting those living in far away countries. So the threat of climate change is effectively not tangible.

The aim of the United Nations Framework Convention on Climate Change (UNFCCC) "to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" is laudable, but what do individual countries have to do after Kyoto in order to achieve this goal? How can the long-term perspective be linked to the short-term mitigation policies and planning? How do we get the stakeholders to engage here and now?

IIASA's Greenhouse Gas Initiative is currently developing a novel approach to bridging the gap between long-term objectives for the globe, on the one hand, and national and short-term policies, on the other. This Policy Assessment Framework will build on IIASA's expertise in integrated assessment modeling at different scales and its experience with engaging in dialog with stakeholders.

IIASA's energy model (MESSAGE) and greenhouse gas/air pollution model (GAINS) will play integral roles in this framework, and their interplay will form the methodological backbone of the approach. These models, widely respected by both scientists and stakeholders, will help build a tool that takes into account major feedbacks at different scales without losing sight of real world policy perspectives.

Our starting point will be a set of national energy scenarios for the next 10 to 30 years that are developed by stakeholders for the purpose of national planning. These plans are then linked into a global framework to assess national perspectives in the context of global climate change over a time horizon of 100 years. Linking these time scales will allow us to telescopically view national policies in the long run, and vice versa, to observe the short-term implications of long-term targets, such as those specified by the UNFCCC.

By engaging with stakeholders and taking climate and other relevant policies into account, our results will become directly relevant to ongoing post-Kyoto negotiations. At the same time, the Policy Assessment Framework will embed national planning perspectives into a global picture and eventually help to answer the question "How much mitigation is enough?" for individual countries. ■

There is concern in all countries about the national and global impacts of climate change and variability. Whether beneficial or detrimental, climate change will affect many areas of life, including human welfare, domestic and international policies, trading patterns, and resource use.

Food production is high on the list of human activities and ecosystem services under threat from dangerous anthropogenic interference in Earth's climate. As far as agriculture is concerned, climate change will result in new combinations of soil, climate, atmospheric constituents, solar radiation, pests, diseases, and weeds. The responses of plants to climate change have been studied in countless experiments, and detailed modeling of basic biological processes has provided a basic understanding of the direct and indirect effects of climate change on agricultural productivity.

Current research confirms that while crops would respond positively to elevated CO₂ in the absence of climate change, the associated impacts of high temperatures, altered precipitation patterns, and possibly the increased frequency of extreme events such as drought and floods, are likely to combine to depress yields and increase production risks in many regions. Moreover, developing countries, where about 800 million people are undernourished, are more vulnerable to climate change than developed countries because of their dependence on agriculture, lack of capital for adaptation measures, warmer baseline climates, and heightened exposure to extreme events.

Analyzing impacts

What are the implications for global and regional agricultural production of mitigating greenhouse gas emissions, and thus slowing climate change over time? By when and by how much will impacts be reduced? Where do measures matter most? These questions were investigated within a new scenario of development and emissions recently elaborated at IIASA.

To assess the impacts of climate change on agriculture over the twenty-first century, with and without climate change mitigation, IIASA scientists devised a two-step strategy. First, the impacts of socioeconomic variables were analyzed against current conditions, without climate change. Second, the impacts of climate change, without and with mitigation, were superimposed on the first scenario, and the differences between unmitigated and mitigated climates were computed. Simulations were performed for 1990–2080, with global coverage and also significant regional detail. The key trends expected over this century for food demand, production, and trade were computed, with specific focus on the potential monetary (aggregate value added) and human (risk of hunger and malnutrition) implications of mitigation.

The study quantified the potential benefits of mitigation to the agricultural sector as a whole, and the results can be summarized as follows: (1) The benefits of mitigation in terms of global annual agricultural output in 2080 were in the order of US\$30 billion, measured as differences in agricultural gross domestic product (GDP) between the mitigated and unmitigated scenarios (at constant 1990 prices); (2) Mitigation clearly benefits developing regions but may reduce the gains of some export-oriented developed countries; (3) Mitigation would reduce the number of people at risk of hunger in 2080 by 70–90

million people or 12–16 percent of the total number of people at risk of hunger projected in the baseline scenario in 2080 (see bottom two charts). Thus, mitigation of climate change would have significant positive effects on agriculture and food security, compared to unmitigated climate change.

The water factor

There is concern not only about the impacts of climate change on rain-fed crop production. What about future agricultural water availability under the combined effects of climate change, growing population demands, and competition from other economic sectors? Renewable water resources are

LAND USE CHANGE

Food, water,

With its multidisciplinary methodology and models for analyzing and formulating policy response options, IIASA has made a unique evaluation of the potential impacts of climate change on food and water resources around the world. The picture is not completely bleak—but the pursuit of sustainable development will be instrumental in achieving lasting climate change mitigation and adaptation, and thus food and water security.

increasingly recognized as essential to the sustainability of human societies, but approximately 1.7 billion people, roughly one-quarter of the world's population, currently live in countries experiencing water stress. This is set to rise to 5 billion by 2025, according to the United Nations *Comprehensive Assessment of the Freshwater Resources of the World*.

Climate change may worsen these patterns, with some parts of the world receiving more precipitation, and others less. Because of evapotranspiration, temperature increases will raise the water demand of ecosystems, and climate change will also impact the availability and quality of freshwater resources.

Water is a key driver of agricultural production. Today, over 270 million hectares worldwide (about 18 percent of total cultivated land) is under irrigation accounting for 70 percent of the total anthropogenic use of renewable water resources in 2000 of around 3815 billion m³. However, only about half of agricultural water withdrawals reach the crops; the remainder is lost through leaking and/or evaporation from irrigation infrastructure.

Potential changes in demand for global and regional agricultural water for irrigation were investigated within a new socioeconomic scenario developed at IIASA, with and without climate change, and with and without mitigation of greenhouse gas emissions. Our results indicate that future socioeconomic development and climate change may both significantly impact global and regional irrigation requirements and thus agricultural water withdrawals. Against

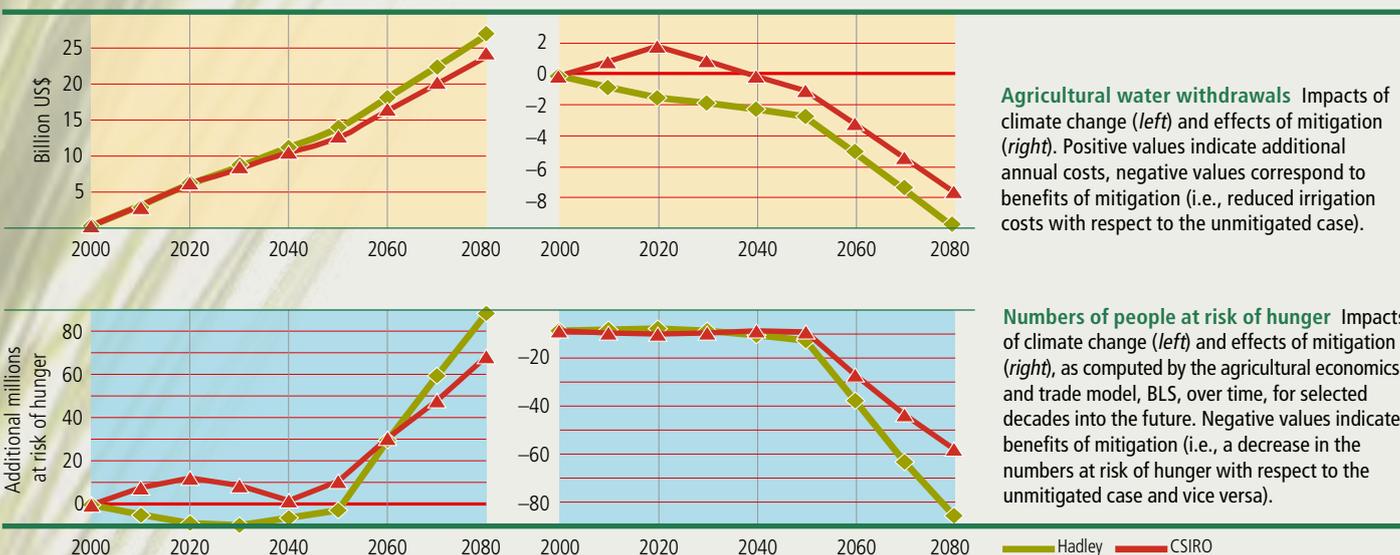
the current amount of about 1,350 billion m³, we computed a 45 percent increase in net irrigation water requirements, i.e. excluding water losses in irrigation infrastructure, by 2080 to over 1,960 billion m³ worldwide. Assuming improvements in irrigation efficiency, the increases in gross agricultural water withdrawals, i.e. including losses, were around 20 percent, from about 2630 billion m³ water in 2000 to about 3,280 billion m³ in 2080.

The impacts of climate change on global irrigation water requirements were also significant. Total increases of about 400 billion m³ water in 2080 were projected, a 20% increase above the reference case (without climate change).

production are geographically very unevenly distributed, and aggregate global figures reveal little.

While there is some uncertainty regarding a number of essential factors—magnitude and geographical detail of impacts, the future capacity for and effectiveness of adaptation and mitigation measures—the results nevertheless strongly suggest critical asymmetries in terms of impacts due to both climate and socioeconomic structures. These losses will be felt most profoundly in the poor developing countries with low capacity to cope and adapt. Climate change impacts

and climate change



The figures compare results using two general circulation models (global climate models), Hadley and CSIRO.

Results suggest that climate change mitigation would also significantly mitigate regional and global irrigation water demand, compared to unmitigated climate change, with quite similar beneficial effects for developing and developed regions. By 2080 this provided annual savings in water withdrawals of 125–160 billion m³ and estimated cost benefits of some US\$10 billion annually (see top two charts).

The simulation results suggest that, in this century, the global impacts of climate change on increasing irrigation water requirements could be nearly as large as irrigation increases projected due to socioeconomic development. In addition, mitigation could bring large overall savings in irrigation water, globally and regionally.

Hunger and poverty

Some fairly robust conclusions emerge from the analysis of climate-change impacts on agriculture and food availability. First, climate change will most likely increase the number of people at risk of hunger. Second, however, the importance and significance of the climate-change impacts on undernourishment will depend mainly on the level of economic development and poverty reduction achieved in the coming decades. Though the aggregate impacts of projected climate change on the global food system are relatively small, the impacts of climate change on crop

are thus almost certain to deepen current production and consumption gaps between developed and developing countries. Integrating mitigation, adaptation, and sustainable development policies appears to improve the prospects of achieving long-term environmental goals and meeting the development needs of the least-developed countries.

Combating climate change and variability is vital to the pursuit of sustainable development; equally, the pursuit of sustainable development is integral to lasting climate change mitigation and adaptation. The climate change issue is global, long-term, and involves complex interaction between climatic, social, environmental, economic, technological, institutional, and political processes. It has significant international and intergenerational implications. Mitigation and adaptation to climate change can only succeed in an international partnership. ■

Further information IIASA's Land Use Change and Agriculture Program at www.iiasa.ac.at/Research/LUC

Dipl Ing Günther Fischer is the leader of IIASA's Land Use Change and Agriculture Program. **Dr Mahendra Shah** and **Dr Harrij van Velthuisen** are senior scientists in IIASA's Land Use Change and Agriculture Program.

From ice age to heat

*From natural science to interdisciplinary research:
IIASA and the history of climate change research*

In the early 1970s chilling warnings of global cooling appeared in the media as some scientists concluded the Earth was gradually heading toward a new ice age. Yet, by the end of that decade global warming was scientifically recognized as a major problem.

What caused this shift in opinion from global cooling to global warming? Part of the reason is the complex nature of climate change. The science of climate change crosses national boundaries and spans academic disciplines. And it was only in the 1970s that scientists from different disciplines recognized the huge complexity of the planet's environment and began to work closely together.

Wind patterns, melting ice sheets, ocean circulation, soil respiration, clouds—scientists were discovering that, as far as climate was concerned, everything seemed to interact with everything else. In addition, researchers were learning that an increase in temperatures could set off other even more serious climate-warming mechanisms. No longer could climate scientists study climate change in isolation.

As the natural science of climate change began to come together in the mid-1970s, two key questions were raised that researchers had scarcely examined in any depth. What were the practical implications of climate change for human beings? And how could human beings influence climate change over the coming decades? After all, changes to the climate take place over decades and centuries, during which time societies and economies also change significantly.

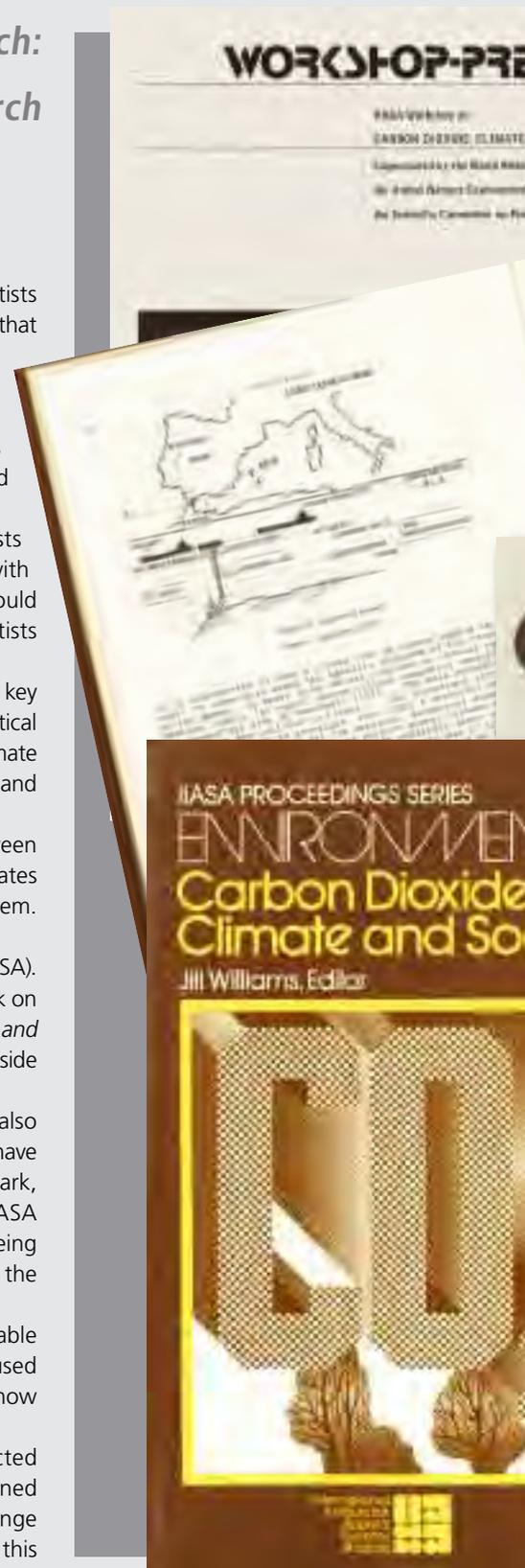
For governments, answers to these questions were crucial to bridging the gap between science and government policy. And so, in 1978 the White House asked the United States National Academy of Sciences for advice on what was then called the carbon dioxide problem. The Academy appointed economist, Tom Schelling, now a Nobel Laureate, to investigate.

In his research, Schelling came across the International Institute for Applied Systems Analysis (IIASA). "I never, at the time, discovered any other research organization that had done integrated work on the subject (the carbon dioxide problem)," he recalls in an article in *Technological Forecasting and Social Change*. He goes on to argue that only at IIASA, where different disciplines work alongside each other, was the proper scientific attention placed on a problem that spans all disciplines.

In the 1970s IIASA provided the arena to bring together natural and social scientists. It also brought together different nationalities. "With something as global as climate, nobody would have got far without involving both the east and the west in sorting it out," observes William C. Clark, a Harvard University professor, who was at IIASA in the 1970s and 1980s. At this time IIASA was one of only four international organizations working in this area, the other three being the United Nations Environment Programme, the World Meteorological Organization, and the International Council of Scientific Unions.

IIASA did not simply provide the place for researchers to collaborate; it was also a valuable provider of research. Unlike the other three international organizations, whose work focused mainly on the natural science of climate change, IIASA led a sustained research effort into how climate change would affect human beings and also into what could be done about it.

In 1979, using far simpler models than today's sophisticated models, IIASA predicted temperature rises of between 1°C and 4°C by 2050. This range of increase has remained remarkably constant, with the latest report of the Intergovernmental Panel on Climate Change (IPCC) in 2001 predicting temperature rises of between 1.4°C and 5.8°C by the end of this



wave

century. Although this may have more to do with stickiness (the tendency for findings, once stated, to resist modification even in the face of new evidence) it shows the influential role of being first to research an area.

IIASA's models were just part of its larger investigation into the impact the world's energy system would have on our climate, which in turn was part of IIASA's, and indeed the world's, first comprehensive, truly global assessment of energy issues.

In February 1978 IIASA held what has turned out to be the key conference, "Carbon Dioxide, Climate, and Society." The conference culminated in one of the earliest international assessments of the climate problem, with 40 authors from 11 countries contributing technical papers. "Although we now know many more details, the prevailing assessment of overall climate sensitivity and biogeochemical apportioning of emissions has changed only modestly since IIASA issued its climate report," wrote Clark and Jill Jäger, who led IIASA's Energy and Climate Subtask in the 1970s, as they reviewed part of the IPCC's Second Assessment Report written nearly 20 years later.

Many of the issues raised at that conference are still discussed today. The use of alternative, renewable energy sources such as biomass; carbon capture and storage; how to reduce the world's energy demand—even uncertainty, which dominated and still dominates every aspect of climate change from emission rates through environmental consequences to the socioeconomic impacts themselves. Indeed, the conference examined what are the tolerable rates of burning fossil fuel that will keep governments' options open for developing effective energy strategies at some future point when climate change is better understood.

Subsequently, IIASA's work became foremost in demonstrating to governments the error of adopting energy policies that emphasize the use of fossil fuels. Such mistaken policies needed to be revised because of the impact of burning fossil fuels on the climate.

Other IIASA research in the 1970s was equally pioneering. At the beginning of the decade, there was the work of the man the *Economist* calls the father of climate change economics, Bill Nordhaus. Many of the currently dominant climate change policy models trace their conceptual and methodological roots to models developed by him at IIASA. "My own first serious research on global warming started when I spent a year in Vienna at IIASA," remembers Nordhaus. "Research on global warming is deeply interdisciplinary, and IIASA at that time was uniquely able to foster interdisciplinary work. It was here that I published my first (and I believe the first) economic model of global warming as an IIASA working paper in 1975."

In 1976 IIASA scientist Cesare Marchetti proposed collecting CO₂ from the burning of fossil fuels as it was released. Once captured, the CO₂ would be injected into certain ocean currents that carry and spread it deep into the ocean to be stored for hundreds of years.

Says Jill Jäger: "By 1979, IIASA's research had fed into the Charney Report, the first major study on global warming by the US National Academy of Sciences, and on to the agenda of the World Climate Conference in Geneva." The Charney Report and the Geneva conference marked the emergence of a new scientific consensus. Both concluded that the dangers of increasing CO₂ levels would lead to possibly major long-term changes in the planet's climate.

However, it was not until nearly 10 years later that climate change emerged from the scientific community and fully entered the mainstream political agenda with the founding of the Intergovernmental Panel on Climate Change (IPCC) in 1988. During this period much-needed research gathered pace.

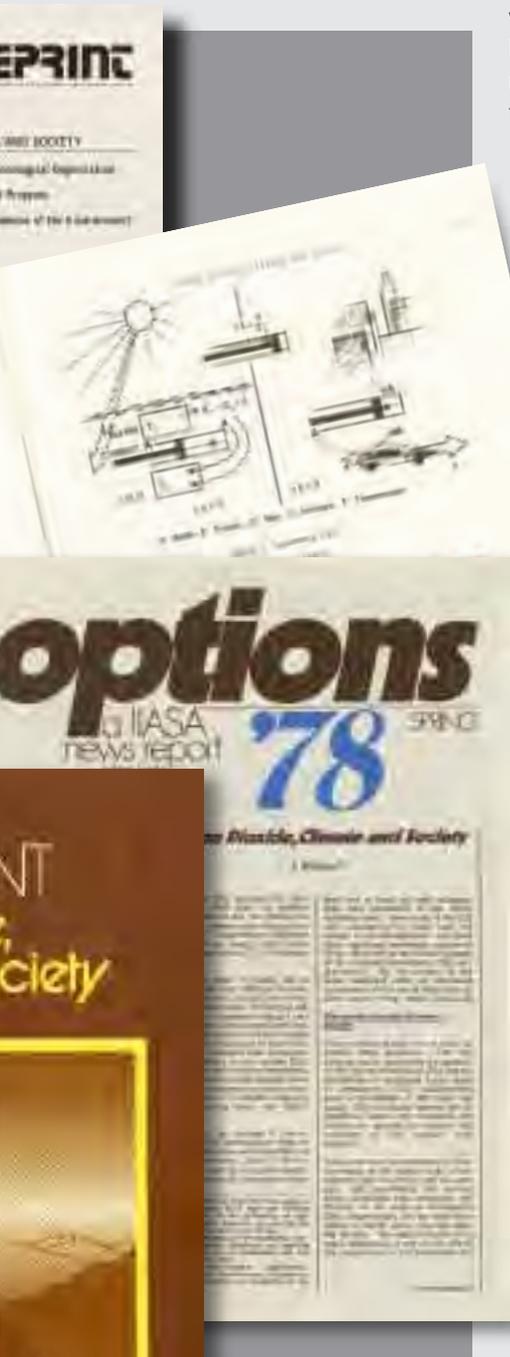
Again IIASA played a key role, this time at an international conference in Villach, Austria, in 1985, where 89 scientists from 23 countries gathered to speak independently, free from government constraints. In a conference statement, the scientists forecast "significant warming" and warned climate change "would have profound effects on global ecosystems, agriculture, water resources and sea ice." William C. Clark from IIASA was invited to give the keynote presentation on the practical implications of the carbon dioxide question.

The *New Scientist* writes that the Villach conference was key to recasting climate change as a problem for today and that it led to the establishment of the IPCC. Says Clark: "It moved the science into the policy arena."

But this was nearly a decade since IIASA's first research project into climate change—work that continues today. ■

Further information A list of sources can be found online at www.iiasa.ac.at/Options/sources.

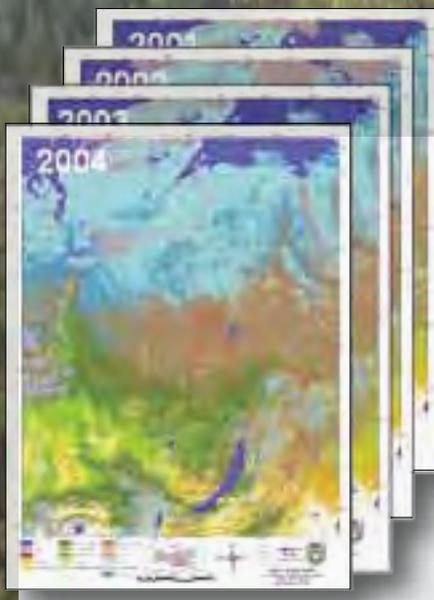
Iain Stewart is the manager of IIASA's Publications Department.



In February 1978 IIASA held the conference, "Carbon Dioxide, Climate, and Society," which culminated in one of the earliest international assessments of the climate problem with 40 authors from 11 countries contributing technical papers.

Helping to understand a changing world

The forests of Siberia cover over 300 million hectares and represent a significant part of the Earth's northern biome which plays a critical role in global climate. While, potentially, the Siberian taiga is a vast sink for greenhouse gases like CO₂, little is known about Siberia's role in the global carbon cycle. IIASA's Forestry Program was among 14 European and Russian scientific institutes taking part in the Siberia-II project, which used some of the world's most advanced technologies and climate models to quantify carbon fluxes between land and atmosphere.



The aim of the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol is to cut emissions of greenhouse gases resulting from human activities. Neither the Convention nor the Protocol cover natural releases of carbon from the biosphere, for example, from thawing permafrost and drained peat lands. Yet, without reliable information regarding the interactions between Earth's climate system and biosphere, none of the major goals of the international agreements can be effectively implemented. A crucial step toward understanding them is Full Greenhouse Gas Accounting (FGGA) of a region's biota. Obviously, only a *verified* FGGA—where the uncertainties of all results are reliably and comprehensively estimated—can be used for important political and economic decision making in the area of climate change mitigation.

Old problem

Full Greenhouse Gas Accounting, like standard accounting, comprises assets (e.g., carbon sinks) and liabilities (emissions). By definition, full greenhouse gas accounting includes all the major greenhouse gases emitted from all ecosystems all the time. However, even with the advanced environmental systems and modeling tools available today, a verified FGGA is very difficult to obtain, especially for large regions, countries, and continents. FGGA therefore operates under substantial uncertainty, and we must always ask: How reliable are our results and how greatly do our estimates differ from reality? And, as current and incomplete estimates of uncertainties often exceed 100 percent: Can uncertainties be decreased to a level that would have sense for policy makers?

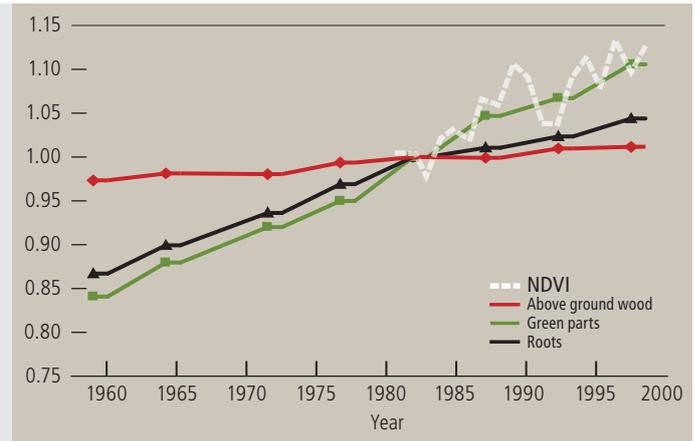
The region and case study

The region includes all vegetation zones of the boreal biome stretching for some 4,000 km along the 90th meridian—from polar deserts in the north to dry steppe and semideserts in the south (see map and forest photo). Dramatic global climate changes are expected in this region—annual temperature is likely to increase by up to 6–10°C by end of this century, and the impacts of such changes may be critical. These territories comprise huge amounts of organic carbon stored in wetlands and soil, particularly in permafrost. The resulting release of greenhouse gases into the atmosphere through warming and melting of permafrost could dramatically accelerate global warming. Taiga forests are especially important as the “lungs of the Earth” and contain over half the world's marketable coniferous wood.

While a substantial part of the region is situated in remote and sparsely populated areas, where the greenhouse gas balance is driven by climate change, there are vast territories with globally important storages of hydrocarbons and other deposits facing critical anthropogenic pressure. The largest smelter on the planet, the Norilsk metallurgical plant, emits more than 2 million tonnes of dangerous pollutants per year and has already destroyed vegetation on over 2 million hectares of surrounding forest tundra landscapes. ■



The Siberia-II team was based 1,000 km north of Krasnoyarsk, close to the Arctic Circle.



Satellite observation of Russian forests The share of live biomass in the green parts of trees increased substantially from 1960 to 2000, while that in above-ground wood and roots decreased slightly. (NDVI—seasonally accumulated normalized difference vegetation index. All data are normalized to 1983 values.)

New approach

From 2001 to 2005 IIASA's Forestry (FOR) program carried out advanced modeling work and systems analysis for the European Commission funded project Siberia-II (see team photo). Because of the project's huge size and complexity, a complete systems integration of all the relevant information sources, methods, and models, was required, including sophisticated vegetation models and an Integrated Land Information System (ILIS) of land cover, individual ecosystems, and landscapes. A number of original models were also developed to describe intra-ecosystem links and interactions. Partner institutes took new in situ measurements of different ecological parameters, worked with process-based vegetation models, and 12 Earth observation instruments aboard eight satellites were used for remote sensing.

Siberia-II Findings

The warming in the region during recent decades has been dramatic, with temperature increases two to three times the Russian average and decreased rainfall. FOR's investigations demonstrated that ongoing climate change substantially impacts the condition and functioning of ecosystems. For instance, during the last 50 years, the share of the above-ground wood and roots of trees slightly decreased, while the share of the green parts increased substantially (see graph). This was important for the application of remote sensing tools, which use the amount and condition of the green parts to assess important ecological indicators.

Because of increasing aridness and seasonal climate instability, there have been unprecedented regional disturbances. The area of wild fire, for example, reached its

peak in 2003, with 3.2 million hectares of forest being burned in the region and 23 million across Asian Russia. In 1993–1996 an outbreak of Siberian moth almost completely destroyed one million hectares of highly productive coniferous forest in Central Siberia. The second outbreak in 2001–2003 affected more than 10 million hectares of larch forests in the northeast, where—luckily—even complete defoliation does not lead to substantial forest death.

Nonetheless, during the last few years, Siberian landscapes (mostly forests and wetlands) did serve as a net carbon sink, with about 25 g C m⁻² per year, or 275 Tg CO₂ yr⁻¹ being taken up by the region's vegetation. If carbon fluxes to the atmosphere due to disturbances were minimized, carbon sequestration would increase about one and a half times; however, estimates for the region show that fluxes of other greenhouse gases (e.g., methane, nitrous oxide), comprising about one-third of the territory's global warming potential, also need to be addressed.

Lessons learned

Siberia-II brings scientists much closer to the possibility of a verified FGGA. The uncertainty of the final results are estimated to be 40–60 percent (half that previously reported). The uncertainty level could be halved if improvements were made to all components of the accounting system. Remote sensing is an irreplaceable source of information, but the capabilities of the satellite instruments are significantly inconsistent with FGGA requirements, and only the combined use of different sources of information was able to provide reliable system inputs. Process-based dynamic vegetation models, the only tools for understanding mechanisms

of ecosystems' dynamics and functioning in a changing world, need to be adapted to actual land cover and conditions; much previously collected empirical data turned out to be biased; the changing environment also impacts the links and interactions in ecosystems. Thus, careful historical analysis and the updating of many empirical models are needed; but with the system itself undergoing change, even the predictive capacity of historical empirical data is questionable.

The major practical lesson is that adaptation to and mitigation of the negative consequences of climate change have to be addressed now. If the expected climate changes in the boreal biome become a reality and the level of protection is not significantly increased, the forests of Northern Eurasia may not survive to the end of this century, and their associated environment and living conditions will be dramatically altered. The thawing of permafrost will substantially change the hydrological regime of vast territories. Catastrophic fires and insect outbreaks will be accelerated by increased dryness. Eventually, huge taiga areas are very likely to be replaced by dry northern steppe and stone fields—the process of "green desertification" can already be observed on tens of millions of hectares. Anticipatory mitigation and adaptation strategies are thus a prerequisite of integrated land management and sustainable forest management in the boreal world. ■

Further information IIASA's Forestry Program and the Siberia-II project at www.iiasa.ac.at/Research/FOR/siberia.html and at www.siberia2.uni-jena.de

Professor Anatoly Shvidenko is a senior research scientist and **Ian McCallum** is a research scholar in IIASA's Forestry Program.

Running cars on methanol



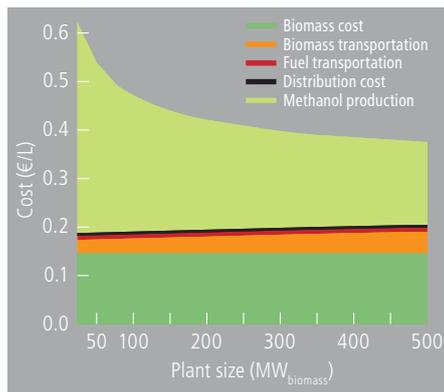
Could methanol prove to be the answer to some of the world's energy woes? A new study by Sylvain Leduc of IIASA's Forestry Program indicates that the biofuel methanol offers huge potential as an alternative to traditional energy sources. In his research, methanol emerges as an economically plausible and environmentally sound alternative to gasoline.

Biofuels, such as methanol, are—in simple terms—produced from plants. Among other uses, they are capable of powering motor vehicles ranging from cars to trucks. Generating energy from plants clearly offers potential solutions to a host of seemingly intractable global problems.

High on the list of thorny international issues, for example, is climate change. As motor vehicles are among the largest contributors to air pollution, biofuel use offers the means to dramatically cut net greenhouse gas emissions to the atmosphere. The gasoline-run car returns carbon to the atmosphere that was absorbed millions of years ago by plankton before it decayed, was buried, and turned to oil. A car running on methanol, which is produced from trees that absorb carbon from the atmosphere while they are growing, returns carbon that has only recently been absorbed. Thus, although the greenhouse gas emissions from a methanol-run car are very similar to those from a gasoline-run car, methanol fuel is markedly less harmful to the atmosphere because the carbon dioxide released is offset by the amount of gas absorbed by the trees when they grew. In other words, it is carbon neutral.

In his study, Leduc examines the sustainability and economic consequences of using methanol as an alternative to fossil fuels for the transport sector. Unlike the more widely used biofuel ethanol, methanol is not fermented but rather produced from wood through a process of gasification, the result of which is a gas with a high energy content. Methanol is just one example of a biofuel that is produced by the gasification of biomass. Other second-generation biofuels that can be substituted for diesel and gasoline include Fischer Tropsch liquids and diesel DME (dimethyl ether).

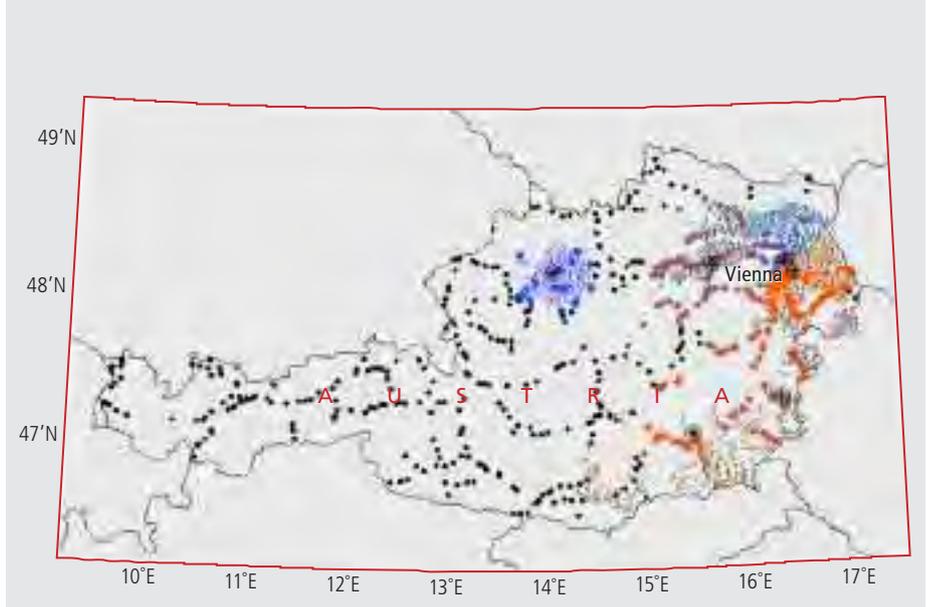
After gasification, the gas is processed and cleaned to make liquid methanol which is then usually mixed with 15 percent gasoline. The rationale behind adding gasoline is that pure methanol flames are nearly invisible in daylight. Gasoline is thus added as a safety precaution to provide color to the flame. It is also easier to start an engine at low temperatures with gasoline in the mix.



A breakdown of the cost of methanol (in euros per liter) by the size of the biofuel plant (in MW).

Leduc modeled the estimated costs for each part of the methanol-for-fuel chain from harvesting and transporting the wood, through methanol production and transportation, to distribution to the consumer. He applied his bioenergy model to the state of Baden-Württemberg in Germany before extending it to Austria.

His calculations show that planting 20 percent of Austria's existing arable land with poplar trees (which can be harvested every four to five years) would provide sufficient methanol for almost half of Austria's 1,990 gas stations at a price that is competitive with current pump prices. Leduc's research shows that a 200 MW plant could produce methanol at a price between 0.3 €/L (euros per liter) and 0.5 €/L, or between 0.6 €/L and 1 €/L in gasoline price equivalent, as twice as much methanol as gasoline is



Distribution of seven methanol plants in Austria A star with a black circle represents the methanol plants; the colored dots represent the biomass for the closest plant; the larger colored dots represent the cities that are supplied with methanol from the plant of the same color; the remaining black dots are the cities that are not supplied with methanol.

needed to drive the same distance using today's standard engine technology. As a comparison, unleaded gasoline fuel cost 1.02 €/L in October 2006 in Austria.

To assess the economic viability of the use of methanol fuel, Leduc made a detailed breakdown of the costs involved in producing it (see graph). As percentages of the total cost, biomass (i.e., trees) represents 36 percent, biomass transport 17 percent, methanol transport 3 percent, methanol distribution 1 percent, and methanol production 43 percent.

Using sensitivity analysis, the study identified the three specific aspects of the methanol fuel process with the greatest impact on the fuel's final cost. It found that the efficiency of the biomass conversion plant has the strongest influence on the methanol price. Indeed, differences in technology can increase the price of methanol by a factor of two. Leduc's cost analysis is based on current technology. Production costs are likely to continue falling as the technology develops, which will make the price of methanol even more competitive.

Wood costs are the next most influential factor, with variations in wood costs influencing the variability of the final price by 70 percent. The running hours of the methanol production plant also have a major impact on price. For example, running a plant for 8,000 hours, as opposed to 6,500 hours, can mean savings on the total methanol production cost of 20 percent.

For methanol fuel to be competitive, Leduc concludes, particular attention must be paid to building the most efficient production plants in the best geographic locations in terms of biomass supply and fuel distribution. Applying this model to

Austria reveals that seven methanol plants of similar technology and size (250 MW) would produce optimal results in terms of a competitive methanol price (see map). In view of such promising results based on one European country, Leduc believes that now is the time to extend this model more widely to Europe as a whole.

Further information Leduc's research project, "Spatially explicit analysis of bioenergy systems," was part of the IIASA-coordinated network, "Integrated Sink Enhancement Assessment." See www.insea-eu.info.

Sylvain Leduc is a research scholar in IIASA's Forestry Program

Methanol: A few facts

- First discovered in 1823, methanol is a colorless, odorless, slightly inflammable liquid, also called methyl alcohol or wood alcohol. Liquid methanol can be produced from just about anything, including trees, that contains carbon. Methanol has been used for more than 100 years as a solvent and to make products such as plastics, plywood, and paint.
- Pure methanol (M100) has been used to power heavy-duty trucks and transit buses equipped with compression-ignition diesel engines. Since 1965, M100 has been the official race fuel for Indianapolis 500 race cars. In 1964, the last time gasoline was used in the Indianapolis 500, a pile-up of cars resulted in a gasoline fire and deaths. And while pouring water on to gasoline spreads a fire, M100 fuel can be extinguished with water if an accident occurs.
- A blend of 85 percent methanol and 15 percent gasoline (M85) is typically used in cars and light trucks. Power and acceleration using M85 are comparable with those of other fuels in equivalent internal combustion engines. M85 has a high octane rating of 102, compared with 87 for regular unleaded gasoline. Methanol can be dispensed from pumps in the same way as gasoline or diesel. As methanol is corrosive, however, fuel storage tanks and dispensing equipment must be corrosion-resistant.

A last resort

How could the world respond if it suddenly faced major, unexpectedly rapid climate change? Nobel laureate Paul Crutzen has begun investigating an emergency measure to inject sulfur into the atmosphere. Preliminary results suggest that this would dramatically slow global warming.

Injecting sulfur into the atmosphere can also be observed naturally during volcanic eruptions, as in the Mount Pinatubo eruption in 1991, which injected sulfur into the stratosphere. The enhanced reflection of solar radiation to space by the particles cooled Earth's surface by an average of 0.5°C in the year following the eruption.

Fossil fuel burning releases carbon dioxide into the atmosphere, which contributes significantly to global warming. Burning fossil fuel also releases sulfur into Earth's atmosphere in the form of sulfate particles. Ironically, these sulfate particles help to cool down the planet by reflecting solar radiation back into space. Crutzen's proposed planet-saving scheme, which involves artificially injecting sulfur into the stratosphere (the atmospheric layer second closest to Earth) to offset greenhouse gas warming, is based on this phenomenon.

His "albedo enhancement method," or, in other words, his proposed way of increasing Earth's reflective powers so that a significant proportion of solar radiation is reflected back into space, aims to replicate the cooling effect these man-made sulfate particles achieve.

"Some people argue that we shouldn't even be considering these types of 'solutions.' I hope the sulfur scheme will never have to be conducted, but we should not rule out that it might," says Crutzen. "It should only be

conducted when major, unexpectedly rapid climate change takes place, similar to what happened with ozone over the Antarctic."

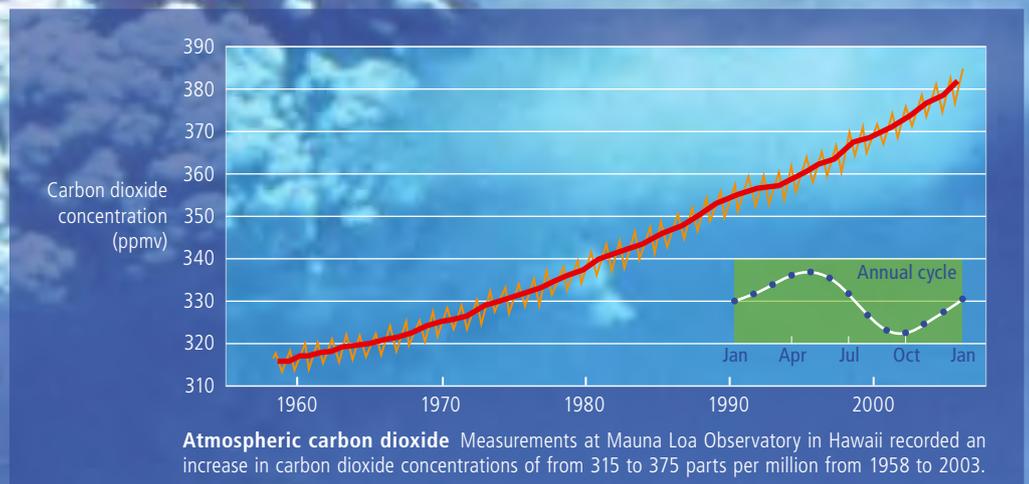
It is against the background of grossly disappointing international political response to cutting greenhouse gas emissions that Crutzen argues his research is worthy of serious consideration. Measurements at Mauna Loa Observatory in Hawaii recorded an increase in carbon dioxide concentrations of from 315 to 375 parts per million from 1958 to 2003 (see graph above). This carbon dioxide traps heat within Earth's atmosphere like a greenhouse and results in global warming. Scientists of the Intergovernmental Panel on Climate Change demonstrate convincingly that most of the global warming over the last 50 years is attributable to human activities.

And more recent research shows how global warming is already having a major impact on our planet. New studies indicate that the Arctic Ocean's ice cover is 40 percent thinner than 20–40 years ago. Some studies suggest that global warming increases the risk of extreme weather, including floods

and desertification. Others show increasing heat waves in Europe such as that in the summer of 2003. Research also predicts that the melting of the permafrost will release more carbon dioxide and methane into the atmosphere and so accelerate the process of global warming. And it is unlikely that Earth's ecosystems and biodiversity will be able to adapt to rapid climate change.

At the Earth Summit in 1992 in Rio de Janeiro, the world agreed to prevent "dangerous" climate change. But it was not until 13 years later that the Kyoto Protocol came into force, and even then without the commitment of key countries such as Australia and the United States. The Protocol will bring modest emission reductions from industrialized countries, but much deeper cuts are needed and developing nations, which have large and growing populations, will also have to do their part.

Injecting sulfur into the atmosphere can also be observed naturally during volcanic eruptions. Crutzen uses the eruption of Mount Pinatubo in the Philippines in 1991 as



a model for his idea. The volcanic eruption injected sulfur into the stratosphere. The enhanced reflection of solar radiation to space by the particles cooled the Earth's surface by an average of 0.5°C in the year following the eruption.

Crutzen's initial research can be found in a recent article in *Climatic Change*. He is now working with Phil Rasch of the US National Center for Atmospheric Research in Colorado. They are using a relatively sophisticated General Circulation Model for a somewhat more quantitative and comprehensive look at the problem. Early results suggest sulfur injection of about one million tons per year might be highly effective in preventing global warming brought about by a doubling of carbon dioxide levels.

And results would be quick. In Crutzen's experiment, artificially enhancing Earth's reflective powers would be achieved by carrying sulfur into the stratosphere on balloons, by using artillery guns, or, possibly most effective, by using specially designed aircraft that release the sulfur in the tropics at an altitude of about 25 km.

The sulfur would then diffuse into the rest of the stratosphere and from there into the troposphere.

In contrast to the slowly developing effects of global warming associated with man-made carbon dioxide emissions, the climatic response of the albedo enhancement method could theoretically start taking effect within six months, reaching full strength after about 10 years. The reflective particles would remain in the stratosphere for up to two years and need to be continuously replaced. The stratospheric injections represent only a few percent of the sulfur that is emitted at ground level by fossil fuel burning, and so would add only slightly to acid rain.

Notwithstanding these promising results, Crutzen insists the potential side effects of the sulfate scheme need to be properly researched. These could include ozone depletion, an impact on cloud formation in the upper tropospheric regions, acid rain, and the amelioration of only some of the effects of carbon dioxide. For example, the gases could combine to

further increase the acidification of our planet's oceans.

Above all, Crutzen hopes that such an emergency measure will never be needed. The most sustainable and effective solution to global warming is for the world to reduce its greenhouse gas emissions. But this is a slow process as it requires major changes to the world's economy and society, which will take decades, if not centuries. However, if major and unexpectedly rapid climate change did begin, the sulfate scheme could buy the world enough time to implement these changes. In addition, by posing such a grotesque solution, Crutzen is also hopeful that it may galvanize the nations of the world into deeper cuts in greenhouse gas emissions. ■

Further information Crutzen P (2006). Albedo enhancement by stratospheric sulfur injections: A contribution to resolve a policy dilemma? *Climatic Change*; DOI 10.1007/s10584-006-9101-y.

Professor Paul Crutzen is an IIASA institute scholar. He won the Nobel Prize for Chemistry in 1995. He also researches at the Max Planck Institute for Chemistry in Germany and the Scripps Institution of Oceanography, University of California at San Diego.

Climate change policies are often discussed from the perspective of one of two very different time-scales: long-term objectives a century or more in the future or near-term targets for the coming decade or two. Climate policy demands a long-term perspective, as several of the greenhouse gases (GHGs), particularly carbon dioxide, have atmospheric life times of a century or more, and other aspects of the climate system respond over the course of decades, centuries, and even millennia. At the same time, the international regime is premised on the idea that the design and implementation of policies consistent with potential long-term objectives ought to begin now.

But between the long term and the short term lies a yawning gap that cannot be effectively bridged by current policy perspectives. First, there are no clear signals about where emissions should be headed over the next few decades, and policy certainty over a timescale of several decades is necessary to support investments in the long-lived capital that would facilitate the additional emission reductions needed in the medium term.

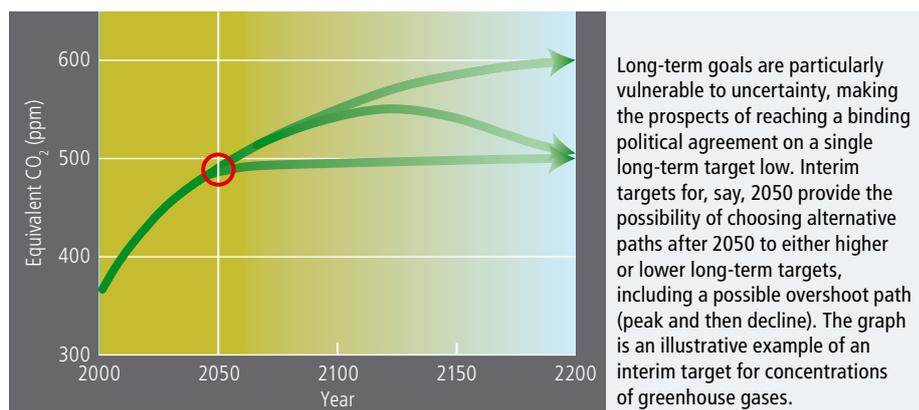
Second, a pair of short- and long-term targets cannot by itself constrain the rate of climate change in the intervening period. A short-term target covers only a limited period of time. A long-term goal can limit maximum levels of climate change but is particularly vulnerable to uncertainty: the longer the time horizon, the more scientific uncertainty accumulates. As a result, the prospects for soon reaching a binding political agreement on a single long-term target are dim.

Yet, as deferring action until agreement is achieved risks committing the world to potentially dangerous climate change, international climate policy would greatly benefit from the development and adoption of interim targets for atmospheric concentrations 25–50 years in the future, in addition to near- and short-term targets. Interim targets, which could be accommodated within the framework of the UN Framework Convention on Climate Change/Kyoto Protocol, would bridge the gap between the short term and the long term in three ways.

First, an interim concentration target can more effectively address the risk of dangerously high rates of climate change than any particular pair of short- and long-term targets because it directs emissions and concentration pathways over the next few decades much more clearly.

“Interim targets” would strengthen climate policy

Surprisingly, interim targets have received little attention in climate policy circles until recently, when several countries and US states adopted or proposed interim domestic emissions targets. Scientists argue that international climate change policy could also be strengthened by the development and adoption of targets for atmospheric concentrations of greenhouse gases 25–50 years in the future in addition to near- and long-term targets.



Second, the process of developing, adopting, and re-evaluating interim targets would better inform near-term policy decisions and provide important signals to decision makers who have multi-decade planning horizons, such as those addressing investments in emissions-producing infrastructure and capital stock. Of course, targets alone are not enough: only if economic agents believe in the ability of governments to maintain targets for limiting GHG emissions will emitters' expectations support the kind of multi-decade investment decisions required to stabilize concentrations. Carefully selected interim targets, with regular reviews of progress and of the targets themselves, could play a vital role in anchoring those expectations. Industry leaders have begun asking for precisely this kind of direction, with some calling on governments to announce, well before 2012, “quantified objectives” to

2020, 2030, 2040, and 2050. (For example, see Executive Forum on Climate Change at www.climateforchange.ca.)

Third, an interim target could be designed to ensure that a range of century-scale objectives remains feasible while uncertainties are narrowed. A strategy of keeping long-term options open may broaden the grounds for agreement in climate policy discussions. Parties that may not be able to agree now to a common long-term target might be able to agree to the lesser objective that the option to achieve such a target should be preserved, in case it should turn out to be necessary. An interim target would be a useful means of implementing such a consensus. ■

Further information For full article on interim targets, see O'Neill BC, Oppenheimer M & Petsonk A (2005). Interim Targets and the Climate Treaty Regime. *Climate Policy* 5(2005) 639–645.

Dr Brian O'Neill is the leader of IIASA's Population and Climate Change Program.

“Óh természet, óh dicső természet!”

“Oh nature, oh glorious nature!”—A line from a poem on the River Tisza by Hungarian poet Sándor Petőfi

Managing the world's river systems



The flood prone Tisza River Basin

IASA is taking part in the scientifically challenging NeWater project, the focus of which is to support the transition of typical key elements of current river basin management systems to more adaptive regimes in the future. Its first case study is the Tisza river basin on the borders of Hungary and Ukraine.

In early 2000 three spills of cyanide and heavy metals from Romania entered the River Tisza in Hungary. The pollution disrupted the river's entire ecosystem, killing an estimated 650 tonnes of fish and wiping out plankton and other microorganisms in the water and bed of the Tisza and its tributaries. Birds, plants, animals, and human livelihoods were also destroyed in what has been called Europe's worst environmental disaster since Chernobyl. The cleanup continues, and safeguards against renewed pollution are being put in place. But what worries people living beside the Tisza even more than the pollution is the flooding.

The Tisza, at 966 km the longest tributary of the Danube, is historically flood-prone, and in the last 200 years several flood control initiatives have taken place along both rivers. Between 1998 and 2001, however, four extraordinary floods, likely due to long-term climate change, occurred in the Tisza River Basin. In terms of the magnitude

of the endangered areas, the populations threatened, and the goods damaged, these floods broke every record. The March 2001 flood, which was the most severe, inundated 80 square kilometers and caused the evacuation of 35,000 people from 200 villages; it also killed 90 percent of livestock in the affected villages and damaged or destroyed over 20,000 dwellings.

Thus, when the European Commission-funded project NeWater was launched last year with the focus of exploring different transition paths from the currently prevailing regimes of river basin water management to more adaptive future regimes, the obvious choice of case study was the Tisza. The Tisza flooding, along with the scarcity of local clean drinking water resources in dry periods, made the population of the Tisza floodplains and surrounding freshwater wetland ecosystems particularly vulnerable. Moreover, the Tisza river basin, being located on the borders of the European Union and the Ukraine, was itself vulnerable to differences in national and regional water management.

Water resource management is both complex and challenging, particularly amid the growing uncertainties of global climate change where water managers have to consider the long-term implications of every decision made. The challenges of water management range from balancing

water quantity and quality, through dealing with flooding and drought, to maintaining biodiversity and ecological functions and services—all in a context where human lives, traditions, and values are at stake.

The NeWater project recognizes the value of highly integrated solutions and advocates using the concept of integrated water resource management (IWRM), according to which the many different uses of water resources—environmental, agricultural, water supply and sanitation—are interdependent and must be treated as such. A more integrated approach to water resource management is now more important than ever because of growing pressure on Earth's finite water from population growth, economic activity, and intensifying competition among water users, to say nothing of the impact of climate change that brings more intense floods and droughts in different parts of the world.

In some months river basins can face both floods and droughts under the present management scheme of high dike defense systems. With climate change likely to cause more intense and longer floods and droughts, the whipsaw effect of being pulled in one and then the other direction may be far more devastating than simply dealing with a serious flood.

The transition to integrated management will also mean that water resources that were once managed locally or regionally will need to be combined with integrative river basin approaches. Moreover, related research areas that once developed rather independently with little exchange among them will now need to be linked.

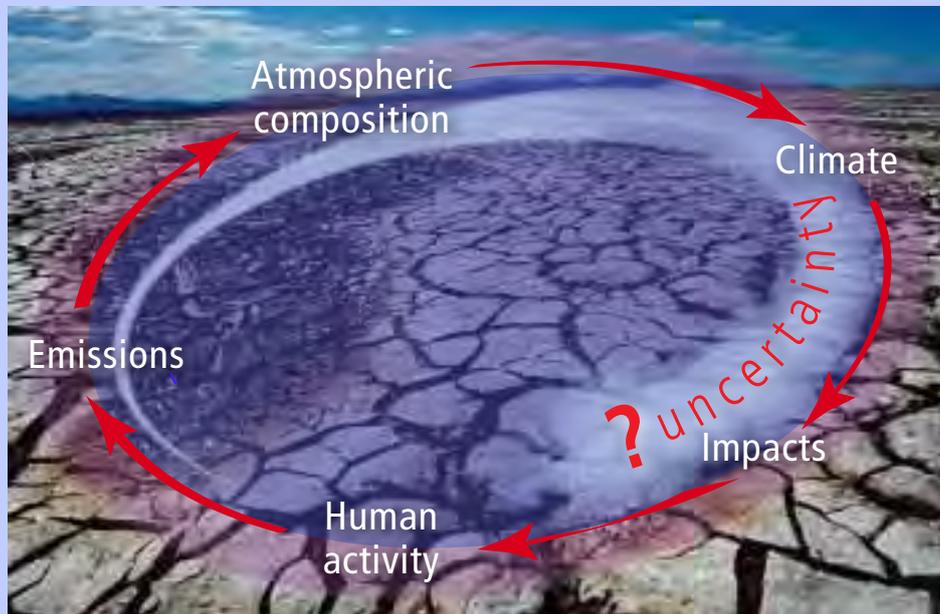
Researchers from IASA's Risk and Vulnerability Program are participating in the NeWater project which concludes in 2008. NeWater is expected to deliver many new insights, if not breakthroughs, in water management: the integration of water management with climate change adaptation strategies; new methods of resolving water resource use conflicts; enhanced information management; innovative methods of designing water infrastructure, such as better water storage management; and stakeholder participation and dialog to promote new ways of bridging science, policy, and implementation. ■

Further information www.newater.info/everyone and IASA's Risk and Vulnerability Program at www.iiasa.ac.at/Research/RAV

Dr Jan Sendzimir leads IASA's participation in the NeWater project and is a senior research scholar in IASA's Risk and Vulnerability Program.

How do we define this?

Uncertainty and learning in the context of global climate change



Climate change involves a cascade of uncertainty from human activity to its ultimate impacts. Should we wait to learn more before acting, or should we act now to avoid possible irreversible effects? Answers depend in part on how fast we might learn.

For decades now, the climate-change debate has been fraught with such questions as: How much will temperature change, and how soon? How sensitive is the climate to atmospheric greenhouse gases? How will actions to limit emissions taken now affect future temperatures? Uncertainty is an essential component of any decision or discussion related to this highly complex issue, and it is no longer possible to conduct an analysis of global climate change without accounting for it. Indeed, according to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), “climate change decision making is essentially a sequential process under general uncertainty.”

One famously striking example of uncertainty came in 2001 when the world’s leading authority in the field of climate change, the IPCC, projected a possible change in global mean temperature in the absence of policy from 1990 to 2100 of 1.4–5.8°C, thereby significantly upping and widening the scale of its 1995 forecast of 1.0–3.5°C. To the layperson, it may seem puzzling that climate-change forecasting cannot be more explicit. In the climate-change domain, there are, of course, “robust” findings—theses that are sustainable under numerous approaches, methods, and assumptions and are therefore

expected to be relatively unaffected by uncertainty. One robust finding holds that reducing emissions of greenhouse gases will delay and decrease the damages caused by climate change. However, even an in-depth expert study such as an IPCC assessment report cannot say by exactly how much. Moreover, for many climate-change forecasts, the range of possible magnitudes can involve variations of several hundred percent.

The net result has been to change the way scientists approach climate change analysis. Emissions scenarios are no longer single forecasts but sets of many alternative outcomes; and climate projections increasingly take the form of ensembles of results from multiple models or multiple runs of a single model. Our current conception of climate-change-related uncertainty is likely to change over time. How fast, in what way, and what the implications are for today’s decisions are just beginning to be explored, which inherently brings a second layer of uncertainty into play.

The acquisition of new information that leads to changes in uncertainty is known as “learning.” Hitherto, learning has focused on the problem of optimal decisions, such as the optimal timing of emission reductions; however, outcomes here have been ambiguous. For example, if we will learn over time, are we actually better off

undertaking more mitigation now or less, given that the mitigation measures taken today may ultimately—and expensively—be unnecessary. Come to that, will the new information we acquire make things more uncertain or less?

Scientific reaction to that particular conundrum is to attempt to learn about learning itself—to simulate realistically what kind of learning could take place in the coming decades and what it might imply for today’s decisions. Most attention has gone to the technological learning potential, but learning about the physical climate system and sociological processes, such as population growth, is also being investigated. The only problem is that learning itself is uncertain. For instance how much and how fast might we really learn about different aspects of a problem? ■

Further information For more details see O’Neill B, Ermoliev Y & Ermolieva T (2005). *Endogenous Risks and Learning in Climate Change Decisions Analysis*. IIASA Interim Report IR-05-037. Available at www.iiasa.ac.at/Research/PCC/pubs/Oneilletal2006_CwU_inpress.pdf. For general background information on learning about climate change see: www.iiasa.ac.at/Research/PCC/learn-conf/background-10feb.pdf.

Dr Brian O’Neill is the leader of IIASA’s Population and Climate Change Program. **Professor Yuri Ermoliev** is an Institute Scholar at IIASA. **Tatiana Ermolieva** is a research scholar in IIASA’s Land Use Change and Agriculture Program.

NATIONAL MEMBER ORGANIZATION

Medal for Kurt Komarek

Kurt Komarek, Austrian Member of the IIASA Council and Chairman of the Finance Committee, has been awarded the "Ehrenzeichen für Wissenschaft und Kunst," the highest award given by Austria in the arts and sciences. The Austrian President Heinz Fischer conferred the medal personally at a ceremony at the Academy of Sciences in Vienna on 21 September. The award is an expression of national respect, appreciation, and thanks to the recipient for particularly outstanding creative achievements.

Professor Komarek joined the IIASA Council in June 1991 representing the Austrian National Member Organization, the Austrian Academy of Sciences. He received his Ph.D. in physical chemistry from the



University of Vienna and taught at New York University as well as at the University of Vienna, where he became president in the late 1970s. He has won numerous awards for his research and has authored more than 120 articles in American, German, and Austrian specialist journals. ■

DIRECTOR AWARDED DEGREE

Honor for Leen Hordijk



IIASA's Director **Leen Hordijk** has been presented with an honorary doctorate from the Academy of Sciences of Ukraine in recognition of his "considerable

contribution to science development, social progress, peace ensuring, mutual understanding and cooperation between the nations." ■

DR JAMES MARTIN

Future imperfect

The "guru of the information age," **Dr James Martin**, delivered the Koopmans lecture at IIASA on 16 October. The lecture, "The Meaning of the 21st Century," was based on his latest book, *The Meaning of the 21st Century: Transformation and Survival*.

The lecture covered some of the extraordinary changes that will mark the twenty-first century, making our grandchildren's world almost incomprehensible from current perspectives. During this century, Dr Martin warned, humanity will have to learn how to control the avalanche of changes that have occurred since the Industrial Revolution began and that will grow exponentially for centuries to come. A new generation of young people, around the planet—the Transition Generation (the T-Generation)—will shoulder the responsibility for the momentous changes, Dr Martin asserted, and it is thus vital to teach them the meaning of the twenty-first century.

Painting a picture of the profound contrasts that lie ahead, Dr Martin spoke of the technologies that will inevitably transform wealthy civilizations, extending human life spans and capability, while billions eke out a precarious existence in shanty-cities. Against a background of fast population expansion, environmental degradation, and extreme climate change, there will be feverish consumerism, especially in China and India, which will continue their furious growth. Religious belligerence and cultural antagonism will also be rife at a time when building atomic and biological weapons is becoming easier.

Solutions do exist, Dr Martin stressed. However, in most areas they are not being implemented because of severe political and institutional blockages. If the roadblocks to change continue, then pressure will build for discontinuous change and a twenty-first century revolution will be inevitable. ■



Dr James Martin is founder and chairman emeritus of Headstrong, a global consultancy that helps leading companies worldwide create real business values from digital technologies. He heads the James Martin Institute for Science and Civilization (www.martininstitute.ox.ac.uk/jmi) and The School for the 21st Century at Oxford University (www.21school.ox.ac.uk).

ALUMNI ASSOCIATION

IIASA Society



Elections were recently completed for the officers of the IIASA Society. The new President is **Hans-Holger Rogner** who has had a long association with IIASA. He currently works at the International Atomic Energy Agency on issues of sustainable energy development and technology change and contributes to United Nations' efforts related to Agenda 21, including climate change. ■

Biographies of the recently elected Board members can be found at www.iiasa.ac.at/IIASA_Society

INTERNATIONAL NEGOTIATIONS

Lessons learned

A book edited by IIASA's Processes of International Negotiation (PIN) network was "required reading" for participants in a recent e-learning course run by the Multilateral Diplomacy and International Affairs Management Programme of the United Nations Institute for Training and Research (UNITAR). The book, *Negotiating International Regimes. Lessons Learned from the United Nations Conference on Environment and Development (UNCED)*, explains and analyzes the negotiation process involved in building international environmental regimes. It was used as a reference work by diplomats, senior government officers, and staff of non-governmental organizations taking part in the online course "Performing Effectively in Multilateral Conferences and Diplomacy," the aim of which was to familiarize participants with multilateral conferences and improve their performance as delegates. ■

Spector BI, Sjöstedt G, and Zartman IW (eds) (1994). *Negotiating International Regimes. Lessons Learned from the United Nations Conference on Environment and Development (UNCED)*. Kluwer Academic Publishing Group, Norwell, MA, USA.



RISK AND VULNERABILITY

Caribbean catastrophes

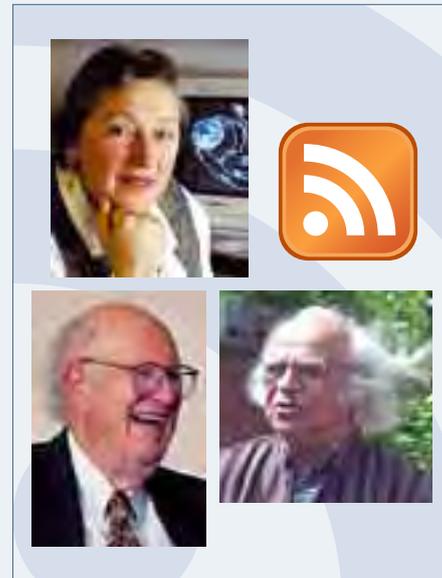
Two IIASA scientists, Reinhard Mechler and Stefan Hochrainer of IIASA's Risk and Vulnerability (RAV) Program, facilitated a two-day technical workshop in Barbados on "Mainstreaming disaster risk management into fiscal and budget planning" with hands-on training by IIASA's CATastrophe SIMulation (CATSIM) model. The workshop, which took place at the start of the hurricane season, was organized by the Caribbean Development Bank and the Inter-American Development Bank and attended by participants from 18 hazard-prone Caribbean countries.



Historically, many developing countries have relied on diversions from national budgets and loans and donations from the international community to finance their natural-disaster-related losses—a risky and potentially costly strategy given that the necessary funds may not always be available when needed. The CATSIM model, which emphasizes pre-disaster financial planning, can be used by planners to assess and manage the financial and economic dimensions of disaster risk.

The Barbados workshop demonstrated that CATSIM has significant practical application for building the capacity of policy makers to use ex ante financial instruments to cope with disasters, including insurance, catastrophe bonds, contingent credit arrangements and other disaster hedges, and to compare the benefits of these with investments in loss reduction. Workshops participants from finance and disaster management authorities received the CATSIM and are currently exploring how it can assist their planning processes. ■

For more information on CATSIM, see: www.iiasa.ac.at/Research/RAV/Projects/Risk_Management.html?sb=6



AUDIO LECTURES

IIASA podcasts

Podcasts of three lectures given by distinguished academics, Howard Raiffa, Yash Pal, and Lynn Margulis, in the course of IIASA's 2006 Young Scientists Summer Program are now available to the public for a trial period on the IIASA Web site.

Howard Raiffa's lecture, "Analytical Roots of a Decision Scientist," combines biographical details with examples of his research into how people make decisions. IIASA's first director, Howard Raiffa is currently Professor of Managerial Economics at Harvard University and one of the world's leading researchers in decision analysis.

In "Back and Forth Between the Intimate and the Cosmic," the noted space scientist and educationist Professor Yash Pal shares his passion for life with numerous scientific explanations about every day events. He also shares his fears, particularly about recent terrorist attacks in India and the plight of the Indian farmer.

Professor Lynn Margulis, in her lecture, "Slanted Truths and Life's Evolution: The Scientific Search for Truth Even if We Don't Like What We Find," gives a powerful introduction to her theory of symbiogenesis, which challenges a central tenet of Neo-Darwinism. Lynn Margulis is Distinguished University Professor in the Department of Geosciences at the University of Massachusetts, Amherst. ■

For more details and to listen to podcasts, see www.iiasa.ac.at/Publications/podcast

Summer modeling work

Every summer IIASA holds its Young Scientists Summer Program attended by around 50 young people from over 20 countries. Advanced graduate students Kate Calvin (USA) and Kiarash Nasserisadi (Iran) took part in the 2006 program.

It is said that most of today's policy decisions are too complex to be made without a sizable substantive input. How can "mere" politicians muster the necessary scientific and technical arguments to gain national advantages or concessions at, for example, the climate change talks—unless they receive appropriate expert advice?

Kate Calvin, carrying out research related to game theory and its application to the climate change negotiations as part of IIASA's 2006 Young Scientists Summer Program (YSSP), is likely to be among a future generation of experts involved in top-level scientific briefings. Although her home country, the United States, signed the Kyoto Protocol in 1998, the Bush administration withdrew three years later, claiming the treaty was "fatally flawed." Nevertheless, the Stanford University PhD student, who is working with IIASA's Processes of International Negotiation Network to develop a model to clarify the climate talks negotiation process, believes that a stronger system of financial incentives might convince the United States and other nonsignatories to relax their stance. Such countries could be persuaded to sign up to instruments such as Kyoto, says Kate, but only if they see emission reductions as being in their own interests.

Reducing the impact of earthquakes is unquestionably in the best interests of Iran, which experienced some 64 earthquakes of varying magnitudes between 15 July and 15 August this year. Since 1989 the country has a dedicated International Institute of Earthquake Engineering and Seismology (IIEES) in Tehran, where YSSP participant Kiarash Nasserisadi is finishing his PhD. In conjunction with IIASA's Risk and Vulnerability Program, Kiarash is modeling the most appropriate and cost-effective methods of managing the direct and indirect impacts of earthquakes—from physical preparedness to predisaster insurance schemes—on oil-related industrial facilities.

YSSP participants enjoy the challenging interdisciplinary atmosphere at IIASA where experienced scientists are accessible, not just for lectures, courses, and workshops, but also for one-on-one discussions and advice. During the Program, which was founded in 1977, young scientists research and produce a paper with a policy-related theme on a topic related to IIASA's current research activities and methodology. YSSP leisure activities and relaxation, including strenuous alpine hiking, are also high on Kate and Kiarash's agenda, and good friends and contacts have been made. Kate will be meeting up with two 2006 YSSPs running the November New York marathon, and Kiarash hopes some YSSP contacts will visit him in Tehran next year.

Could Kate and Kiarash's work at IIASA this summer influence future relations between their respective countries? Possibly. If Iran, which signed the Kyoto Protocol in 2003, should find itself locked in climate change negotiations with the United States, then Kate could be advising her government on how to do an advantageous deal.

And with Iran and the United States both being earthquake-prone countries, Kiarash could one day be exchanging valuable information on earthquake impacts with US counterparts, perhaps even at Kate's alma mater, Stanford University. Interestingly, 2006 marks the centenary of the Great San Francisco Earthquake, which damaged several Stanford buildings. ■



Daily schedule of Kate and Kiarash

- 7.00 Get up and have breakfast at hostel in Mödling, a picturesque town next to Vienna
- 7.45 Cycle to work with other YSSPs from Mödling along the bike path to IIASA at Laxenburg
- 8.00 Catch up on e-mails
- 9.00 Do some reading for summer research project or meet with supervisor
- 10.30 Attend YSSP Outbreak Forum, attend a lecture, research project
- 13.00 Lunch at IIASA's Schloss restaurant followed perhaps by relaxation in Laxenburg Park
- 14.15 Further work on summer research; consultation with scientists and other students to gain "new angles" on work
- 18.00 Bike to Biedermansdorf for a drink at a Heuriger on the way home with other students staying at Liesing and Wienerberg; then back to Mödling
or
Attend evening social events such as dinner, sport, or barbecue

YSSP



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Young

Scientists

Summer Program

YSSP, the Young Scientists Summer Program at the International Institute for Applied Systems Analysis near Vienna, Austria, offers advanced graduate students from around the world the opportunity to spend a summer working with distinguished scientists on projects related to their own doctoral research in the natural and social sciences. Applications are due in January for participation in the summer of the same year.

For details visit www.iiasa.ac.at/yssp

be a part of a new generation of scientists