1. AIM Modeling: Overview and Major Findings

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Summary. The Asia-Pacific Integrated Model (AIM) is a set of computer simulation models for assessing policy options on sustainable development particularly in the Asia-Pacific region. It started as a tool to evaluate policy options to mitigate climate change and its impacts, and extended its function to analyze other environmental issues such as air pollution control, water resources management, land use management, and environmental industry encouragement. More than 20 models have been developed so far, and they are classified into emission models, climate models and impact models from the viewpoint of climate policy assessment. The outline of these models is explained in this chapter. These models have been used as single models or in combinations depending on the policy needs, and they have contributed not only to the governments in the Asian regions, but also to international organizations such as IPCC, UNEP, Eco Asia, ESCAP, and OECD. Previous assessment based on AIM could clarify many important knowledge related to mitigation policies of climate change at global, regional, and country levels. These findings which are summarized in this chapter, have been or are expected to be reflected to the climate policies as well as sustainable development policies.

1.1 Introduction

It is predicted that global climate change will have significant impacts on the society and economy of the Asia-Pacific region, and that the adoption of measures to tackle global climate change will force the region to carry a very large economic burden. Also, if the Asian-Pacific region fails to adopt such countermeasures, it has been estimated that its greenhouse gas emissions will increase to over one-half of total global emissions by 2100. In order to respond to such serious and long-term threats, it is essential to establish communication and evaluation tools for policy makers and scientists in the region. Integrated Assessment Model (IAM) provides a convenient framework for combining knowledge from a wide range of disciplines, and is one of the most effective tools to increase the interaction among these groups.

The Asia-Pacific Integrated Model (AIM) is one of the most frequently used models in the world. The distinguished feature of AIM is that it involves Asian country teams from China, India, Korea, Indonesia, Thailand, Malaysia, Vietnam, Japan and so on, has very detailed description on technologies, and uses information from a detailed geographic information system to evaluate and present

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the distribution of impacts at the local and global levels. Besides preparing country models for detailed evaluation at the state and national level, we have also developed global models to analyze international economic relationships and climate impacts for evaluating policy options from global viewpoint. Although AIM model has been developed primarily to help respond to climate change problems, it has been extended to be applied to other closely related environmental problems such as air pollution, waste management, and water resources problems.

This chapter is organized as follows: Section 1.2 reviews the global environment issues determining the integrated assessment modeling approach, future directions of integrated assessment model development, and characteristics of AIM. Section 1.3 describes the structure of AIM model and main characteristics of its component models while main findings from global and country assessments are summarized in Section 1.4.

1.2 Integrated Assessment Approach and AIM

1.2.1 Global environmental issues and integrated assessment

When one considers policy making in the context of global environment, the starting point must be the characteristics of global environmental issues themselves. These determine the nature of the assessment approach and also its implementation.

a. Global environmental science is a very broad field, incorporating many distinct scientific disciplines, often with diverse theoretical frameworks and analytical approaches.
b. It also touches, directly and indirectly, upon many social and economic issues. Therefore global environmental issues can be characterized by involving the simultaneous evolution of research and policy making processes.

The importance of these two characteristics cannot be over-emphasized. The need to link wide scientific frontiers/interests to equally wide, and often distinctly differing, political interests and opinions, represents one of the most problematic characteristics of global environmental issues.

c. Many serious environmental problems are found in developing countries. Here the interface between scientific concerns (methodological and practical) and political concerns (economic and social) is characterized by loose linkages.

There are many epistemological gaps which need to be bridged between the science and policy fields, and also between different scientific disciplines. First, policy-makers are intelligent, but often lack the scientific training necessary to be able to interpret and implement detailed research results. Second, scientists have few incentives to link their research results to the policy-making process, and to integrate their own results with those from other scientific fields.

Integrated Assessment (IA) has a vital role to play in bridging these gaps. It is a necessary tool which greatly facilitates the optimal development of institutional and research linkages, projects and policy recommendations.

IA represents the "best available synthesis of current scientific, technical, economic, and sociopolitical knowledge" (IPCC 1995). It differs from disciplinary research as IA aims specifically to inform knowledge and policy decision making using a breadth of knowledge sources from a variety of disciplines.

1.2.2 Integrated assessment models

An Integrated Assessment Model (IAM) is a large-scale computer simulation model to assimilate many different factors and disciplinary inputs. As such it represents a core tool for Integrated Assessment approaches.

Though the first trial of model development for IA can be observed in the beginning of 1970s (Meadows *et al.* 1972; Mesarovic *et al.* 1974), formal IAMs emerged after the late 1970s. Nordhaus (1979), Haefele *et al.* (1981) and Edmonds *et al.* (1985) developed energy-economy integrated models for climate change assessment, and Alcamo *et al.* (1990) developed the first IAM to extend fully from emission to impact for acid rain assessment. In 1990s, IAM studies for climate change assessment have rapidly expanded, and there now exists more than twenty IA models for climate change alone.

IPCC (1996) reviewed twenty-two IAMs for climate policy assessment including AIM. A selection of seven representative models from twenty-two with their characteristics is presented in Table 1. All of the seven models have the components of GHG emissions, climate change, and impacts caused by climate change, which are integrated for the purpose of future scenario assessments as well as climate policy assessments.

IAM studies continue to be developed and the direction of these developments can be classified into the following three. First, modeling targets and phenomena are becoming wider and more detailed than before in order to respond to widened audiences, new policy needs, and new scientific knowledge. Very detailed climate change scenarios were prepared for IAMs (Hulme *et al.* 2002), special dynamic models of land use and land degradation are trying to be integrated with emission and impact models (Hootsman *et al.* 2001; Groeneveld *et al.* 2000), technology factors are trying to be introduced as endogenous variables in IAMs (Weyant and Olavson 1999), and pluralism in value system are trying to be operated and reflected to future projection in IAMs (Janssen *et al.* 1998; van Asselt *et al.* 2002). Furthermore, institutional factors such as governmental regulations, international regime and cultural systems have been proposed to be incorporated with IAMs.

The second direction is to apply IAMs to participatory IA process where stakeholders including policy makers and scientists communicate with each other to recognize the priority of information and decisions. The typical examples of the participatory IAM application are ULYSSES (Urban Lifestyles, Sustainability and Integrated Environmental Assessment) project (van Asselt *et al.* 2001), VISIONS (Integrated Visions for a Sustainable Europe) project (Rotmans *et al.* 2001), and

COOL (Climate Options for the Long Term) project (Berk *et al.* 1999). These

Table 1. Seven representative IAMs

model name	model type	model components			reference
		emission	climate	impact	
AIM (Asia-Pacific Integrated Model	Large-scale policy assessment model	complex	complex	complex	---
DICE (Dynamic Integrated Climate & Economy model)	Policy optimization model	simple	simple	simple	Noldhaus (1994)
IIASA (International Institute for Applied System Analysis	Large-scale policy assessment model	complex	simple	complex	WEC/IIASA (1995)
IMAGE2.0 (Integrated Model to Assess the Greenhouse Effect)	Large-scale policy assessment model	complex	complex	complex	Alcamo (1994)
MERGE (Model for Evaluating Regional & Global Effects of GHG Reduction Policies)	Policy optimization model	complex	simple	simple	Manne *et al*. (1993)
MiniCAM (Mini Global Change Assessment Model)	Large-scale policy assessment model	complex	simple	simple	Edmonds *et al*. (1994)
TARGETS (Tool to Assess Regional &Global Environmental &	Strategic policy assessment	simple	simple	complex	Rotmans *et al*.

projects supported European scenario development process of long term environmental change and policy introductions with policy makers and citizens.

The third direction of IAM development is to apply IAMs to regional and local assessment rather than global scale assessment. Lorenzoni *et al.* (2000) downscaled the IPCC global emission scenarios (IPCC 2000) into British impact assessment by means of their IAM, Green *et al.* (2000) estimated co-benefit of air pollution abatement policies and global warming mitigation policies for several countries, Amann *et al.* (2001) tries to extend an IAM on acid rain (RAINS) to multi-pollution and multi-effect model including air pollutants of SO_2, NO_x, VOC, NH_3 and to integrate it with country models (NIAM: National Integrated Assessment Model) to assess environmental impact in a national level (Johansson *et al.* 2001).

Such new developments of IAMs increase the audience and users, and IAMs are been adopting in many important processes of environmental policy making as core tool to link science frontier to their processes.

1.2.3 Characteristics of AIM

Our research project of IAM modeling, the Asia-Pacific Integrated Model (AIM), started in 1991, relatively a little later timing than those of other representative IAMs. However, our project has established a unique position among these IAMs.

First, AIM is only one IAM focusing on Asia, and the AIM project has been specifically developed using a collaborative approach of the Asian region, based on an international collaboration program with participation of governments and researchers of the Asian countries. The AIM project has strongly supported Asian developing countries to get their own IA tool, and these countries have already applied own IAMs to their actual policy making processes.

Second, AIM has several unique structures of model integration in addition to the emission-climate-impact integration which is commonly observed in representative IAM models.

1. integration between economic modules and environmental modules in order to analyze tradeoffs between Asian rapid economic growth and its environmental conservation, and to assess sustainable development policies in Asia;
2. linkage between top-down modules and bottom-up modules for comprehensive and consistent assessment of various policy options including top-down macro-economic policies and bottom-up technological options, which are both essential to solve the Asian complicated environmental issues;
3. linkage between short/middle-term simulation modules and long-tem simulation modules in order to integrate urgent Asian policies against current pollution and nature destruction issues with long-term policies for climate change mitigation;
4. linkage between country/local modules and world modules in order to design effective policies for regional collaboration in Asia, that include technology transfer and assistance in environmental investment desired by most of developing countries in the region.

These structures were prepared to respond to actual requests from policy making processes. These unique structures enable us easily to advance our studies toward the new direction of world IAM community written above, and AIM has already started evolving in the new directions.

Third, AIM has been used in the actual policy making process in the Asian region. Several Asian countries have adopted this model as an in-house model for policy assessment, and Environmental Ministers' Congress for Asia and Pacific (Eco Asia) adopted AIM as core tool for policy design. AIM also contributed to other international activities: AIM was selected as reference model in the Special Report on Emission Scenarios (SRES) and in Third Assessment Report (TAR) both of Intergovernmental Panel on Climate Change (IPCC) and also in the Global Environment Outlook (GEO) of United Nations Environmental Program (UNEP). AIM simulation results were used by many other international organizations including OECD, ESCAP, ADB, UNU, and WWF. Recently, the AIM modeling team started to prepare new set of models for Millennium Ecosystem Assessment (MA) and Asia-Pacific Environmental Innovation Strategy Project (APEIS).

1.3 Structure of the AIM Model

1.3.1 AIM for climate policy assessment

The roadmap of AIM models is shown in Fig. 1 and Color Plate 1. These figures also show the correspondence between these models and chapters covering their descriptions.

The original AIM is an integrated 'top-down and bottom-up' model and comprises three main models - the greenhouse gas emission model (**AIM/Emission**), the global climate change model (**AIM/Climate**) and the climate change impact model (**AIM/Impact**) (Morita *et al.* 1993; Matsuoka *et al.* 2000).

Several emission models including both top-down and bottom-up models have been developed to estimate greenhouse gas emissions and other related gases. One is a bottom-up energy model which we call **AIM/Enduse** model. It focuses on the end-use technology selection in energy consumption as well as energy production. It calculates future demand of energy services for several sectors, determines the optimal set of technologies for the demand by total cost minimization based on exogenous energy price, and then, it estimates future energy consumptions as well as future emissions of GHGs. AIM/Enduse was recently evolved to AIM/Local model which is linked to local emission inventories in order to simulate multi-gas emissions from large point source. AIM/Enduse was developed also for more comprehensive bottom-up model (**AIM/Bottom-up**) by adding industrial process module and lifestyle change module to the energy endues model.

For AIM/Emission, three kinds of top-down models were developed, those are, AIM/Energy-Economics, AIM/CGE (Energy), and AIM/Land-Equilibrium. **AIM/Energy-Economics** is a partial equilibrium model to analyze long-term

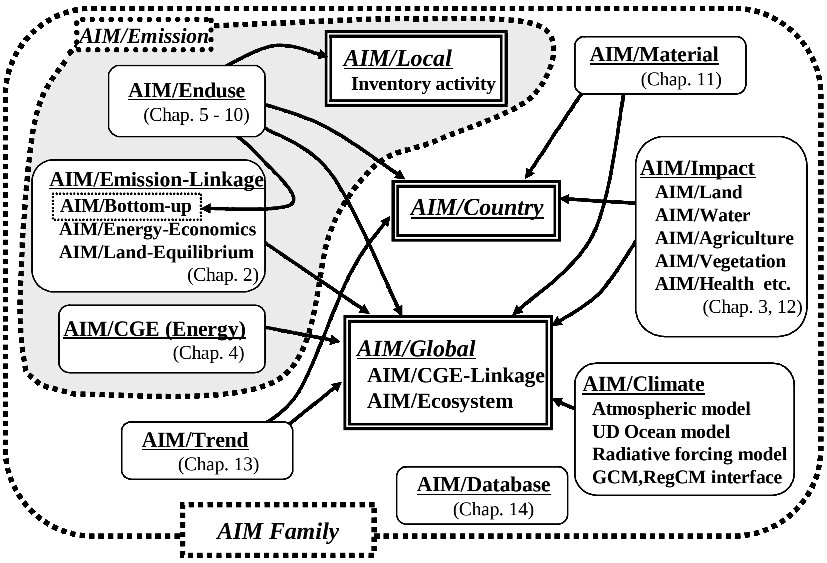

Fig. 1. Roadmap of AIM family (see color plates)

energy demand and supply. It was mainly used for GHG emission forecast over next one century. **AIM/CGE (Energy)** is a general equilibrium model focused on energy sectors to analyze the relationship between emissions and international trade. It was frequently used for the assessment of Kyoto Mechanism such as emission trade and Clean Development Mechanism. The third top-down model, **AIM/Land-Equilibrium** is a general equilibrium model focused on agriculture and forestry sector in order to analyze land use change based on international agricultural market. This model was applied to quantification of GHG emissions caused by land use change.

For the purpose of quantifying comprehensive emission scenarios for IPCC, a specific linkage model, **AIM/Emission-Linkage** was developed. Three models were combined in this model, those were, AIM/Bottom-up, AIM/Energy-Economics, and AIM/Land-Equilibrium, and then, comprehensive GHGs emissions as well as related gas emissions such as SO_2, NO_x were simulated based on the model.

The estimated GHG emissions and related gas emissions are input into the **AIM/Climate**. Except for CO_2, GHGs emitted into the atmosphere are gradually transformed by chemical reactions, which are calculated within the AIM/Climate. For short-life chemicals such as ozone and OH radicals, pseudo-equilibrium state is assumed, and the oxidation and photochemical reactions of CH_4 and other molecules are represented by simple kinetic equations. The absorption of CO_2 and heat to ocean is calculated using an upwelling-diffusion (UD) model with the oceans divided into a surface mixed layer and an intermediate layer, which extends down to about the 1000 meters. Carbon cycle between atmosphere and terrestrial ecosystem is also reproduced by simple model which was validated by dynamic vegetation simulations.

Global averaged surface temperature changes are calculated by a simple radiative forcing model which is linked to an energy balance/upwelling-diffusion ocean model. Regional distribution of climate parameters is estimated based on the experiments of GCMs and regional climate models. AIM/Climate includes specific interface between simple module of AIM/Climate and GCMs and regional climate models in order to interpolate regional climate distribution.

The **AIM/Impact** treats mainly the impact on water supply, vegetation change, primary production industries such as agriculture and forest products, and on human health such as malaria spread. It can also be used to assess higher-order impacts on the regional economy. For these impact assessments, environmental and socio-economic data of the region have been gathered and filed in a geographical information system (GIS). The resolution of the data is from half degree to five minutes in latitude.

AIM/Database for AIM/Emission as well as AIM impact has been developed to support the development and utilization of AIM models. As mentioned above, AIM model has been developed as an international collaboration program, and the database has also been developed by the collaborative program.

1.3.2 Other models of AIM Family

Over the years of developing AIM models, a variety of new models, which are interrelated and interconnected, have been added to the family shown in Fig. 1 and Color Plate 1. These new models are AIM/Trend, AIM/Material, AIM/CGE-Linkage, AIM/Ecosystems, AIM/Country, and AIM/Global.

AIM/Trend is developed to project the basic trend of economy, energy and environment in Asia-Pacific region. It covers as wide a range of countries in Asia-Pacific region (42 countries), and it estimates environmental conditions through 2032. It uses simple method (econometric) and develops several scenarios for capacity building. **AIM/Material** intends to estimate economic and environmental effects of environmental investment. It assesses the effects of policy integration for comprehensive environmental problems including solid, water and air pollution. It achieves consistency of material flow along with economic activities. **AIM/CGE-Linkage** integrates original global CGE model with Material, Energy-economics and Land-equilibrium modules to assess global economic development taking into account the international markets. **AIM/Ecosystem** is an extended version of AIM/Impact and intends to evaluate not only the impact of climate change, but also other important environmental issues especially ecosystem assessment. It has several modules to estimate surface runoff, river discharge, potential crops productivity, vegetation classification, and health impacts. **AIM/Country** and **AIM/Global** models integrate various modules at country and global levels respectively in order to assess the country and global sustainable development.

1.4 Major Findings

1.4.1 Findings from global assessment

Major findings from global assessment written in Part II can be summarized as follows:

1. Without the Kyoto target, the global temperature would increase by more than 2°C in 2100. In such a case, severe impacts can be predicted on water resource supply, agriculture productions, vegetation and human health (Chapter 2, 3, 4).
2. Their impacts would be significant and with serious negative damages in the low latitude regions, especially developing countries in tropical and sub-tropical zones, while climate change could cause positive effects in the high latitude regions (Chapter 3).
3. Future development of the Asia-Pacific region has significant influence on global emission scenarios. The Developing Asia-Pacific becomes dominant in climate change issue (Chapter 2).
4. Different development paths require different technology/policy measures and show different costs of mitigation to stabilize atmospheric CO_2 concentrations at the same level. No single type of measure will be sufficient for the timely

development, adoption and diffusion of mitigation options for CO_2 stabilization (Chapter 2).

5. It is predicted that ratification of the Kyoto Protocol may cause economic impacts. However there are several ways including technological development and international cooperation to mitigate the economic impacts and a possibility of promoting the growth of economies (Chapter 4).

1.4.2 Findings from regional and country assessment

The followings are also major findings from regional and country assessment written in Part II and III:

1. It could be possible for the Developing Asia-Pacific to continue high economic growth while maintaining GHG emissions at a low level. Technological progress and technology transfer should be emphasized to maintain low GHG emissions in the Developing Asia-Pacific's economic development. The market mechanism is an efficient way to achieve the diffusion of advanced technologies (Chapter 2, 5, 6, 7, 8, 9, 13).
2. It is important for the Developing Asia-Pacific to introduce sophisticated measures to control GHG emissions before 2030. Robust policy options should be designed to respond to very wide range of alternative development path (Chapter 2, 5). In China, sophisticated policies should be designed at the sectoral level, especially in transport, commerce and the chemical industry (Chapter 5).
3. New environmental policies are required that are designed for the early stages of development in China and India in order to integrate strategies for both the global environment and local environment including pollution control and waste management. Although under a SO_2 mitigation policy regime, the SO_2 and CO_2 trajectories get decoupled in India, extents of SO_2 mitigation and CO_2 mitigation are strongly correlated under a CO_2 mitigation policy regime (Chapter 5, 7, 11, 13).
4. Long-term adaptation investment for climate change could create co-benefit in other policy fields. Chinese current flood damage could be drastically reduced by the adaptation investment in flood prevention infrastructure to mitigate climate change impact (Chapter 12).
5. The LPS would continue to be responsible for considerable part of the carbon emissions. Power sector is the predominant emission source for CO_2 and SO_2. Operational improvements (like heat rate reduction, excess air control etc.), better maintenance, reducing transmission and distribution losses in the power sector would go a long way in emissions mitigation in India and China (Chapter 5, 6).
6. Energy savings or low CO_2 emitting devices could be difficult to introduce into the market in every sector by 2020 without any climate policy measures in Korea. The marginally higher cost of new low CO_2 emitting devices is too large for them to penetrate the Korean market (Chapter 8).

7. Japanese cost to reach Kyoto target depends on Japan's future development pattern and climate policy design. The development toward "Recycle-based Society (B1)" could reduce cost and lead economic growth. Japanese cost could also be reduced by increased environmental investment, environmental industry encouragement, technology improvement, integration with waste management policy, shift to green consumption, and introduction of Kyoto mechanism (Chapter 4, 10, 11).
8. International collaboration for capacity building and knowledge transfer on IA and IAM is essential for global participation in climate change mitigation (Chapter 1, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14).

References

Alcomo J, Shaw R and Hordijk L (eds) (1990) The RAINS model of acidification: Science and strategies in Europe, Kluwer, Dordrecht, The Netherlands

Alcamo J (ed) (1994) IMAGE 2.0 - Integrated model of global climate change. Kluwer Academic Publishers, Dordecht

Amann M, Johansson A, Lukewille D *et al.* (2001) An integrated assessment model for fine particulate matter in Europe. Water, Air, and Soil Pollution 130:223-228

Berk MM, Hordijk L *et al.* (1999) Climate options for the long term (COOL). Interim report, NOP, Bilthoven, the Netherlands

Edmonds J and Reilly J (1985) Global energy: Assessing the future, Oxford University Press, New York

Edmons J, Wise M, MacCracken (1994) Advanced energy technologies and climate change: an analysis using the global change assessment model (GCAM). Presentation to the Air and Waste Management Meeting, 6 April, Tempre AZ, Air and Waste Management Association, Pittsburgh

Green C (ed) (2000) Developing country case-studies: integrated strategies for air pollution and greenhouse gas mitigation. Progress Report for the International Co-Control Benefits Analysis Program, The National Renewable Energy Laboratory, The Office of Atmosphere Programs of the US Environmental Protection Agency

Groenveld RA, van Ierland EC (2000) Economic modelling approaches to land use and cover change. NRP Report No.410200045, Wageningen University

Haefele W, Anderer J, McDonald A and Nakicenovic N (1981) Energy in a finite world, Ballinger, Cambridge, MA

Hootsman RM, Bouwman AF, Leemans R, Kreileman GJ (2001) Modeling land degradation in IMAGE 2. RIVM report 481508009, National Institute of Public Health and the Environment, The Netherlands

Hulme M, Lu X, Turnpenny J, Mitchell T *et al.* (2002) Climate change scenarios for the United Kingdom. The UKCIPO2 Scientific Report, Tyndall Centre, Department for Environment, Food and Rural Affairs, UK

IPCC (1996) Climate change 1995: economic and social dimensions of climate change. Bruce JP, Lee H, Haites E (eds), Cambridge University Press, Cambridge

IPCC (2000) Special report on emissions scenarios. Nakicenovic N *et al.* (eds), Cambridge University Press, Cambridge

Jannsen M, de Vries B (1998) The battle of perspectives: a multi-agent model with adaptive responses to climate change. Ecological Economics 26:43-65

Johansson M, Alveteg A, Amann M *et al.* (2001) Integrated assessment modeling of air pollution in four European countries. Water, Air, and Soil Pollution 130:175-186

Lorenzoni I, Jordan A, O'Riordan T, *et al*. (2000) A co-evolutionary approach to climate change impact assessment: Part II. a scenario-based case study in East Anglia (UK). Global Environmental Change 10:145-155

Manne AS and Richels RG (1993) MERGE - A model for evaluation regional and global effects of GHG reduction policies. Energy Policy, 23(1):17-34

Matsuoka Y (2000) Extrapolation of carbon dioxide emission scenarios to meet long-term atmospheric stabilization targets. Environmental Economics and Policy Studies, 3: 255-265

Meadows DH, Meadows DL, Randers J and Behrens WW (1972) The limits to growth, Universe Books, New York

Mesarovic MD and Pestel E (1974) Mankind at the turning point: The second report to the Club of Rome, Dutton, New York

Morita T, Matsuoka Y, *et al.* (1993) AIM - Asian Pacific integrated model for evaluating policy options to reduce GHG emissions and global warming impacts. In “Global warming issue in Asia", Asian Institute of Technology, pp.254-273

Nordhaus WD (1979) The efficient use of energy resources, Yale University Press, New Haven, CT

Nordhaus WD (1994) Managing the global commons: the economics of climate change. The MIT Press

Rotmans J (1995) TARGETS in transition. RIVM report, Bilthoven, The Netherlands

Rotmans J, van Asselt M *et al.* (2001) Integrated visions for a sustainable Europe: changing mental maps:VISIONS final report. ICIS, Maastricht/Utrecht

van Asselt MA, Middelkoop H *et al.* (2001) Integrated water management strategies for the Rhine and Meuse basins in a changing environment. Final Report of the NRP project 0/958273/01, ICIS, Maastricht/Utrecht

van Asselt MA, Rotmans J (2002) Uncertainty in integrated assessment modeling, from positivism to pluralism. Climate Change 54:75-105

WEC and IIASA (1995) Global energy perspectives to 2050 and beyond. World Energy Council, London

Weyant JP, Olavson T (1999) Issues in modeling induced technological change in energy, environmental, and climate policy. Environmental Modeling and Assessment 4:67-85