24. Global GHGs Emission Scenarios for Climate Change
温室効果ガス排出シナリオの作成について

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Abstract: In order to make policy to response for climate change, it is essential to forecast future GHGs emissions in a long term. The IPCC decided at its 1996 plenary session to develop a new set of reference emission scenarios. Four modeling groups including us have started to formulate the scenarios and test them for consistency in terms of both qualitative and quantitative factors with their models. In this paper, we describe one of the efforts, i.e. AIM quantification and its rationale.
Keywords: climate change, Emission scenario, Integrated Assessment, Energy model

1. Background

In order to make policy to response for climate change, it is essential to forecast future GHGs emissions in a long term. The IPCC decided at its May 1996 plenary session in Mexico City to develop a new set of reference emission scenarios reported as an IPCC Special Report. The Working Group III of the IPCC was charged with the task of appointing the writing team for the Special Report on Emissions Scenarios (SRES). The main objective of the SRES is to review the literature, and based on the outcome, formulated a new set of scenarios to replace the six IPCC IS92 scenarios that are widely used as reference emissions trajectories.

The writing team agreed that the scenario development process would consist of four major components. First, a review of existing global and regional emissions scenarios; second, an analysis of the main scenario characteristics and relationship; third, a formulation of ***story lines*** as narrative scenario characteristics and development of quantitative ***template*** for the new scenarios; and fourth, an ***open*** scenario modeling process involving feedback from various modeling groups worldwide resulting in the final revisions of the new emissions scenarios.

The first step was the formulation of narrative story lines to be used as additional information for defining quantitative characteristics of initial scenarios. Now the narrative descriptions are available as background material for the modeling groups to work on scenario quantification. The second step involves quantification of development envisaged in the story lines so that this can be captured in models quantitatively, resulting in initial scenario formulations. In January 1998, four modeling groups that are represented by members of the writing team have started to formulate the initial scenarios and test them for consistency in term of both qualitative and quantitative factors with their models. Asian-Pacific Integrated Model (AIM) developed by National Institute for Environment Studies and Kyoto University of Japan is one of the four modeling groups. This paper presents the GHGs emission scenario quantification analysis by AIM for the process of third component.

The AIM is large scale Integrated Assessment Model (IAM) being used in 5 major Asian countries include Japan, China, India, Korea and Indonesia by more then 10 research teams through the AIM project. This research network supplied strong support to the scenario story line quantification by AIM to reflect the perspective in Asian countries. By sending inquiry form for the model

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assumption, suggestion and advice was feedback by experts in Asian countries and was used in the model analysis.

In order to quantify the scenario story line, we developed a model which link several models to calibrate the data and make the scenario quantification under the story lines. The model has time span up to 2100 and 12 period to match the requirement of story line quantification. By the model, major emission resources including energy activities, industries, land use, agriculture and forest can be simulated.

2. Description of the story lines and assumption for models

An emission scenario database was developed by Morita and Lee (1998) for SRES to be used in the scenario development and to generate the new story lines. The database includes 371 scenarios from 135 literature and scenario evaluation activities, such as EMF13 (Energy Modeling Forum 13) and IEW (International Energy Workshop). The scenarios span a wide range of assumptions for demographic trends, level of economic development, energy consumption and efficiency patterns, and other factors. We can find from Figure 1 that the range for global CO_2 emission is very wide. By looking through the assumptions setting up for the global CO_2 emission forecast, there also is very wide range for the key factors. Based on the review of these research activities and recent social development, a series story lines for emission scenario were presented by the SRES writing team and used as modeling assumption to analyze the future long-term GHGs emissions. Four story lines were formally defined for the emission scenarios. They are briefly described as following.

Scenario A1. This scenario describes a case of rapid and successful economic development. The primary drivers for economic growth and development are high human capital (education), innovation, technology diffusion and free trade. Prosperity becomes the key scenario driver. The scenario logic of successful development assumes smooth growth with no major political discontinuities or catastrophic events. The scenario's development model is based on the most successful historical examples of economic growth, i.e., on the development path of the now affluent OECD economics. "Intangible" assets (human capital, stable political climate) under this scenario take precedence over "Tangible" assets (capital, resource, and technology availability) in providing the conditions for a take-off into accelerated rate of development. Comparing to the quick economic growth, population increase keeps low level as the results of high education, stable social relations, and incentives for innovation and experimentation. Developing countries will follow a similar transition of OECD countries by the mid-21st century. Fertility rates in the scenario range between 1.3 to 1.7 children per woman. Global population grows to around 9 billion by 2050, and declines to 7 billion by 2100. The gaps between today's developed countries and developing countries will close up in a similar way as between Western Europe and Japan compared to the U.S. in the 20th century.

The scenario unfolds into several sub-scenarios as a function of different direction taken by technology change. The key question is which primary resources may become economically accessible in the future, and which technologies will become available to convert these primary resources into to the final goods and services demands by consumers. Three pathways are possible:

1) ***Clean coal*** technologies scenario (i.e., environmentally friendly except for GHG emissions and possible resource extraction impacts)
2) ***Oil/Gas*** scenario. Smooth transition from conventional to unconventional oil and gas, tapping the vast occurrence of unconventional fossil fuels, including methane clathrates.
3) ***Bio-nuclear*** scenario. Rapid technological progress in non-fossil supply and end-use technologies, such as solar, nuclear and hydrogen-fueled end-use devices, such as fuel cell.

For the scenario quantification, several contrasting typological cases have been evaluated with the aid of formal energy models. They are **A1T**: non-fossil (Bio-nuclear scenario), **A1O**: fossil fuel by the dominance of coal (Clean coal scenario), **A1F**: fossil fuel by the dominance of unconventional oil and gas, including methane hydrate (Oil/Gas scenario).

Scenario A2. The basic thrust of the story line is that the world ***consolidates*** into a series of roughly continental economic regions. Regions pursue different economic strategies based on the resource and options available to them. Low-income regions increase per capita incomes slowly while high-income regions seek to increase the income of residents. Income inequality becomes more pronounced within low-income regions and increase between regions. Because of the limited trade between regions, technology diffusion gets slow. Technological change is rapid in some regions, slow in other regions.

Scenario B1. The central element of this scenario include high levels of environmental consciousness, successful governance including major social innovation, and major reductions in income and social inequality. It is also a high growth scenario. Technology development keeps high level, which is implemented in a pollution prevention mode. In the scenario, resource availability is high, population level is low.

Scenario B2. This scenario is described as ***Regional Stewardship***, it is based on a natural evolution of the present institutional policies and structures. It can be characterized as limit population growth, medium economic growth, inequality reduction, weak global governance but strong national and regional governance, strong deurbanization trend, strongly pursued environment improvement, encouraged renewable energy use.

Based on the description of those story lines, quantified key scenario drivers and assumption of scenarios used in our model are listed in Table 1 and Table 2.

Table 1. Key scenario drivers assumption for the modeling

	A1	A2	B1	B2
World Population	9 bill in 2050 7 bill in 2100	15 bill in 2100, Higher growth in non-OECD	9 bill in 2050 7 bill in 2100	11.7 bill in 2100
Potential GDP	550 trillion $ in 2100,High growth in non-OECD	250 trillion $ in 2100	350 trillion $ in 2100	250 trillion $ in 2100
Adjusted GDP	509 to 513 trillion $ for A1F,A1O,A1T	245 trillion $	343 trillion $	223 trillion $
Annex-I GDP/capita	2050: 43000$ 2100: 100000$	2050: 34400$ 2100: 57700$	2050: 43700$ 2100: 95500$	2050: 35000$ 2100: 66700
Non-Annex-I GDP/capita	2050: 15000$ 2100: 65000$	2050: 5000$ 2100: 10500$	2050: 9200$ 2100: 36600$	2050: 5700$ 2100: 12200$
Trade	High trade Low trade cost	Low trade across regions, High trade within regions, High trade cost	High trade Low trade cost	Low trade across regions Low trade cost
Urbanization	Rapid increase	Increase in non-OECD Decrease in OECD	Increase	Decrease

3. The model

For the simulations for the IPCC SRES Quantification, a new linked version of the AIM model (AIM/Emission Linkage model) was utilized. This new model structure maximizes the ability to simulate a variety of inputs at a variety of levels, incorporating the strengths of both top-down and bottom-up approaches. The bottom-up model reproduces very detailed processes of technology development related to energy supply and demand in order to determine future improvement of enduse efficiency. The top-down model estimates equilibrium of energy supply and demand, and then, determine energy price which is reflected not only to the energy service demand but also energy efficiency improvement. The structure of the AIM/Emission Linkage model is presented in the diagram of Figure 1.

The AIM/end-use model is a part of the Asian-Pacific Integrated Model (AIM) which was developed by National Institute for Environment Studies and Kyoto University (AIM Project Team, 1996). It is a bottom-up, energy-technology model. Based on detailed description of energy service and technology, it calculated the total energy consumption and production from the ***bottom-up*** way. The model was used in several major countries in Asian countries. Among the advantages of bottom-up models, the most important is that their results can be interpreted clearly because they are based on detailed description of changes in human activities and technologies.

Table 2. Assumptions for scenarios.

	A1F	A1O	A1T	A2	B1	B2
Resource availability	Oil/gas: low Coal:High	Unconventional oil/gas: high	Oil/gas: med. Biomass: high	Fossil fuel: medium	Unconventional oil/gas: high; Biomass: high	Oil/gas: medium Biomass: high
Resource price	Oil/gas: high Coal: low	Unconventional oil/gas: low Coal: med.	Oil/gas: medium Coal: high	Regional variation Premium on local resources	Unconventional oil/gas: low Solar: 6cent/kWh at 2060	Regional variation
Electricity production cost	Solar: 30cent/kWh in 1990, 10cent/kWh in 2080 Nuclear: 19.26$/EJ in 1990, 17.92$/EJ in 2100	Oil/gas: low Solar: 30cent/kWh in 1990, 8cent/kWh in 2080 Nuclear: 19.26$/EJ in 1990, 20.23$/EJ in 2100	Renewable/ nuclear/ biomass: low Solar: 30cent/kWh in 1990, 2.5cent/kWh in 2080 Nuclear: 19.26$/EJ in 1990, 8$/EJ in 2100	Regional variation Solar: 30cent/kWh in 1990, 18cent/kWh in 2080 Nuclear: 19.26$/EJ in 1990, 26.06$/EJ in 2100	Renewable/ biomass: low Solar: 30cent/kWh in 1990, 6cent/kWh in 2080 Nuclear: 19.26$/EJ in 1990, 12.8$/EJ in 2100	Regional variation Solar: 30cent/kWh in 1990, 6cent/kWh in 2080 Nuclear: 19.26$/EJ in 1990, 9.7$/EJ in 2100
Technology efficiency improvement	Oil/gas: low Clean coal: high Renewable: low End use technology: high	Oil/gas: high Coal: low Renewable: low End use technology: high	Oil/gas: medium Coal: low Renewable: high End use technology: high	Based on local resources OECD: renewable & synfuels	Major improvement in energy & emission saving technologies	Improvement in emission saving technologies
Social efficiency improvement	High Intangible assets take precedence	High	High	Higher in OECD, lower in developing countries	Very high	Medium

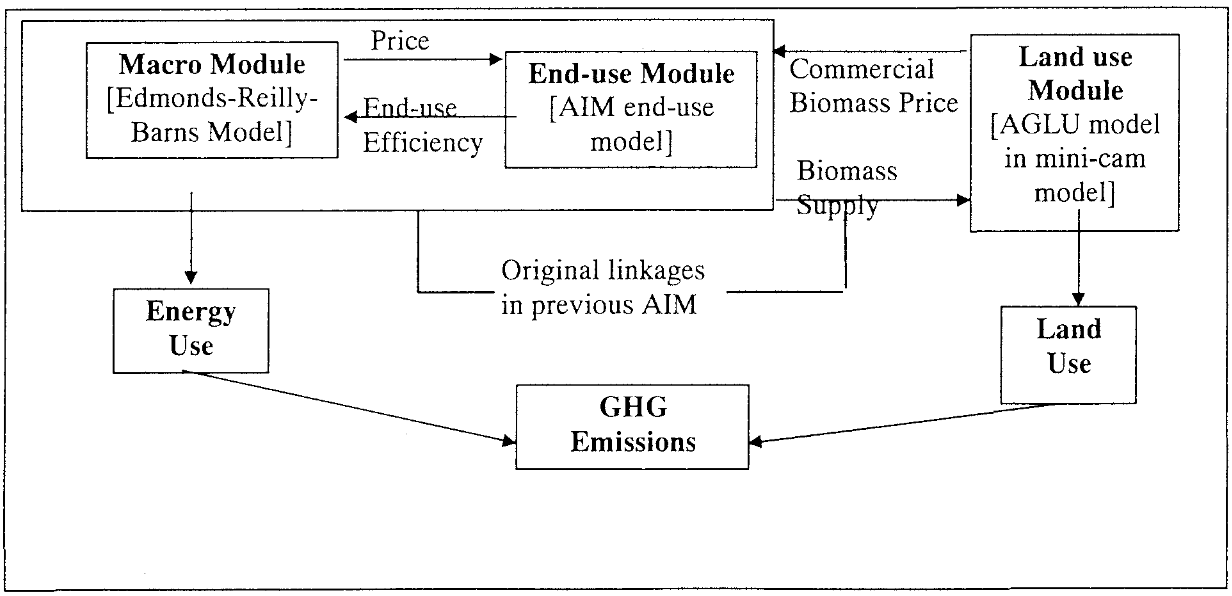

Figure 1. Outline of AIM/Emission-Linkage

The Edmonds-Reilly-Barns model is initially developed by Edmonds and Reilly (1987) to provide a consistent, conditional representation of economic, demographic, technical, and policy factors as they affect energy use and production. It is a macro economic partial equilibrium model which deal with the energy activities and forecast the energy demand in a long term. It uses GDP and population as future development driver, combined with other energy related parameters to forecast energy demand based on the supply and demand balance.

The AGLU(Agriculture, Land use, and Commercial Biomass Energy) model is developed by the Pacific Northwest National Laboratory (PNNL). It is designed to explicitly model agriculture and land use, endogenously determine land use change emission, explore the use of biomass as an element of a strategy of anthropogenic carbon emission.

The AIM/Emission Linkage model couples these several components together to calculated the future GHGs emission in a relatively full range analysis. The model has nine regions: USA, Western Europe OECD and Canada, Pacific OECD, Eastern Europe and Former Soviet Union, China and Central Planned Asia, South and East Asia, Middle East, Africa, Central and South America. It has the time horizon from 1990 to 2100. Before 2030 the period step is 5 year, then 2050, 2075 and 2100. The GHGs and related gasses include CO_2, SO_2, N_2O, CO, NO_x, CH_4.

4. The results

Based on the AIM/Emission Linkage model, the global GHGs emissions were projected. Fig.2 shows the emission from the activities of energy supply and consumption. From this figure, we can find that A2 scenario keeps the highest position in all the indicators while B1 scenario keep the lowest. The range for these forecasts still keep large, for example the highest CO_2 emission (A2) is nearly two times of lowest CO_2 emission (B1), this reflect the difference of scenario assumption. All of the scenarios show the demand of primary energy will continue to increase as a factor to support economic development and better life level.

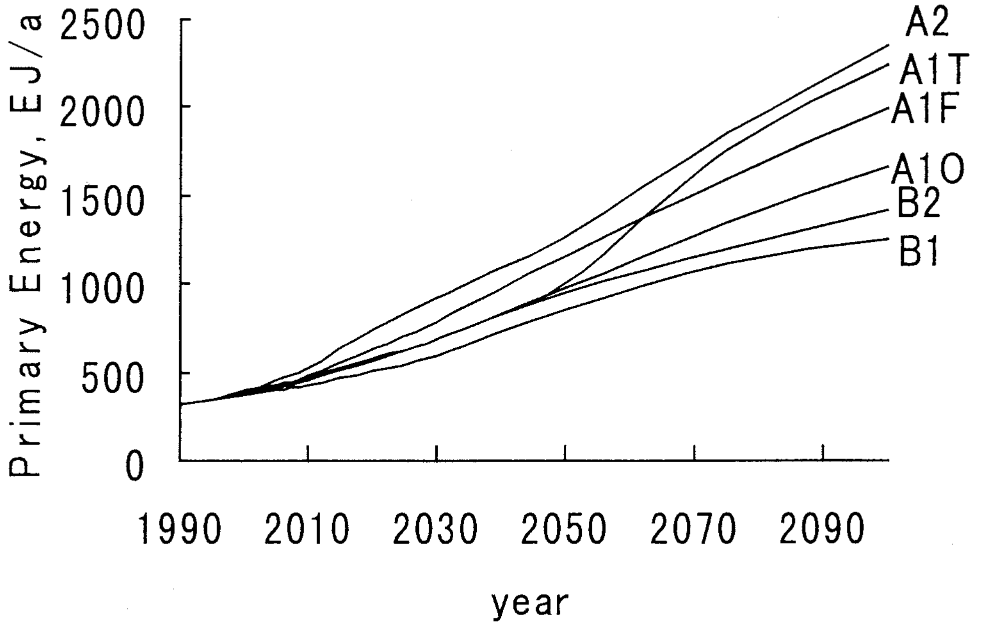

Figure 2. World Primary Energy Demand

SO_2 emission shows somewhat different pattern from CO_2 emission. This is because of fast spreading of desulfurization devices, which is resulted in a typical environmental Kuznets curve in all cases.

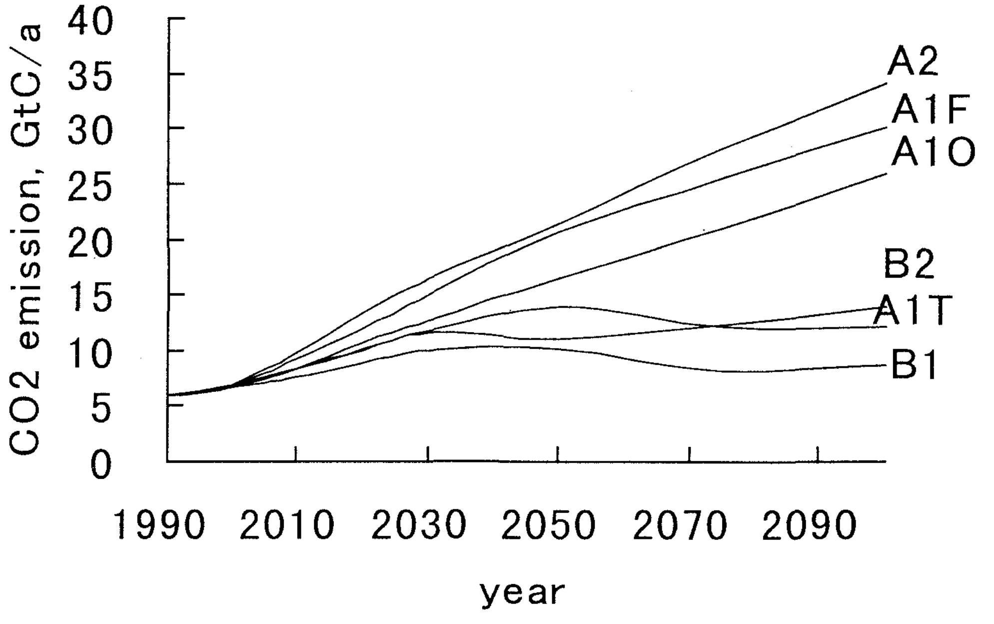

Figure 3. World CO_2 Emission

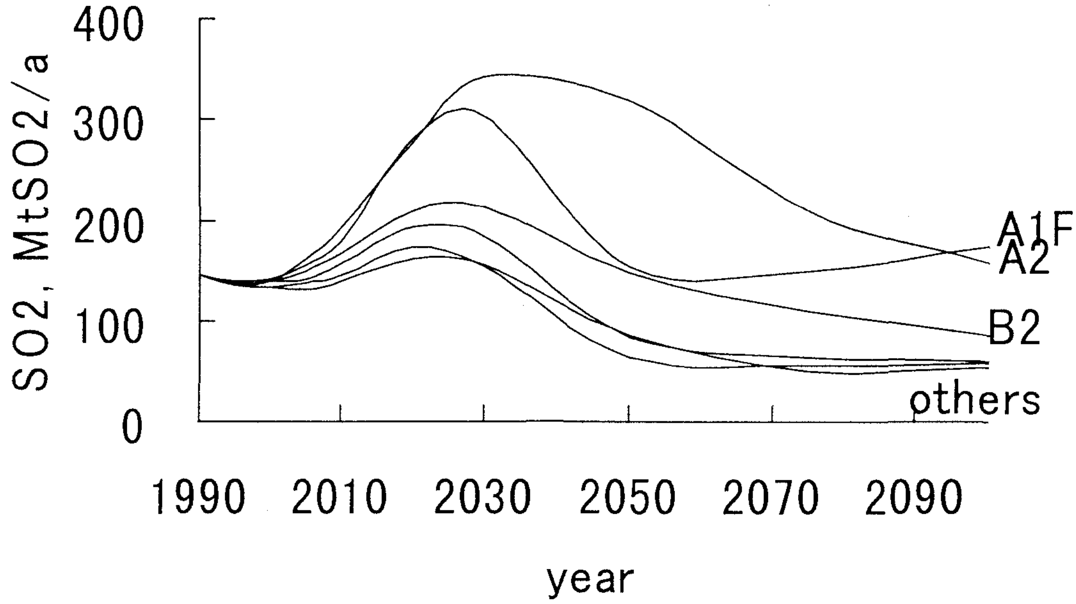

Figure 4. World SO_2 Emission

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