B-54.2 Special Collaborative Studies for Refining and Simplifying the Asian-Pacific Integrated Model (AIM) (Final Report)

Contact person Mikiko Kainuma
Head of Global Warming Response Team
National Institute for Environmental Studies
16-2 Onogawa, Tsukuba, Ibaraki 305-0053, Japan
Tel:+81-298-50-2422 Fax:+81-298-50-2524
E-mail: mikiko@nies.go.jp

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Abstract: The Asian-Pacific Integrated Model (AIM) has been developed for scenario analyses of greenhouse gas emissions and impacts in the Asian-Pacific region. It has been used in several countries to analyze policy options for global warming. Several new modules have been developed and integrated into the AIM. These modules include a land use model for developing IPCC new stabilization scenarios, a new general equilibrium model for analyzing the effects of global warming policies through international market, a simplified climate model for integrated analysis of global warming policies, and an air pollution module for analyzing strategies to effectively reduce both CO_2 and SO_2 emissions in developing countries. Mini-AIM model has also been developed as a user-friendly interface to estimate CO_2 emissions in country and regional levels.

Key Words Global warming, Asian-Pacific region, Greenhouse-gas, End-use model, Global economic model

1. Introduction

AIM is an integrated simulation model developed to project greenhouse gas emissions and assess abatement options and environmental impacts of global warming in the Asia-Pacific region. The original AIM is an integrated 'top-down and bottom-up' model and comprises an emission model, a climate model and an impact model. The emission model consists of energy efficiency improvement module, energy service module and a technology selection module for regional models while for the major global model it uses a general equilibrium model. The climate model is developed to link emission and impact models. The impact model, having a spatial water balance model, an ecological model and a health impact model, is used to estimate the increased risks of droughts, floods, vegetation changes and malaria. During the current project phase, these models have been updated to analyze climate policies in more detail. The development of emission model has two different directions. One is to support CO2 reduction policies of local government and the other is to analyze international effects of mitigation policies through international trade. A simplified climate model has also been developed to analyze climate change based on new emission scenarios.

2. Technology model

Bottom-up models have so far been developed in two directions. First is towards analyzing more efficient technologies and their combination by focusing on the supply and conversion side of energy. The other one, commonly known as "end-use model", focuses on energy demand and consumption side that sums up details about how changing patterns of human activities in each sector change the energy demand.

AIM/technology model focuses on technology side and estimates energy consumption from energy supply and demand sides. As shown in Fig. 1, the model first estimates energy service demands based on socio-economic factors such as population, economic growth, industrial structure, lifestyle, and then calculates what kind of technology will be used to what extent. To compare and consider energy technologies, detailed technological data and energy data are prepared. Once the kind of energy technology to be used is known, the model calculates the energy necessary to provide the energy services and the amount of CO2 emissions produced when each type of energy technology operates.

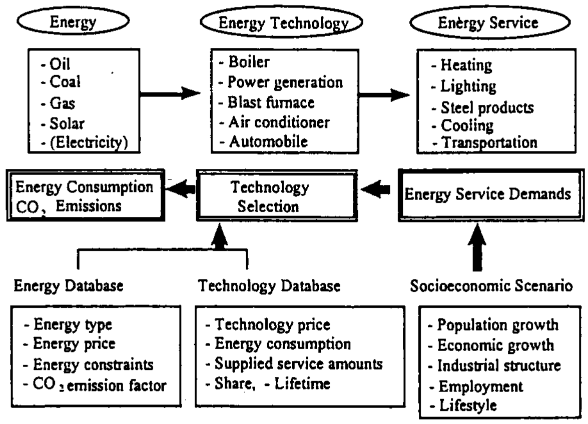

Fig. 1 Structure of technology model

The key factor to mitigate CO2 emissions is the extent to which energy-saving technology can be introduced at the end-use point. AIM focuses on the fact that substitution technology will be available according to energy price and estimates energy efficiency and energy consumption on the basis of each technology. Therefore, it is possible to evaluate the effectiveness of each policy or combine various policies. More than 300 technologies are evaluated. Fig. 2 shows an example of the technology model.

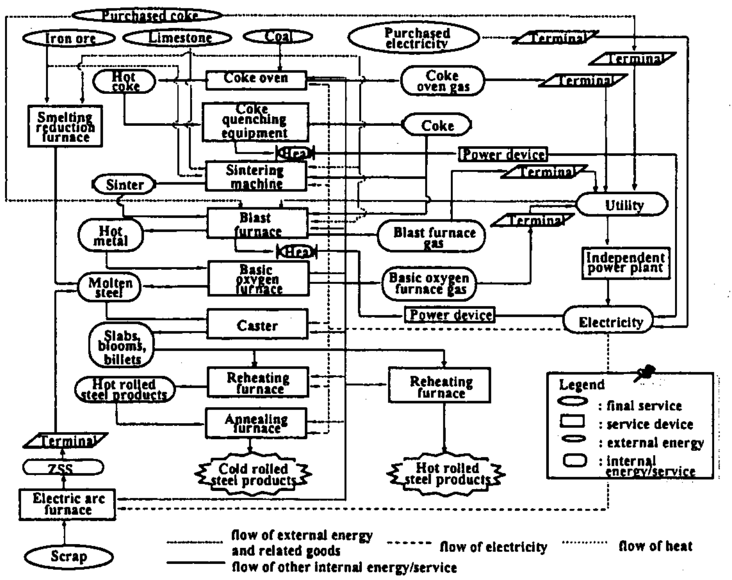

Fig. 2 Structure in the steel industry in Japan

This figure shows the structure of Japanese Iron and Steel Industry model. In this particular case, three types of steel making processes are considered: blast furnace process, electric arc furnace process, and smelting reduction process. The final service is the steel products and is produced with several types of technologies using external energy. Numerous types of internal service/energy are evaluated in the steel making process. There are several alternative technologies in each process. Which technologies should be used - conventional technology or energy-saving - is determined based on costs. This model is applied to estimate CO2 emissions and mitigation potentials in Japan, China, India, and Korea.

3. Development of world economic model

A general equilibrium model has also been developed to estimate costs to reduce CO2 emissions as well as secondary effects on productions through international markets. Fig.3 shows the structure of the AIM/top-down model. The model has three sectors - the production, household, and government sectors - in each region. CO2 and other greenhouse gases are emitted by each of these sectors. The production of electricity and of non-energy goods uses fossil fuels in the production sector, and the use of automobiles and other direct uses of fossil fuels emit CO2 in the household and government sectors. It is assumed that the household sector has carbon emission rights and distributes them to the other sectors and within the household sector itself. Fossil fuels cannot be used without carbon rights. The price of carbon rights depends on several factors such as emission targets and method of emission trading. The household sector also supplies primary factors to the production and government sectors. An agent in the household sector determines consumption and saving. The marginal propensity to save is a calibrated function of a weighted aggregate of regional and global rates of return on fixed capital. A regional investment is calculated with the GDP growth rate, regional and global rates of return. Investment is balanced with saving on a global scale. The model allows for trade in intermediate goods. AIM assumes identical preferences in all countries for foreign versus domestic goods; i.e. the elasticity of substitution is the same for all regions. Domestic and export goods are not perfect substitutes.

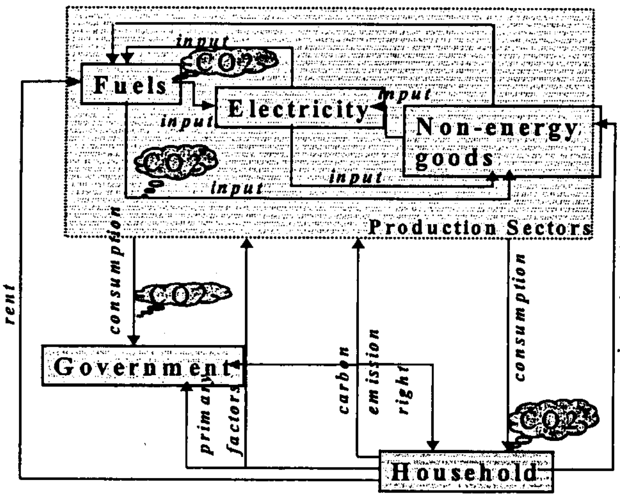

Fig. 3 Structure of world economic model

The model is applied to estimate the effects of post-Kyoto scenarios. Fig. 4 shows the CO2 emissions (bars) and marginal costs (line) in the no trading case in 2010. The left-hand bar for each region shows the 1990 emission level, the second bar shows the target emission level, the third bar shows BaU emission level, and the right-hand bar shows the emission level in the no trading case. The BaU emission of former Soviet Union is less than the target, reflecting the economic deterioration of the region. The difference is the so-called 'hot-air'.

The line graph shows the marginal costs to achieve the emission targets. The emission of the former Soviet Union is below the 1990 level until 2030 in the BaU case, so no policy intervention is necessary in 2010. On the other hand, CO2 emission in New Zealand in the reference case is 11MtC in 2010 and New Zealand has to reduce a large amount of CO2 compassed to the 1990 level, the marginal cost becomes the highest. Apart from New Zealand, the ranking is Japan, EU, USA and Australia, in that order.

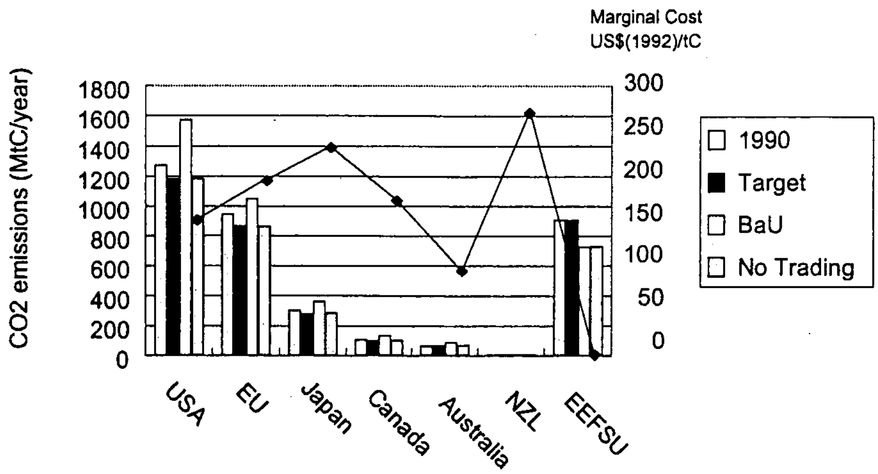

Fig. 4 CO2 emissions and marginal costs in 2010 (No trading case)

Fig. 5 shows the changes in energy trade vs. GDP caused by Kyoto Protocol in 2010. Care must be taken to read this figure. The data in the countries listed above China show the changes in import, and below China shows the changes in export. The reduction in import in Europe is the highest followed by USA. The change in export in Middle East Asia is the highest. Fig. 5 also shows changes in GDP. The economic impact on USA is the highest followed by Europe.

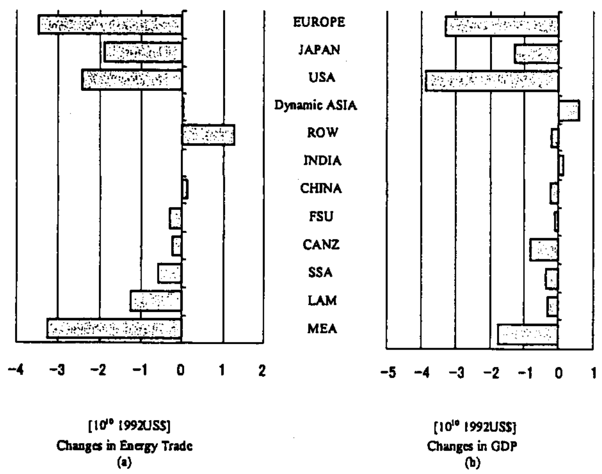

Fig. 5 Changes in Energy Trade vs. GDP Caused by Kyoto Protocol (in 2010)

4. Development of Mini-AIM model

A user-friendly interface has been developed to support developing an action plan in local governments. Fig. 6 shows menu screen for an end-use energy demand model. The model can estimate CO2 emissions region by region. Based on selections in Technology menu and Countermeasure menu, the model estimates energy consumption and CO2 emissions as well as other emissions of air pollutants. The model is applied in Japan and Korea and is found to be effective to analyze countermeasures caused by changes in lifestyle in the residential sector.

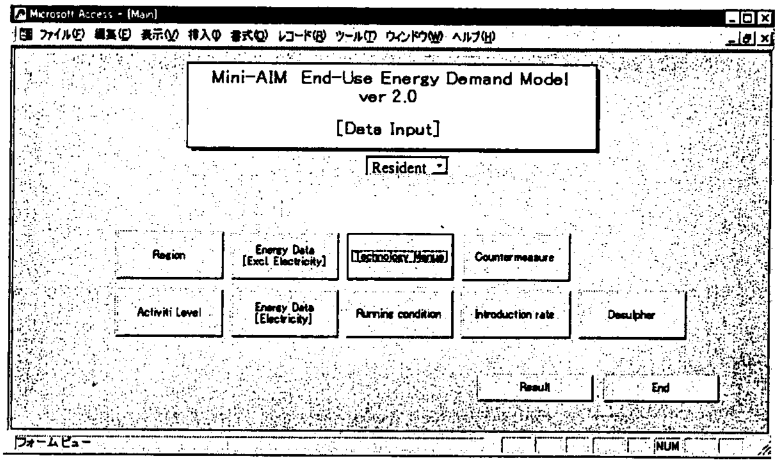

Fig. 6 Main menu for end-use energy demand model

5. Development of land-use model

In order to support Special Report on Emissions Scenarios (SRES) of IPCC, the new general equilibrium model, which can analyze the land use change, has been developed. Fig. 7 shows the structure of the model. This model is based on the database of Global Trade Analysis Project (GTAP). In analyzing the equilibrium of land use, it is assumed that land is distributed among sectors for the maximization of profits in each period similarly to capital and labor, although land use does not change so readily. In this model, the economic sectors and regions are divided into 10 and 17, respectively. Land use is divided into five categories: cropland for agriculture, pasture for livestock, forests, biomass fields, and other land uses. Except for biomass fields, these categories are based on the categories of FAO.

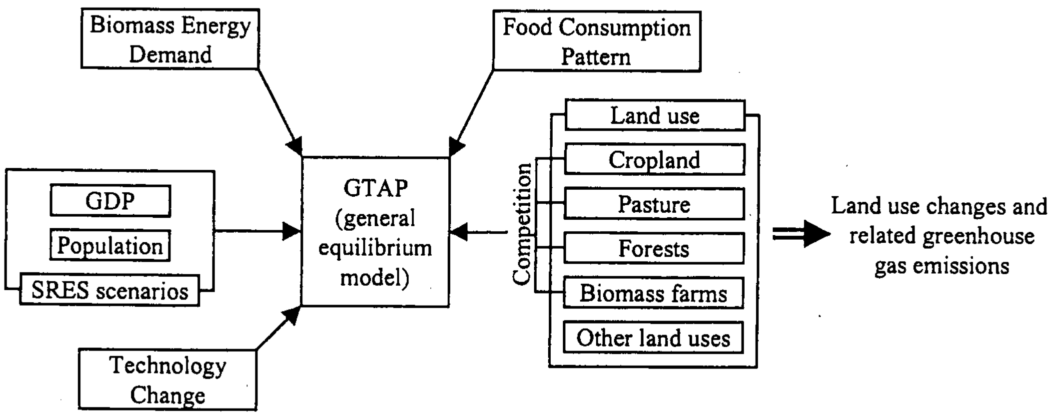

Fig. 7 Structure of land-use model

Based on SRES storylines, the future scenarios on technology improvement, land productivity growth, changes of food demands, and biomass energy demand are inputted. The scenario on energy demand is derived from AIM energy model. Through the general equilibrium process, land will be assigned for use as cropland, pasture, forests, and biomass farms. These land uses as well as land use changes will generate greenhouse gas emissions. Emissions of the following greenhouse gases and related gases were calculated: carbon dioxide (CO2), nitrogen oxides (NOx), sulfur oxides (SOx), methane (CH4), carbon monoxide (CO), and nitrous oxide (N2O). The emissions of each gas are simply calculated from the land use or land use change as well as the relevant emission factor. For example, the emission of carbon due to deforestation was calculated from the area of deforestation multiplied by the carbon emission factor from deforestation.

Results from the simulations indicate that the forest area will increase after the beginning of 21st century in all scenarios, especially B1 and B2 scenarios in which societies consider not only economic development but also environmental preservation. In A1 scenario, although the increase of the meat demand will result in pasture area increase, the growth of land productivity and decrease of population will mitigate this expansion of pasture area after the middle of 21^{st} century. On the other hand, the continuous expansion of crop land will be needed in case of high population growth scenario like A2 scenario. The forest area in Asia will be recovered faster than that in the global. The resulting CO2 emissions from these land-use changes are shown in Fig. 8

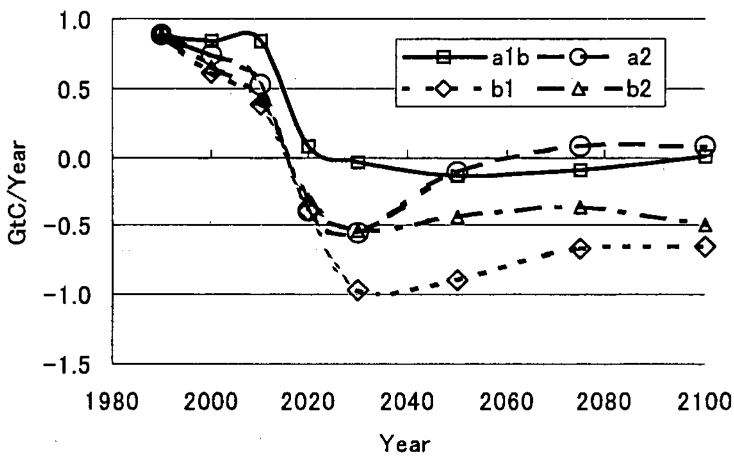

Fig. 8 World CO2 emissions by land-use change

6. Climate change model

Several types of climate change models were developed to represent the CO2 and heat absorption processes of the ocean, and the resulting sea level rise. The basic structure of the model is shown in Fig. 9.

The model begins with GHG emissions, which are input into GHG concentration model. GHG concentration model comprises several modules that represent the hemispherical and altitudinal characteristics of the gases in atmosphere. Carbon dioxide is assumed not to decay, but absorbed by the ocean and terrestrial ecosystems. A simple upwelling diffusion model, an advective-diffusion model or convolution approximations of OGCMs experiments, estimates ocean absorption. As for other GHGs, the decaying processes are modeled with the first order reactions. The kinetic coefficients in the equations were calibrated by comparison with the outputs of more complex, but realistic models. Also the effect of moisture in the stratosphere is calculated using methane concentration. The cooling effect of decreased lower stratospheric ozone is calculated with GHG concentrations, and the cooling effect of aerosol sulfates is calculated with sulfur dioxides emissions.

Sea level rise is calculated from the expansion of seawater due to temperature increase, the melting of the continental glaciers, and changes in the ice sheets of Greenland and Antarctica.

The model is applied to estimate climate change based on 259 published emission scenarios including IPCC new emission scenarios. Fig. 10 shows the range of temperature change based on IPCC scenarios. The temperature is estimated to increase 0.8 degree C to 2.1 degree C in 2050 and 1.3 degree C and in 2100. The corresponding sea level rise is estimated to be 6 to 45 cm in 2050 and 13 to 97 cm in 2100.

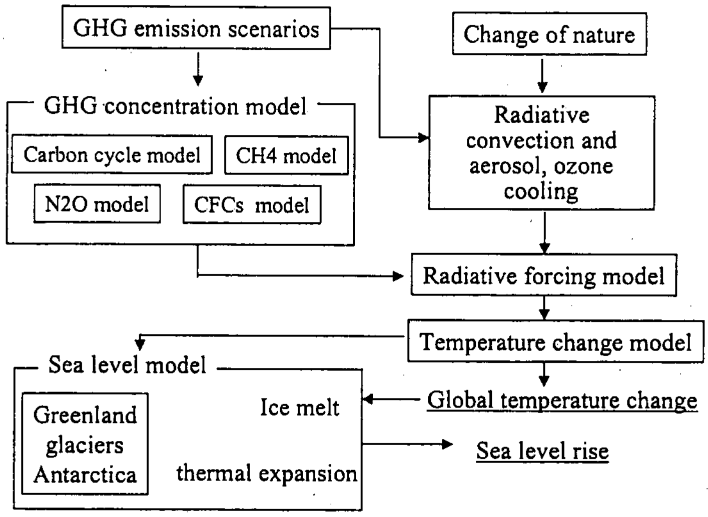

Fig. 9 Outline of AIM climate change model

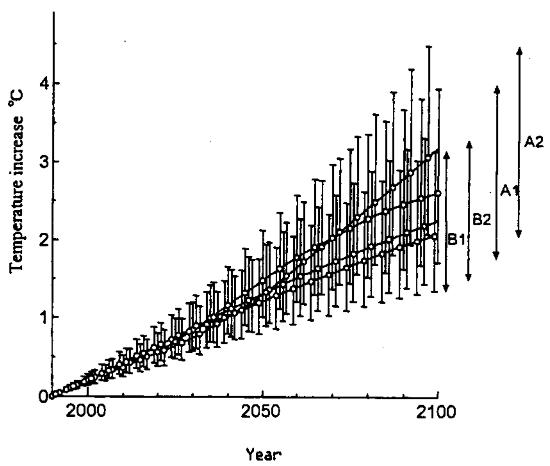

Fig. 10 Temperature change based on SRES scenarios

7. Vegetation model

An estimation of climate impacts on natural vegetation is one of the most important study areas when we examine land-use and forestry. Climate classifications that were developed by Koeppen, Holdridge and other researchers have been often utilized to consider climate change impacts on natural ecosystems. These climatic divisions were defined with reflecting plants' growth requirements.

We estimated the change of classification caused by climate change. Fig. 11 shows the geographical vegetation map, assuming that the temperature will increase about 2 degree C by 2100 and the forest can move at the speed of 1 km/yr. As for the future climate patter, the result of Canadian Center of Climate Change is used. 9% in low case scenario (0.85 degree C increase in 2100), 26% in medium scenario (2 degree C increase) and 43% in high case scenario (3.5 degree C) of the total forest areas are estimated to be destroyed by climate change.

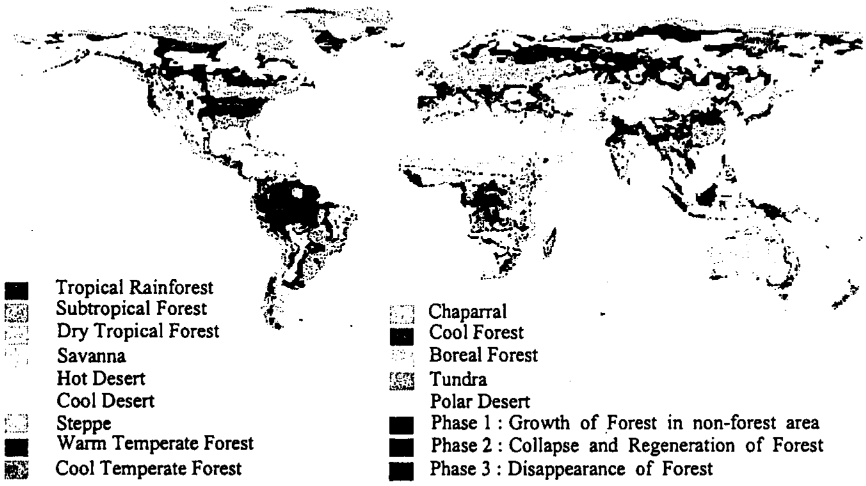

Fig. 11 Estimation of vegetation change in 2100 based on 2 degrees C increase

8. Concluding remarks

During this project period, our team undertook several developments. These include revisions and improvements in AIM country models as well as world economic model, development of Mini-AIM, a land-use model and a climate change model. These models have been successfully applied to make projections of greenhouse gas emissions and to analyze policy designs for their mitigation. Scenarios from AIM model have also been designated as Marker Scenarios by IPCC. Future work on model development in this area is required for further development of the global models. Also, work is required to model local pollution problems in the context of global warming. Additionally, one needs to pay attention on encouragement of environmental industry for achieving high economic growth while keeping the emissions at low levels.

References

Kainuma, M., Y. Matsuoka and T. Morita: Development of AIM for analyzing policy options to reduce greenhouse gas emissions, Abstract of Workshop on Advanced Methodologies of Software and Decision Support Systems, Laxenburg, Austria, 1997

Kainuma, M., Y. Matsuoka and T. Morita: Development of AIM for Analyzing Policy Options to Reduce Greenhouse Gas Emissions, Proceedings of 8th IFAC/IFORS/IMACS.IFIP Symposium on Large Scale Systems: Theory and Applications, Patras, Greece, 1998

Kainuma, M., Y. Matsuoka and T. Morita: Comparison of strategies to reduce greenhouse gas emissions, Report on 1999 Open Meeting of Human Dimensions of Global Environmental Change, Shonan, Japan, 1999

Kainuma, M., Y. Matsuoka and T. Morita: Simulation of air pollution scenarios in Asia and Pacific, Proceedings of 14th IFAC World Congress, Beijing, China, 1999

Kainuma, M., Y. Matsuoka and T. Morita: New directions of AIM modeling, Abstract of Workshop on Advanced Methodologies of Software and Decision Support Systems, Laxenburg, Austria ,1999
Kainuma, M., Y. Matsuoka and T. Morita: Development of AIM for coping with global warming, Proceedings of IEEE Systems, Man and Cybernetics Conference, Tokyo, Japan, 1999
Masui, T., Y. Matsuoka, and T. Morita: Estimation of Greenhouse Gases due to Land Use Changes --Contribution to IPCC Special Report on Emission Scenarios, Proceedings of 1999 NIES Workshop on Information Bases and Modeling for Land Use and Cover Change Studies in East Asia, Tsukuba, Janan, 1999
Masui, T., Y. Matsuoka, and T. Morita: Land use changes and their GHG emissions derived from biomass energy supply and food consumption pattern, Report on 1999 Open Meeting of Human Dimensions of Global Environmental Change, Shonan, Japan, 1999
Matsuoka, Y., M. Kainuma and T. Morita: Energy policy and reduction of air pollutant in Asia and Pacific region, Report on 1999 Open Meeting of Human Dimensions of Global Environmental Change, Shonan, Japan, 1999
Kainuma, M., Y. Matsuoka, T. Morita and G. Hibino: Development of an End-Use Model for Analyzing Policy Options to Reduce Greenhouse gas emissions, *IEEE Trans, Sys. Man and Cybern,* 29 (3)、317-324 (1999)
Kainuma, M., Y. Matsuoka and T. Morita: Estimation of Embodied CO2 Emissions by General Equilibrium Model, Feature Issue of EJOR on Advances in Modeling: Paradigms, Methods and Applications, 122, 392-404 (2000)
Kainuma, M., Y. Matsuoka and T. Morita: The AIM/End-Use Model and its Application to Forecasting of Japanese Carbon Dioxide Emissions, Feature Issue of EJOR on Advances in Modeling: Paradigms, Methods and Applications, 122, 416-425 (2000)
Masui, T., T. Morita, and J. Kyogoku: Analysis on recycling activities using multi-sectoral economic model with material flow, Feature Issue of EJOR on Advances in Modeling: Paradigms, Methods and Applications, 122, 405-415 (1999)