B-15.1.1 Collaborative Studies for Developing AIM/emission Model - Development of Basic Models (Final Report)

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Abstract: This project aims to develop a countrywide greenhouse gas emission model in the Asian-Pacific region, and to improve the global components of the emission and climate models in conjunction with research institutes in the Asian-Pacific region. During 1994-1996, CO2 emission models were developed for China, India, and Indonesia in cooperation with research institutes in these countries. Using these models, emission scenarios and policy options were estimated for each countries. In addition to the models in developing countries, Japanese CO2 emission model has been improved and applied to long-term predictions of emissions. This model has also been applied to evaluation of policy linkage of carbon tax to a special subsidy policy using a newly developed algorithm. These country models were linked to regional and global models in order to estimate the Asian-Pacific emission scenarios and global emission scenarios. Furthermore, The developmental process of Asian environmental policies were compared in order to extend the application of the CO2 emission model for assessment of local secondary effects. On the other hand,a global tropical deforestation model was created to estimate the carbon flux caused by deforestation, and a global terrestrial carbon cycle model was developed to estimate CO2 fertilization of terrestrial vegetation. Then, a simulation was made of temperature increases based on various recent emission scenarios and safe emissions corridors were estimated using the revised climate change and carbon cycle models.

Key Words AIM/emission, greenhouse gases, Asian-Pacific region, end-use model, energy technologies, integrated assessment model

1. Introduction

It is predicted that global warming will have a significant impact on the society and economy of the Asian-Pacific region, and that adoption of measures to tackle global warming 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 become half of all global emissions by the end of the next century. The global warming issue has been recognized as one of the most important policy issues to be solved for the region's development. Japan's role in the region has increased through greater contributions in the fields of ODA, technology transfer, research and joint implementation of countermeasures.

In order to promote adoption of countermeasures, it is necessary to predict precisely the greenhouse gas emissions in the region and also the impact of global warming. The effects of countermeasures on emission reduction and impact abatement also need to be determined, taking into account international cooperative efforts. Such prediction and analyses require an integrated simulation model for the region. The role of this study is to establish that integrated model in cooperation with several research Institutes in the Asian region.

2. Objectives

The objectives of this study are to develop the Asian-Pacific Integrated Model (or Aim for short), so that policy options for stabilizing global climate, particularly in the Asia-Pacific region, can be assessed from the two perspectives of reducing greenhouse gas emissions and avoiding the impacts of climate change. During 1991-1993, a preliminary global module of AIM and several prototype models have been developed. This project intends to develop AIM based on the work of the past three years in conjunction with foreign research institutes, especially in developing countries.

This sub-theme is one component of the AIM development project. The following report concerns the development of country emission model, the regional emission model and the world model including deforestation model, carbon cycle model and climate change model.

3. Outline of AIM emission model

(1)Characteristics

The AIM model integrates emission, climate and impact models and their component processes, as well as preparing country modules and a global integrated module. It is directly linked to, and takes account of, technological changes. With a focus on policy assessment in the Asian-Pacific region, it has the ability to prepare regional overviews. It is a collaborative project, and is being conducted with institutes of various countries in the region. There are only four such models in the world.

(2)AIM's Basic Structure

As shown in **Figure 1**, the three linked models are an emission model (AIM/emission), a climate model (AIM/climate), and an impact model (AIM/impact). The emission model combines an end-use energy model and a technological selection model. More than 100 technologies are evaluated for their potential to improve energy efficiency, and energy demand estimates are linked to a top-down economic model. One component of the emission model is the forest resources alternation model to estimate the global greenhouse emissions from land-use changes. The climate model was created by developing original linkages to join other established models, such as the box-diffusion oceanic model, the IPCC radiative forcing model, the GCM for regional climate change model and the AMAC model for atmospheric composition. The impact model has a spatial water balance model, an ecological matching model and a malaria distribution model. Other related models are being developed.

(3) Outline of AIM/emission

The AIM/emission model has two kinds of linked models, these are, "top-down models" and "bottom-up models". Top-down models start with an economic model and represent the relationships between energy consumption and national products by using prices

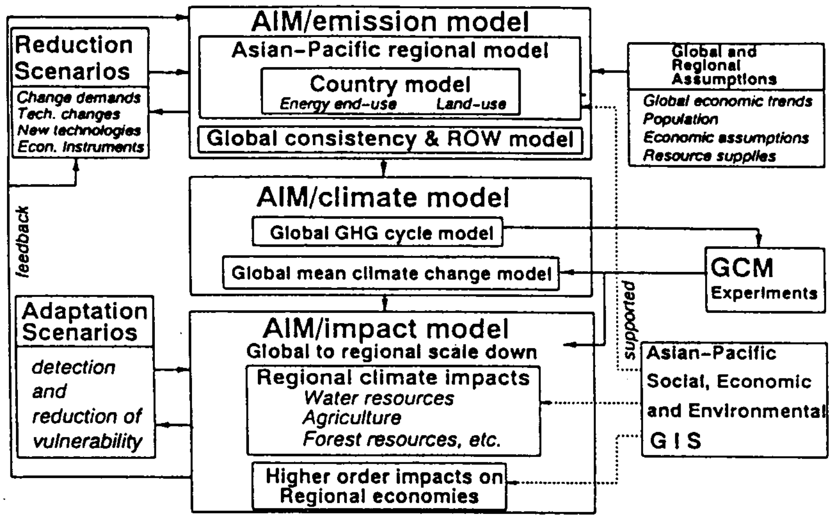

Figure 1 Basic structure of AIM

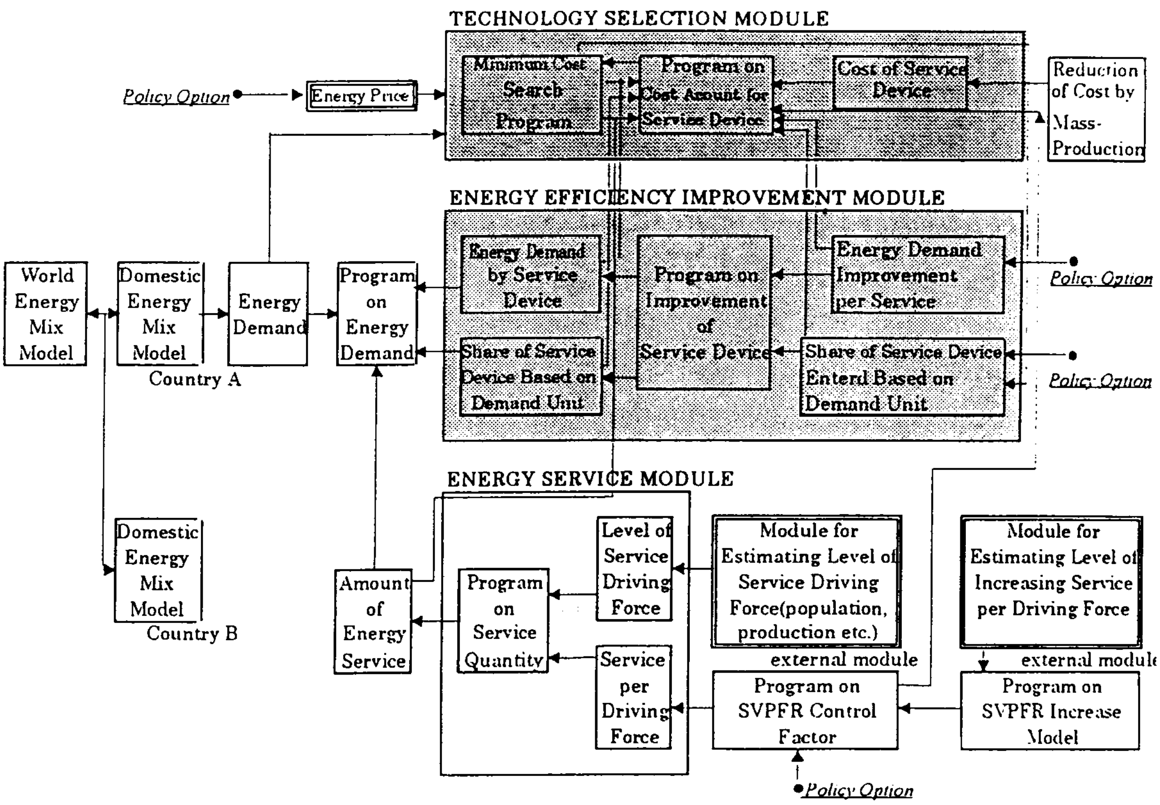

Figure 2 Outline of bottom-up country model of AIM/emission

and elasticities as economic indices. Bottom-up models focus on the activities of the people who deal with energy consumption and production, plus the changes in technologies. Based on detailed descriptions of these items, they calculate the total energy consumption and production from the "bottom-up". The top-down world model of AIM has 19 regions in equilibrium and interacts with the bottom-up country models.

The structure of the bottom-up energy model is shown in **Figure 2**. The end-use model is comprised of 3 modules. The first is an energy service estimate module which estimates various demands that will need to be met using energy (energy services). This module obtains output from other models and scenarios that determine socio-economic variables. It estimates energy service demand based on assumptions about lifestyles and levels of concern for environmental conservation. The second module is an energy efficiency module that calculates the improvements in energy efficiency. It comprised 'the Reference Energy System (RES)' which connects the energy supply from the secondary energy step and energy service demands and links them with technological information about energy tools. The third module selects various service technologies based on an evaluation of the benefits of service devices with criteria such as economic efficiency and then selects the optimal devices for each situation and service. Also included is a module that estimates the optimal solutions for each sector by combining these 3 modules. Their functions are modularized and designed to treat all time periods, all countries and all sectors with a single sub-program and to link them with other models of AIM through the energy macro-economics linkage.

4. Countrywide Models

(1) China's Model

Chinese model has been developed in cooperation with the Energy Research Institute of China since 1994. As shown in **Table 1**, more than 300 technologies were investigated to be considered in the technology selection module of Chinese model. the year 1990 was taken as the base year and projections were then calculated up to 2010. The policy options to control CO2 were: 1)Carbon tax; 2) Carbon tax and extension of pay back period, and two reference cases were induced: 1) Without technological progress, assumes that future technology remains at 1990 level; 2) Technology progress case, assume that technology improves in the market without interventions.

As shown **Figure 3,** a rapid economic development will increase energy consumption and CO2 emissions, and all four cases show this increasing trend. Technology progress will play an important role to reduce CO2 emissions in China, and the economic incentives and pay-back period extension policies are effective ways to reduce CO2 emissions.

In details, industry sector will continue to be the largest CO2 emitter because of the first stage of industrialized economic development pattern in China with its emphasis on heavy industry. The increase in transport energy consumption is notable, because transport services are limited. and will develop very quickly. In particular private transport is expected to grow rapidly, and it is difficult to improve energy use efficiency in this sector.

(2) India's Model

The AIM/Enduse model for India has been developed in collaboration with Indian Institute of Management. It has been set up for forty years horizon from 1995 to 2035, and is developed for six different end-use sectors: 1) industry, 2) transport, 3) agriculture, 4) urban residential, 5) rural residential, and 6) commercial & services. The industry sector is further divided into eleven sub-sectors: steel, aluminum, cement, paper, brick, caustic soda, soda ash, sugar, cotton textiles, fertilizer, and other industries. Each sub-sectoral model

Table 1 Energy technology list in the China's emission model

Classification	Technologies (equipment)
Iron & Steel	Coke oven, Sintering machine, Blast furnace, Open hearth furnace (OH), Basic oxygen furnace (BOF), AC-electric arc furnace, DC-electric arc furnace, Ingot casting machine, Continuous casting machine, Continuous casting machine with rolling machine, steel rolling machine, Continuous steel rolling machine, Equipment of coke dry quenching, Equipment of coke wet quenching, Electric power generated with residue pressure on top of blast furnace (TRT), Equipment of coke oven gas, OH gas and BOF gas recovery, Equipment of co-generation.
Non-ferrous metal	Aluminum production with sintering process, Aluminum production with combination process, Aluminum with Bayer, Electrolytic aluminum with upper-insert cell, Electrolytic aluminum with side-insert cell, crude copper production with flash furnace, crude copper production with electric furnace, Blast furnace, Reverberator furnace, Lead smelting-sintering in blast furnace, Lead smelting with closed blast furnace, Zinc smelting with wet method, Zinc smelting with vertical pot method.
Building materials	Cement: Mechanized shaft kiln, Ordinary shaft kiln, Wet process kiln, Lepol kiln, Ling dry kiln, Rotary kiln with pro-heater, dry process rotary kiln with pre-calciner, Self-owned electric power generator, Electric power generator with residue heat; Brick & Tile: Hoffman kiln, Tunnel kiln; Lime: Ordinary shaft kiln, Mechanized shaft kiln; Glass: Floating process, Vertical process, Colburn process, Smelter.
Chemical industry	Equipment of synthetic ammonia production: Converter, Gasification furnace, Gas-making furnace, Synthetic column, Shifting equipment of sulphur removing; Equipment of caustic soda production: Electronic cell with graphite process, Two-stage effects evaporator, Multi-stage effects evaporator, Equipment of rectification, Ion membrane method; Calcium Carbine production: Limestone calciner, Closed carbine furnace, Open carbine furnace, Equipment of residue heat recovery; Soda ash production: Ammonia & salt water preparation, limestone calcining, distillation column, filter; Fertilizer production: Equipment of organic products production, Equipment of residue heat utilization
Petrochemical Industry	Facilities of atmospheric & vacuum distillation, Facilities of rectification, Facilities of catalyzing & cracking, Facilities of cracking with hydrogen adding, Facilities of delayed coking, Facilities of light carbon cracking, Sequential separator, Naphtha cracker, de-ethane separator, diesel cracker, de-propane cracker, facilities of residue heat utilization from ethylene.
Paper-making	Cooker, facilities of distillation, facilities of washing, facilities of bleaching, evaporator, crusher, facilities of de-water, facilities of finishing, facilities of residue heat utilization, facilities of black liquor recovery, Co-generator, Back pressure electric power generator, condensing electric power generator.
Textile	Cotton weaving process, Chemical fiber process, Wool weaving & textile process, Silk process, Printing & dyeing process, Garment making, Air conditioner, Lighting, Facilities of space heating.
Machinery	Ingot process: Cupola, Electric arc furnace, fan; Forging process: coal-fired pre-heater, Gas-fired pre-heater, Oil-fired pre-heater, Steam hammer, Electric-hydraulic hammer, Pressing machine; Facilities of heat processing: Coal-fired heat processing furnace, Oil-fired heat processing furnace, Gas-fired heat processing furnace, Electric processing furnace; Cutting process: Ordinary cutting, high speed cutting.
Irrigation	Diesel engine, Electric induct motor
Farming works	Tractor, Other agricultural machine
Agricultural products process	Diesel engine, Electric induct motor, processing machine, coal-fired facilities.
Fishery	Diesel engine, Electric induct motor.
Animal husbandry	Diesel engine, Electric induct motor, Other machines.
Space heating in resident	Heat supplying boiler in thermal power plant, Boiler of district heating, Dispersed boiler, Small coal-fired stove, Electric heater, Brick bed linked with stove (Chinese KANG).
Cooling in resident	Air conditioner, Electric fan.
Lighting in resident	Incandescent lamp, Fluorescent lamp, Kerosene lamp.
Cooking & Hot water in resident	Gas burner, bulk coal-fired stove, briquette-fired stove, Kerosene stove, Electric cooker, cow dung-fired stove, firewood-fired stove, methane-fired stove.
Electric Appliance	Television, Cloth washing machine, Refrigerator, others.
Space heating in service sector	Heat supplying boiler in the thermal power plant, Boiler of district heating, dispersed boiler, Electric heater.
Cooling	System of central air conditioner, Air conditioner, Electric fan.
Lighting	Incandescent lamp, fluorescent lamp.
Cooking & Hot water	Gas burner, Electric cooker, Hot water pipeline, Coal-fired stove.
Electric Appliance	Duplicating machine, computer, Elevator, others.
Passenger & freight transport	Railway (passenger & freight): Steam locomotive, Internal combustion engine locomotive, Electric locomotive.; Highway (passenger & freight): Public diesel vehicle, Public gasoline vehicle, Private vehicle, Large diesel freight truck, Large gasoline vehicle, small freight truck. Waterway (passenger & freight): Ocean-going ship, Coastal ship, Inland ship. Aviation (passenger & freight): Freight airplane, passenger airplane.

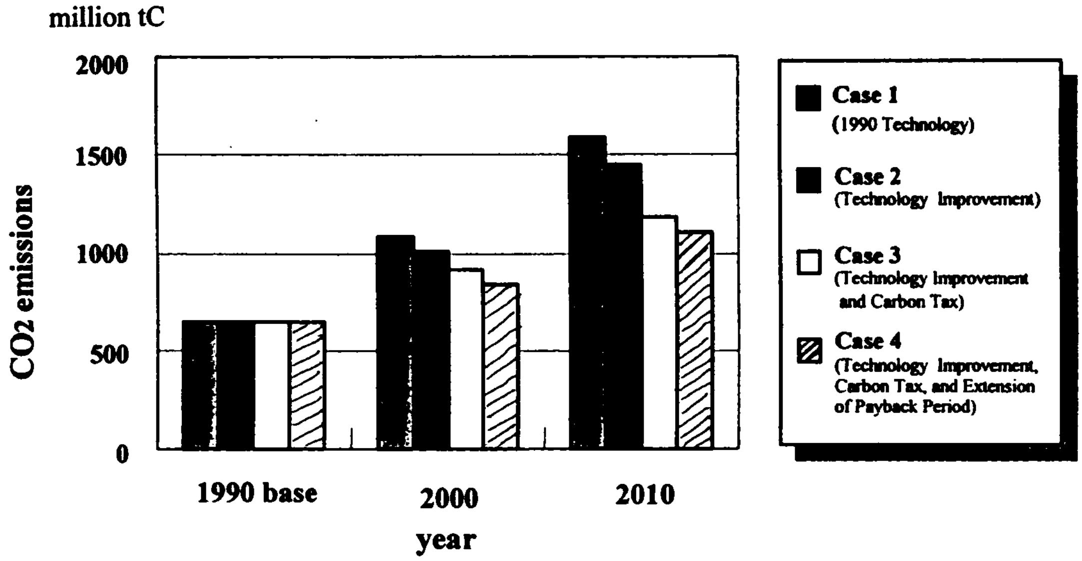

Figure 3 Forecast of CO2 emission in China

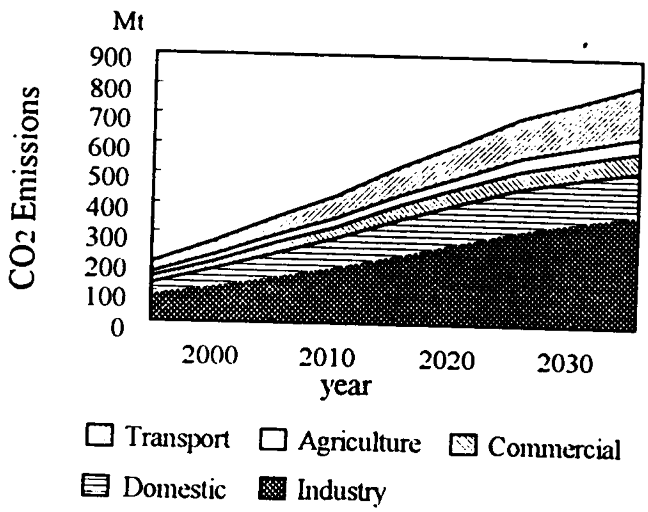

Figure 4 Total CO2 emissions in India by sector

contains detailed technological specifications. For instance, there are thirty technologies in steel, ten in aluminum, twenty five in transport, and twenty in urban residential sector. The entire model is specified with 250 different demand technologies.

The model results for the next forty years in the business-as-usual (BAU) scenario for the end-use sectors suggests the following: i) the total primary energy consumption grows by 2.6 times from 9284 PJ to 23920 PJ ii) the commercial energy consumption (including electricity) grows 4.8 times from 7059 PJ to 33709 PJ, iii) the electricity consumption grows six times from 2498 TWh to 15111 TWh, and iv) total carbon emissions (including from electric power sector) grows four times from 201 million tons to 813 million tons. **Figure 4** shows the contribution of different end-use sectors to total carbon emissions in India from 1995 to 2035. The share of commercial fuels in total energy increases since the biomass use stagnates around five exa joules. The share of biomass in primary energy in the end-use sectors declines from fifty to twenty two percent. The consumption of diesel and gasoline increase at a high rate due to rapid growth of transport. The share of natural gas increases from three to eight percent of primary energy. The share of coal remains around twenty percent.

The AIM/Enduse model is well suited to examine a variety of competitive techno-economic and policy scenarios. For instance, an analysis with the carbon taxes suggests that a uniform $ 63 (1993 US$) per ton of carbon tax applied from 2005 AD onwards will affect a significant shift from coal to natural gas and electricity consuming technologies in Indian industry. (See **Figure 5**) For instance, the carbon emission from Indian steel industry in the year 2035 declines by fifteen percent under such a tax.

(3) Japanese model

The Japanese-module of the AIM end-use model was developed in 1993, and it has been improved for comprehensive estimation and longer-term forecast of Japan's future CO2. In the Japanese model, more than 150 technologies were evaluated for selection based on energy efficiency and cost.

This model was used to determine the level of carbon tax required to stabilize Japanese CO2 emissions. In order to reduce emissions to the 1990 level with a single carbon tax, a high tax rate of 30,000 ¥/tC is required. However, the introduction of such a high tax rate would be politically difficult. An alternative would be to use the revenue from the tax to subsidize investment in energy efficient technologies. In this case, the tax rate would only need to be 3,000 ¥/tC. This combination of tax and subsidy policies can be evaluated with a two dimensional optimization technique. The AIM model can solve these sophisticated algorithms internally.

The model was then used to evaluate policy and emission scenarios to the year 2030. In order to make such long term evaluations, a diverse range of socio-economic scenarios needs to be included to represent energy service estimates based on different sets of social preferences. The materialistic patterns of contemporary society were contrasted with those of a possible future society which emphasized creativity and a knowledge intensive industry and lifestyle. Each scenario results in distinct patterns because of the differences depicted in the two sets of values. Economic growth rates are expected to be lower under the creative scenario with an accelerated shift in employment to the service sector from heavy industries such as the steel and chemical industries. Demand for office floor space and transport differ under the two scenarios with the creative society demanding more floor space and less transport than that predicted for the materialistic scenario. The different level of energy service demands results in significantly divergent levels of energy consumption and CO2

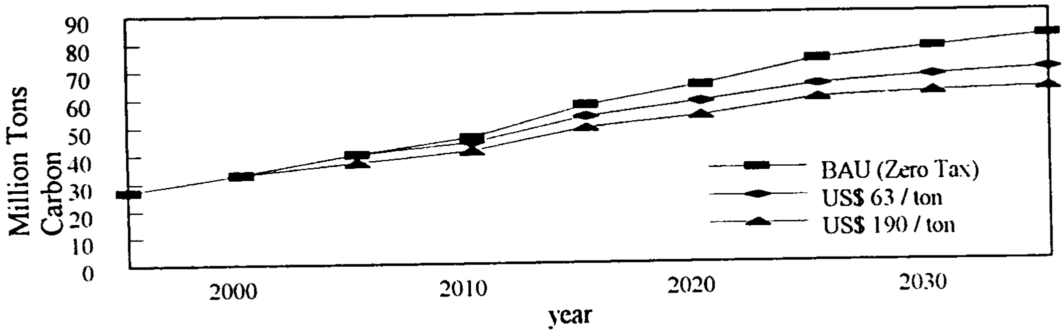

Figure 5 CO2 emission from Indian steel industry under tax scenarios

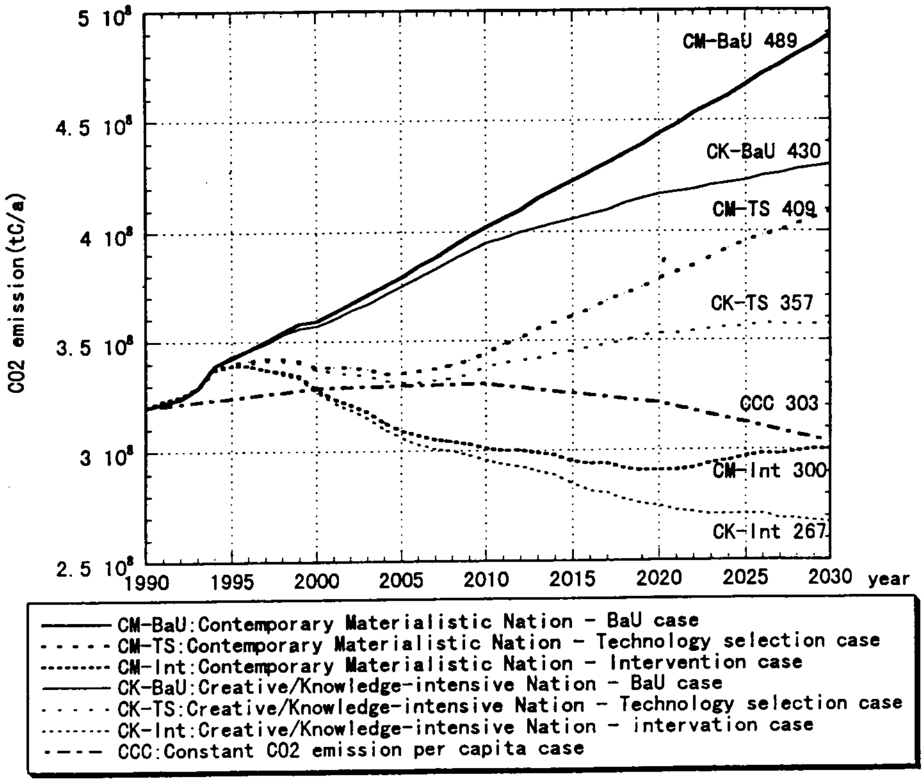

Figure 6 Forecasts of Japanese CO2 emissions until the year 2030

emissions.

As shown in **Figure 6**, the materialistic scenario without intervention predicts a 53% rise in CO2 emissions by 2030, whereas, the creative scenario with intervention predicts a 17% decrease. This decrease is achieved while maintaining the level of total energy services. The introduction of new technologies with high energy efficiencies coupled with low carbon energy sources and increased material recycling account for the overall reduction in CO2. The direct cost of these policies was estimated to be approximated 1 trillion yen per annum around the turn of the century. This represents substantial new markets for advanced technologies and related employment opportunities. These results suggested that changes in the nation's dominant life style could be very beneficial in terms of decreasing carbon dioxide emissions.

Japan has an opportunity to be a global leader in environmental policy. Japan can be a leader and reduce its GHG emissions by becoming the creative and knowledge intensive society depicted in the analysis of this study. A strategy is required to boost its economic and environmental well-being through the promotion of sophisticated technology and the creation of new lifestyles which respect the environment.

(4) Desulfurization Models

Many Asian-Pacific developing countries place a higher priority on local pollution issues than climate change. The AIM model can also be used to address these issues. For example, SO2 emissions have been modeled to assess local and long distance impacts. This model can make projections of future SO2 emissions for a number of scenarios, as well as analyze appropriate policy and investment options to reduce emissions. Both top-down and bottom-up models are used to evaluated desulfurization options. The top-down model simulates changes in the energy mix and investment in desulfurization. The bottom-up model evaluates alternate technologies and selects desulfurization technologies based on economic criteria. A new technology is selected when its cost and the energy related savings from the introduction of more efficient technologies is less than the taxes on sulfur emissions.

Figure 7 shows the simulation result using the top-down SO2 model to represent the Japanese experience from 1960 onward. The SO2 emission trend results from changes in the energy mix, improvements in energy efficiency and investment in desulfurization stack gas devices. The estimated patterns for investment in desulfurization devices and SO2 emissions both follow the actual patterns very closely. This top-down model was then applied to Korea and China to predict the timing of investment in desulfurization stack gas devices. **Figures 8 and 9** show the results of these projections. The damage function or cost of increased SO2 emissions rises rapidly along with economic growth and stimulates initial changes in the energy mix to reduce SO2 emissions. Further reduction in SO2 emissions requires substantial investment in desulfurization technologies as shown in the figures. **Figure 8** indicates that Korean investment in these technologies is expected to rise in the mid 1990s whereas **Figure 9** shows increased Chinese investment in these technologies occurring before 2020.

The results of this SO2 evaluation show how local and global environmental issues, emissions of SO2 and CO2, respectively, can be linked. The AIM model can represent both the selection of more efficient technologies as well as investment in technologies that specifically reduce emissions. The integration of both of these processes enhances the ability of the model to evaluate policy options.

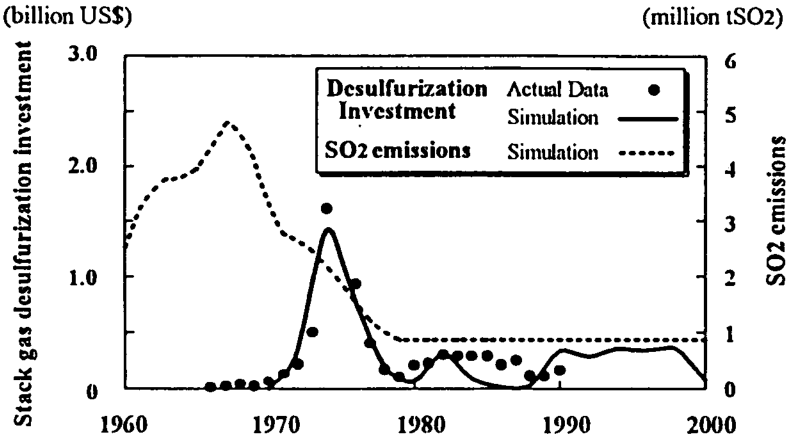

Figure 7　A desulfurization simulation for Japan

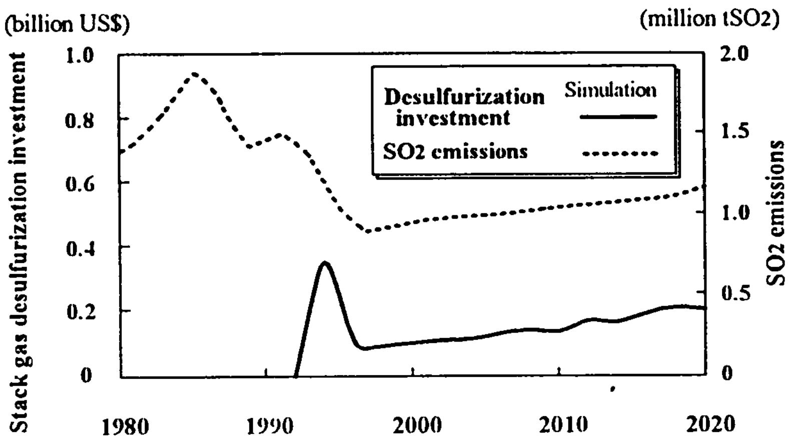

Figure 8　A desulfurization simulation for Korea

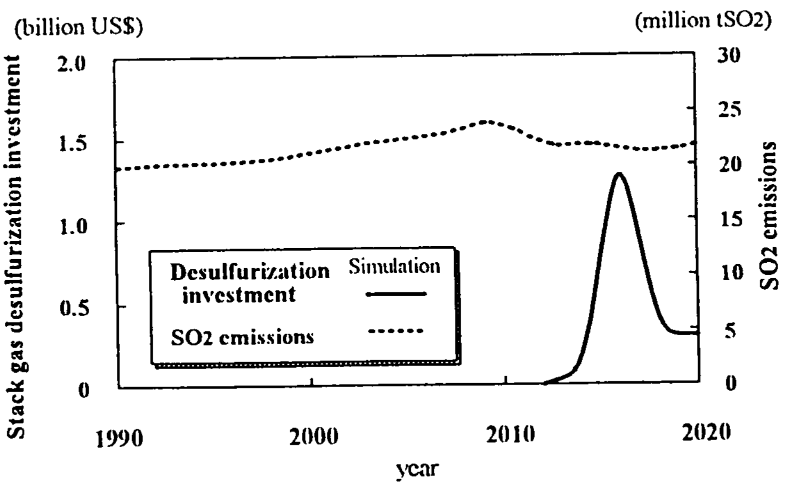

Figure 9　A desulfurization simulation for China

6. Regional and Global Model

(1) Regional and Global Emission Model

All of the country models for the region have not yet been completed, but we have developed a rough emission model, not only for 13 regions of the Asian-Pacific, but also for six regions of the Rest of the World. Using the rough model for these countries in conjunction with the detailed completed models, and making them consistent with the Rest of the World model, we prepared comprehensive estimates of regional and global GHG emissions for the year 2100.

Figure 10 shows global CO2 emission projections from fossil fuel combustion compared with the previous scenarios. Two AIM simulation results have been generated by assuming the upper and lower values for population and economic growth and technological innovation. Carbon dioxide emissions from fossil fuel combustion in 1990 are estimated to have been 5.94 billion tC (ton on a carbon basis). This flux is the largest force driving climate change and comprised 80% of total anthropogenic carbon emissions. With the exception of the RCWA study of 1989, the high and low AIM model scenarios for carbon emissions in 2050, 8.7 to 21.2 billion tC, largely includes the range of carbon emissions projected by the other published models. The AIM model projects carbon emissions of 11 to 40 billion tC in 2100. In general the high emission scenarios assume high economic growth, high rates of technological innovation and low carbon intensity. The low emission scenarios assume low rates of economic growth and technological innovation and high carbon intensity.

Other GHGs are also predicted to rise rapidly as a result of economic growth. The emissions of CO, NOx, N2O, CH4 and SO2 from fuel combustion and biomass burning, as well as CH4 and N2O from changes in agricultural activity have been estimated for several scenarios. These predictions provide an important basis to evaluate policies designed to reduce these emissions and their associated impacts.

(2) Deforestation Model

Carbon dioxide has been released into the atmosphere since humans began altering natural vegetation long ago, and until the beginning of the twentieth century, the main sources of carbon flux were in the middle latitudes of the northern hemisphere. However it is believed that almost all of the carbon flux released from land-use change since 1950 is from deforestation in the tropics. The amount of carbon stored in both soil and vegetation in the tropics is estimated at 200 billion tC each, which is equal to more than 50% of the amount in the atmosphere. Accordingly, predicting carbon behavior is a crucial task for forecasting climate change.

In one version of AIM deforestation model, we assumed the population change is a major factor of deforestation. Trends in the extent of tropical forests now and over the past one hundred years are considered to have a close relationship to population trends. This long term relationship can be observed clearly in the form of Asian tropical deforestation. Population forecasting is of great importance in this study, since it is taken as the major driving force of deforestation. We estimated population under three sets of assumptions: medium, medium-high and medium-low. According to our projection, the population of 2.1 billion in tropical regions in 1990 becomes 5.2 to 7.8 billion in 2050, and 6.5 to 11.76 billion 2100. In other words, the population is forecast to increase between 3 and 5.6 times by 2100.

Table 2 shows the estimate of forest area cleared annually and the carbon flux. With the medium scenario, our deforestation model forecasted that the annual carbon dioxide flux of 1.1 billion tC in 1980 caused by tropical deforestation will peak at 1.3billion tC in the

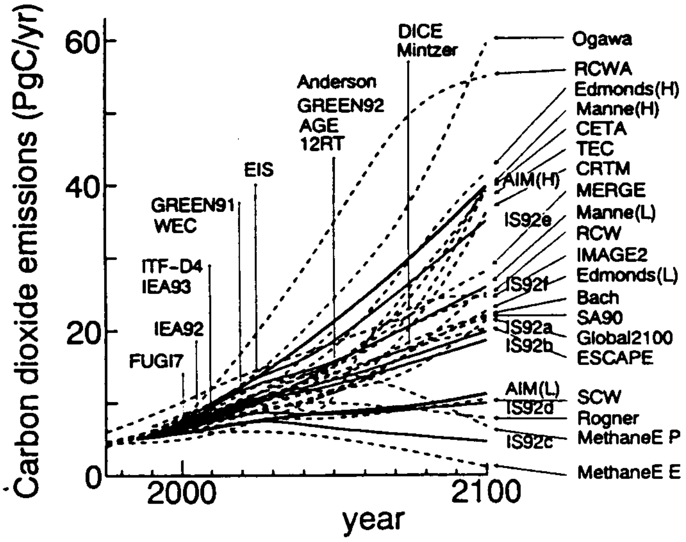

Figure 10 Scenarios of carbon dioxide emissions from fossil fuel burning

Table 2 Area of forest cleared annually (million ha) and carbon flux (PgC)

	Medium		Medium-high		Medium-low	
year	Area	CO_2	Area	CO_2	Area	CO_2
1980	12.3	1.1	12.3	1.1	12.3	1.1
1990	13.3	1.2	14.6	1.3	11.9	1.1
2000	13.6	1.3	16.4	1.5	10.8	1.0
2050	6.7	0.6	11.9	1.1	2.5	0.2
2100	1.5	0.1	4.7	0.4	1.3	0.1
Total area deforested and carbon flux 1980 -2100						
	988.3	91.6	1449.3	134.5	659.9	61.1
Percent of forest cleared 1980-2100						
	53.1		78.1		35.2	

Table 3 Global carbon balances among sources and sinks

scenario	anthropogenic emission	ocean uptake	terrestrial uptake	residual in atmosphere
1860-1989	336	119.8	55.0	161.2
1990-2100				
IS92a	1500	596.5	160.8	742.7
IS92b	1430	553.1	158.3	718.6
IS92c	770	141.6	135.4	493.0
IS92d	980	255.5	145.1	579.3
IS92e	2190	1012.4	179.6	998.0
IS92f	1830	802.9	170.4	856.7

beginning of the next century and then decline. Overall 91.6 billion tC is released during the 120 years from 1980 to 2100.

(3) Carbon Cycle Model

The main function of the carbon cycle model is to geographically evaluate the terrestrial CO2 absorption and storage in response to CO2 emissions. It is a global carbon cycle model with an emphasis on the terrestrial part, the oceanic uptake being simulated by an analytical approximation of the Maier-Reimer and Hasselmann OGCM. It operates on a 0.5x0.5 degree gridded earth, whose land cover is provided by Olson's World Major Ecosystem Complex map. CO2 enters the land grid-cells as Net Primary Productivity (NPP is the difference between gross photosynthesis and respiration), modified by the relative increase in plant growth due to elevated atmospheric carbon dioxide concentrations (CO2 fertilization). The Net Primary Productivity is then allocated to four plant tissues (leaves, stems, branches and roots), which eventually either humidify (litter and roots) or decay into the atmosphere by soil respiration. Humus itself either joins a more stable carbon pool or decays slowly into water and carbon dioxide released in the air. The carbon pool dynamics in each cell are modeled as 1st order kinetic reactions.

Coupling this terrestrial carbon cycle module with the oceanic sink and some standard anthropogenic CO2 emission scenarios, the carbon balances among sources and sinks were calculated. The carbon emissions by the land-use change in **Table 3** were 120 GtC during 1860-1989 and 80 GtC during 1990-2100. On the other hand, the amounts sunk to the terrestrial ecosystem are 55 GtC by 1989 and 135-180 GtC after that. The balances of terrestrial carbon by now is net release of 70 GtC from the ecosystem to atmosphere, and will be canceled out by the end of the next century. 1-2 GtC/y carbon absorbing ability by terrestrial ecosystem will remain at that time, which means the terrestrial plant become the net sink of global carbon from a long time point. The calculation shown here are the results which consider CO2 fertilization and temperature effect as major mechanism of terrestrial carbon sink. The effects of other mechanisms should be also assessed in order to comprehend the total view of future global carbon cycle.

(4) Climate 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 structures of the models are nearly the same, but the sub-modules are modified to depict each process. The basic structure is shown in **Figure 11**.

The model begins with GHG emissions pored into one/several boxes which represent the hemispherical and altitudinal characteristics of the atmosphere. Carbon dioxide is assumed not to decay, but is absorbed by the ocean and terrestrial ecosystems. Ocean absorption is estimated by a simple upwelling diffusion model, an advective-diffusion model or convolution approximations of OGCMs experiments. In our model, carbon dioxide fertilization effect and a temperature effect on net primary production are attributed to the missing sink of the carbon cycle. For the first effect, the β coefficient (the sensitivity of net primary production to CO2 concentration) is assumed in order to balance the global carbon balance. As for the 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. The relation between radiative forcing and GHG concentration is calculated with the equations summarized in the IPCC report(1992). The direct effects of 19 gases (CO2, CH4, N2O, CFC-11, CFC-12, CFC-113, CFC-114,

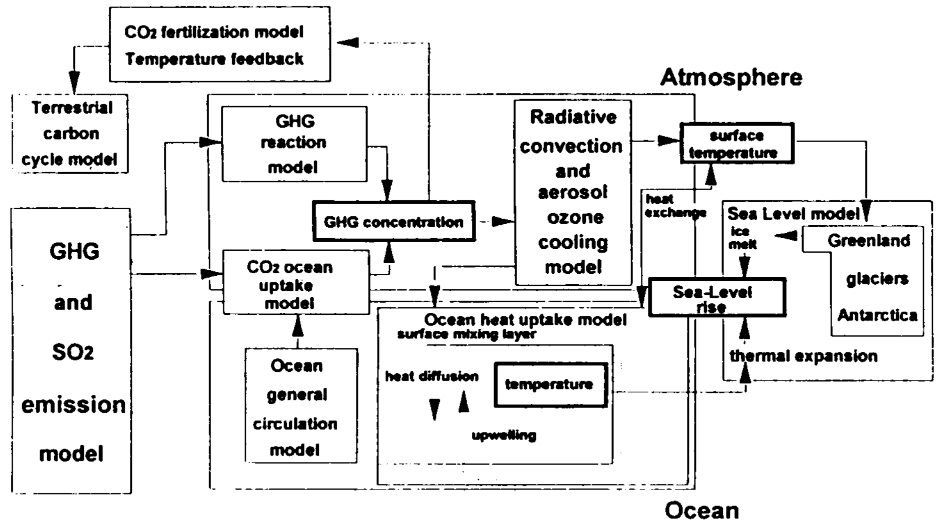

Figure 11　Outline of AIM climate model

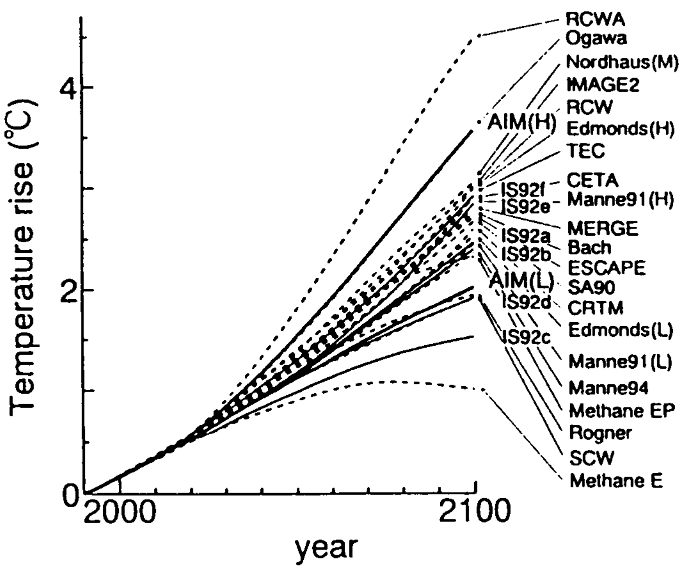

Figure 12　Estimated temperature rise under various scenarios ($\Delta T_{2\times CO_2}$ =2.5℃).

CFC-115, HCFC-22, HCFC123, HCFC-124, HFC-125, HFC-134a, HCFC-141b, HCFC-142b, HFC-152a, CCl4, CH3CCl3, H1301) are calculated. 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.

Figure 12 is the result when climate sensitivity λ is set at 1.748 $W/(m^2 K)$, which is equivalent to an equilibrium temperature increase when CO2 levels have doubled ($\Delta T_{2\times CO_2}$). The emission scenarios used are those reviewed by the AIM team (Morita *et al.*, 1994). The result is an increase from the 1990 value by somewhere between 0.9 to 1.8℃ in 2050 and by 1.0 to 4.5℃ in the year 2100.

7. Concluding Remarks

During these past three years, we developed the countrywide models for emissions in cooperation with research institutes in the Asia Pacific region, and improved regional and global models for emissions and climate changes. Then, we applied them to emission scenario analysis and policy evaluation. Using these models, we plan to assess various policy options including regional collaborative actions for the Asian-Pacific region in cooperation with institutes in each country and develop the project on a regional basis.

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