Asian-Pacific Integrated Model

AIM Project Team
March 1997

＜Contents＞

Preface

Policymakers always wish for a simple straightforward answer to a problem but researchers always respond with answers that are correct only within the limited scope of their study. In the case of a complex, large-scale and interdisciplinary problem like climate change, although the common recognition of the scientific findings and their implications for society is essential, such a discrepancy between the goals of key parties can hinder their mutual understanding of the problem and potential solutions. There has been an urgent need to develop a communication tool with which these group can share an immense body of knowledge in an integrated manner. The protection of our global commons of atmosphere and climate depends on such a shared understandings.

Integrated Assessment Models (IAMs) are that of one tool that connects the scientists' world with that of policy makers. They integrate sectoral and regional scientific findings into one package for decision making. When they are well designed, their findings can be used at all levels of decision making.

The uniqueness of AIM (Asia-Pacific Integrated Model) among IAMs lies in its focus on the Asia Pacific region and in its design to support decisions at the national level. The Asia-Pacific region, with its expanding population and rapid economic growth, appears to be the locomotive of the world economy in the next century and its behavior will affect the global environment immensely. An operational decision supports tool such as AIM will make valuable contributions through the evaluation of concrete policy proposals for each country in the region. As AIM has a technology selection module that undertakes an economic evaluation of more than 300 existing and future technologies, it can provide realistic policy options to national decision makers. Its usefulness was validated by the delivery of evaluations of policy options to the government of Japan during the process of FCCC negotiations.

Another unique feature of AIM is its procedure of constructing national models under close multi-national collaboration. Eminent research institutions in the region, from China, India, Indonesia and Korea, are developing their own specific models, based on a template model of Japan. Each national model is modified to incorporate the distinct features of each country.

I sincerely appreciate the efforts of our Japanese and Asian colleagues who carried out this challenging and exciting work in complete collaboration, especially the excellent leadership of Dr. Tsuneyuki Morita of NIES for his superb project coordination and Professor Yuzuru Matsuoka of Nagoya University for his superior model building capabilities.

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1. Introduction

1.1 Introduction

It is predicted that global climate change will have significant impacts on the society and economy of the Asian-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 the end of the next century.

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 is one of the most effective tools to increase the interaction among these groups. Integrated assessment provides a convenient framework for combining knowledge from a wide range of disciplines. The Asian-Pacific Integrated Model (AIM) is a large scale computer simulation model developed to promote the integrated assessment process in the region.

The main goal of this model is to assess policy options for stabilizing global climate, particularly in the Asian-Pacific region, from the two perspectives of reducing greenhouse gas emissions and avoiding the impacts of climate change.

The AIM model has several distinct characteristics. It:

1. integrates emission, climate and impact models.
2. prepares both country modules for detailed evaluation at the state and national level and global modules to ensure consistency across individual modules
3. integrates bottom-up national modules with top-down global modules
4. is designed to assess alternative policies
5. contains a very detailed technology selection module to evaluate the effect of introducing advanced technologies
6. uses information from a detailed Geographic Information System to evaluate and represent the distribution of impacts at the local level.
7. focuses on the Asian-Pacific region and is based on a collaborative network of international research institutes.

Although this model is being developed primarily to help respond to climate change problems, it can also be applied to other issues, such as local air pollution issues, acid rain problems, forest management policies and other energy, agricultural and water resource management problems.

The research project to develop AIM was started in 1991 by the National Institute for Environmental Studies in collaboration with Professor Matsuoka, currently Kyoto University. The major modules of the AIM model were completed in three years. In 1994, the project was expanded with an international collaborative program to jointly develop national models with leading research institutes in several Asian countries. These national models are then integrated with the regional and global models. This collaboration program will be extended for a further three years from 1997 and expanded to provide more detailed evaluations of a broader range of impacts and policy options.

The research program has already made major contributions at the national, regional and global level of policy deliberations. The AIM model was used to provide global and regional emission scenarios to the IPCC. The impact assessments generated by AIM were used by the IPCC impact working group for their regional evaluations. AIM team members also served as lead authors for IPCC reports. The AIM model was also used at the Stanford Energy Modeling Forum for the international comparison of emission scenarios and impact assessments. At the regional level, AIM has been adopted as an in-house model for the evaluation of alternative policies by Eco Asia, the Congress of Asian Ministers for the Environment. National governments have adopted AIM for the evaluation of policies such as carbon taxes, technology subsidies and changes in consumption behavior. Other uses have included contributions to the Global Environmental Outlook Program of UNEP, the UN Global Modeling Forum and the Asian-Pacific Network Program.

This report provides a brief overview of the results from each major group of modules within AIM. The three major models represent emission processes, climate change processes and the resulting impacts. The emission model contains several national modules and predicts the emission of several gases. The climate change model integrates many carbon cycle attributes and climatic phenomena. The impact model then examines several important impacts that result from interactions with the emission and climate change models.

This program of research has been funded by the Global Environmental Research Fund of the Environment Agency of Japan. This funding is greatly appreciated and has served to create an exciting international network of researchers and policymakers striving to improve the future well-being of people throughout the Asian-Pacific Region.

We appreciate the exchange and sharing of ideas with the international modeling community. We also appreciate Professor Paul Parker for his editorial assistance.

1.2 Structure of the AIM Model

The Asian-Pacific Integrated Model (AIM) is a large-scale model for scenario analyses of greenhouse gas (GHG) emissions and the impacts of global warming in the Asian-Pacific region. This model is being developed mainly to examine global warming response measures in the Asian-Pacific region, but it is linked to a world model so that it is possible to make global estimates.

The AIM comprises three main models - the GHG emission model (AIM/emission), the global climate change model (AIM/climate) and the climate change impact model (AIM/impact). Figure I-2-2 shows the relationships among the main models.

The AIM/emission model consists of Asian Pacific country models integrated into a regional model. This in turn is linked to a Rest of the World (ROW) model, which ensures interactions between these regional models are consistent. A variety of global and regional assumptions about such factors as population, economic trends, as well as government policies, are entered into the model and interact with the regional and country models to provide estimates of energy consumption, land-use changes etc., which ultimately provide predictions of GHG emissions.

The major component of the country model is an end-use energy demand model. Energy demand is calculated by multiplying the energy service (calculated by the energy service submodule) by an energy efficiency factor. This factor is calculated by the energy efficiency submodule, and is the product of assumptions made about the introduction of new technologies for energy conservation as influenced by energy prices. The technology selection submodule determines which technologies will be introduced. More than 100 technologies are evaluated for their potential to improve energy efficiency. Energy demand estimates are linked to a top-down economic model.

The AIM/emission model has several other important components. It includes a land use change model to take into account the effects of deforestation on CO2 levels. Similarly, changes in arable land use are linked to changes in CH4 emissions. Other GHGs such as the CFCs and halons are also taken into account. The model has also been used to predict SO2 emissions under a variety of scenarios.

Except for CO2, greenhouse gases emitted into the atmosphere are gradually transformed by chemical reactions which are reproduced by part of AIM/climate model. We divided these chemicals into two groups based on their reaction rates: long-life chemicals, such as CFCs and halons, and short-life chemicals such as ozone and OH radicals. Pseudo-equilibrium states are assumed for the latter group and the oxidation and photochemical reactions of CH4 and other molecules are represented by simple kinetic equations. The model depicts the atmosphere in two layers as well as being divided between the northern and southern hemispheres. Mean global values for temperature changes are calculated and used for input into the regional models.

The absorption of CO2 and heat by the oceans is calculated using a box diffusion model (part of AIM climate model) with the oceans divided into a surface mixed layer (110m in depth) and an intermediate layer which extends down to about the 1000 meters.

The AIM/climate model provides output for a variety of scenarios used in GCM experiments. Data from the GCM experiments are used as the basic input values for scenarios evaluated in the AIM/impact model, and provide estimates for regional climatic impact assessment. The AIM/impact model then calculates the impact on primary production industries (water supply, agriculture, forest products, etc.) and human health. It can also be used to make predictions of higher-order impacts on the regional economy. Figure I-2-3 shows the relationships among the submodules of the AIM/impact model.

Important economic and environmental data for the region have been gathered and filed in a spatial data-base. Simulation models to estimate water resource changes, vegetation changes and malaria spread caused by global warming have been developed with this data-base.

To function properly, our models require a high-quality spatial data-base. As such, we are developing the Asian-Pacific environmental, social and economic Geographical Information System (GIS). The data-base for this GIS is built primarily at the county or province level. The study area comprises about 3200 regions shown in Figure I-2-1. Social and economic information from many international organizations, as well as individual governments, is integrated with our originally constructed data-base. It is coupled with grided/vectorized ancillary data, such as terrain, ecoregion, or land-cover data and is organized in a format useful to support the AIM study.

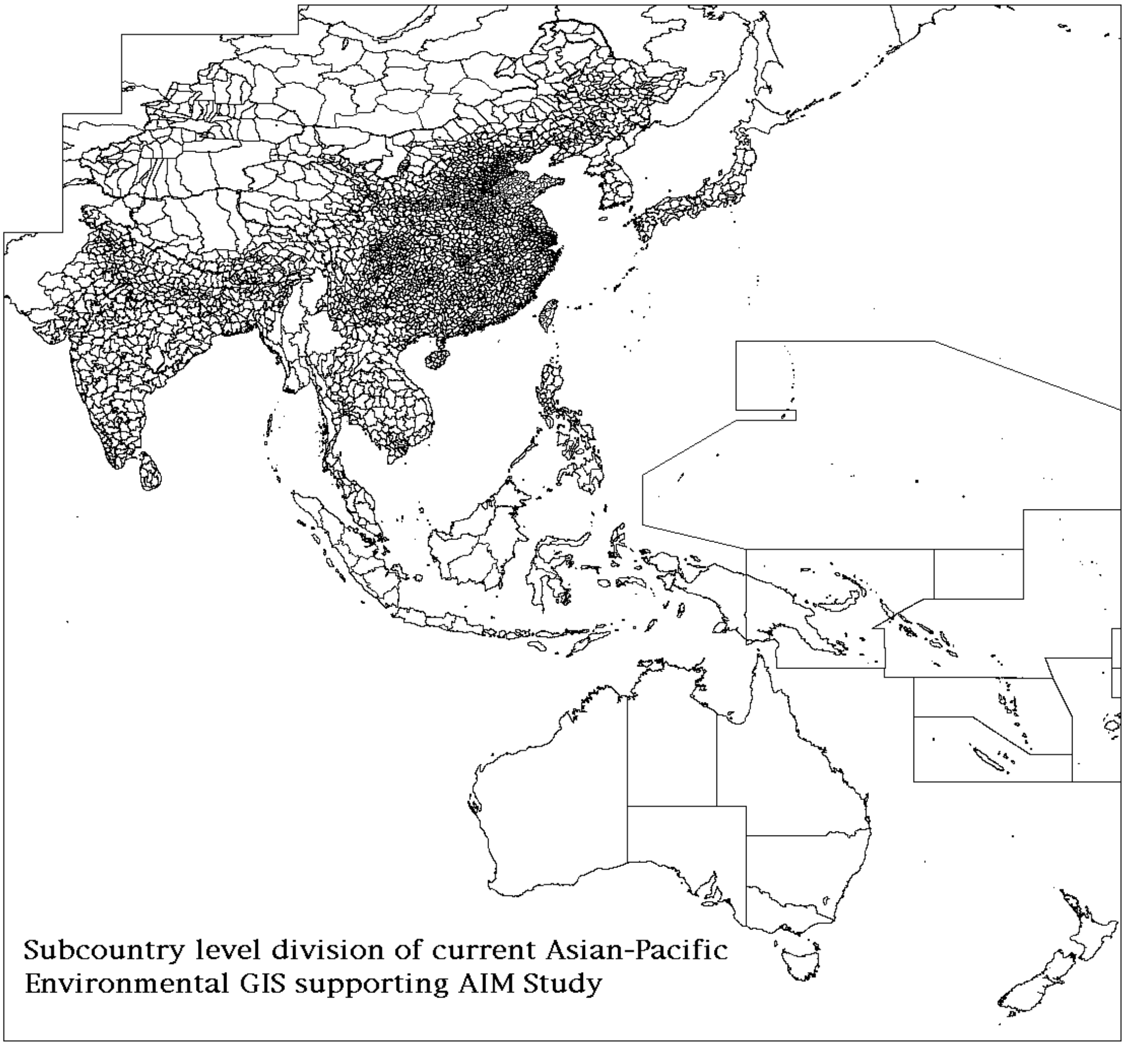

Figure I-2-1 Subcounty level division of an Asian-Pacific GIS supporting AIM study.

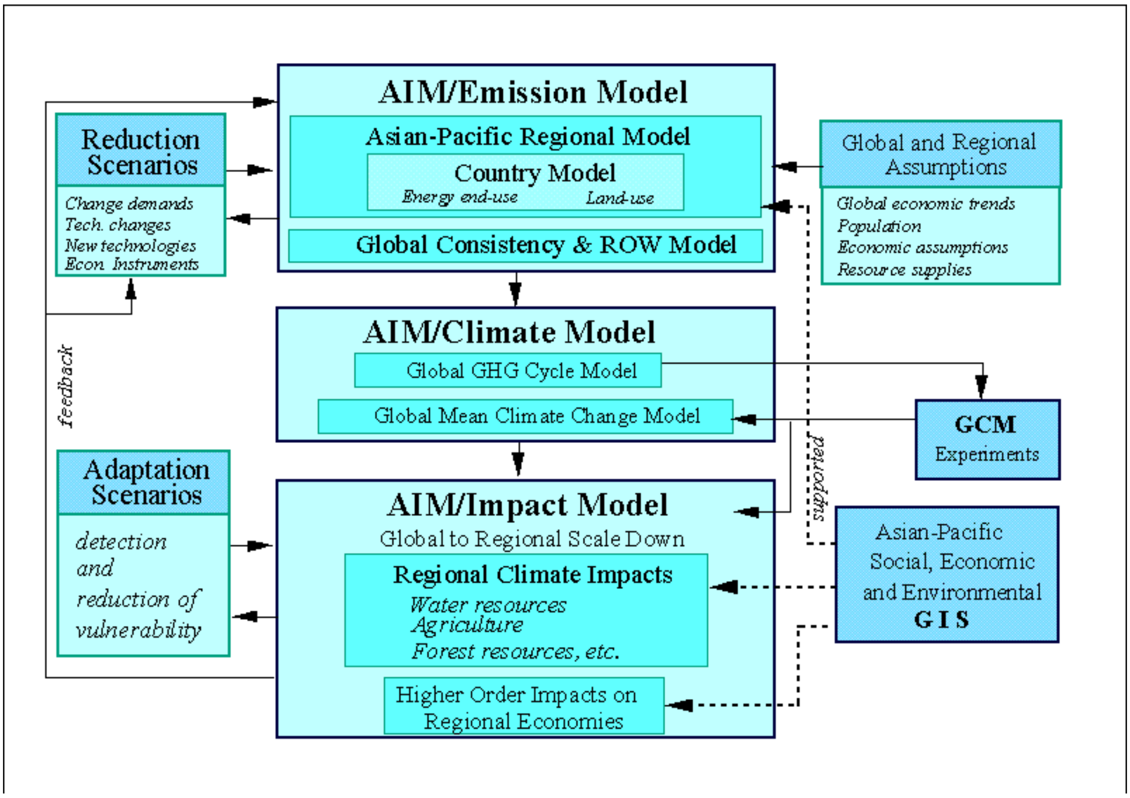

Figure I-2-2 Outline of the AIM model.

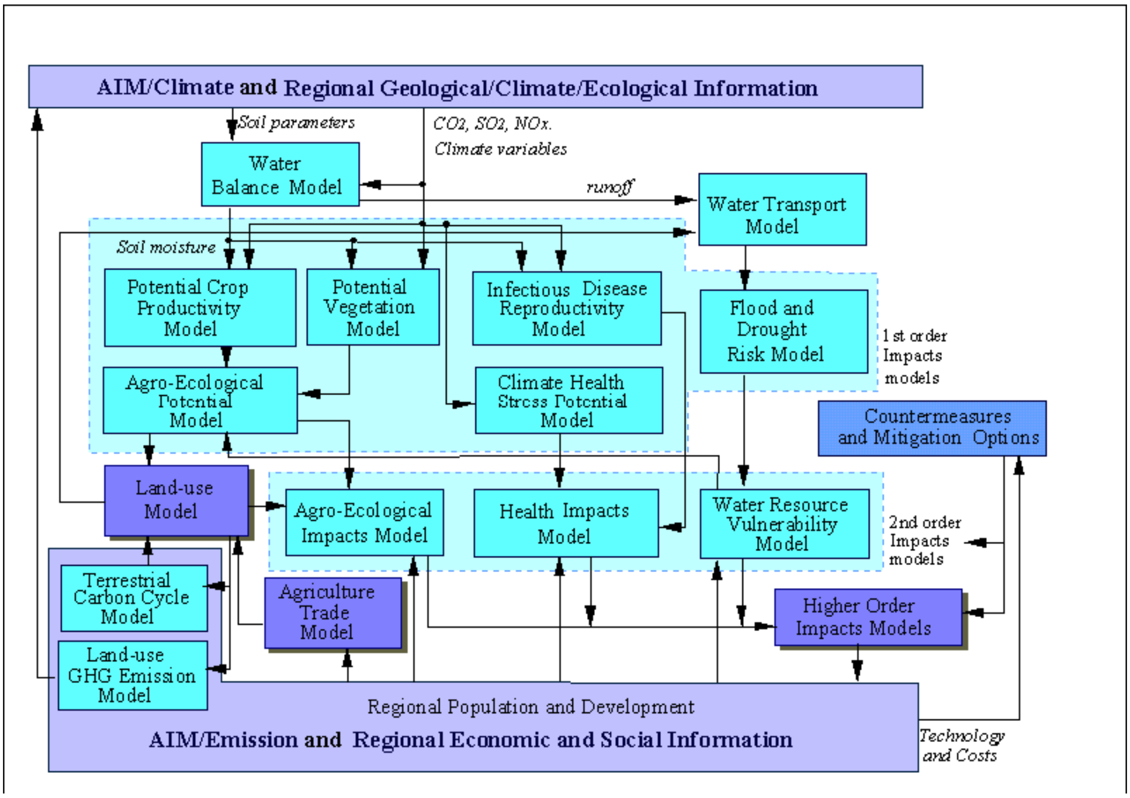

Figure I-2-3 Outline of the AIM/Impact model.

1.3 Policy needs of Integration

The integrated assessment of global warming issues has been required on many occasions in the Asian-Pacific region. Some needs are quite clear, while others are not so obvious. However, these needs can increase quickly. Four major needs were identified and AIM has been designed with a unique structure so that it can be used to meet these needs:

(1) To identify incentives for policy measures.

Many of the countries in the region need concrete examples of global warming damage, secondary short-term benefits and the small economic impacts of policies in order to increase the incentives for policy adoption. To meet this need requires integration of emission and impact models, global warming and local environmental models, and emission and economic models.

- To compare costs and benefits of introducing global warming abatement policies.
  Emission models + Impact models
- To determine secondary effects of global warming abatement policies on regional and/or local environments.
  Global warming models + Acid rain model
  + Local pollution models
  + Natural resource models
- To show the small impact of global abatement policies on national economies.
  Emission models+ Economic model

(2) Systematic assessment of policy options.

Systematic and consistent assessment of policy options is essential if policy makers are to be able to make sound decisions. Assessments need to be made of the technical feasibility for GHG reductions, the combined effects of various policies, the consistency of policy combinations and approaches to GHG reductions. To meet these needs requires integration of technology and economic models, top-down and bottom-up models, energy and lan -use models and CO2 emission and other GHG emission models.

- To asses technological feasibility for GHG reduction considering costs and markets.
  Technology model + Economic model
- To assess combined effects of various policies such as carbon tax with reinvestments of tax revenue.
  Top-down model +Bottom-up model
- To assess consistency of policy combinations, such as increasing biomes use and land availability,
  Energy model+ Land -use model
- To assess comprehensive approaches for GHG reduction including reforestation and methane emission reduction.
  Energy model +Land-use model
  CO2 emission model +Other GHG emission model

(3) Introduce international collaboration.

Many countries in the region desire assistance through international collaboration that can estimate the effects of Joint Implementation programs, design regional integrated policies for global climate stabilization and to assess the effectiveness of inter-regional collaboration. Here, AIM integrates many country models, country and regional models and the Asian-Pacific regional model and the Global model.

- To estimate the effects of joint implementation programs in the Asian-Pacific region.
  Country model +Country model
- To design regional integrated policies for global climate stabilization.
  Country models +Asian-Pacific region model
- To assess collaborative policies between the Asian-Pacific region and other regions.
  Asian-Pacific region model +Global model

(4) Long-term policy option assessment.

This is needed to ensure that short and long-term policies are compatible, and to assess the various feedback loops and interactions among land-use changes and the social and economic impacts of climate change on GHG emissions. To allow these needs to be met, the AIM project is still working on integration of emission and impact models, and land use and carbon cycle models.

- To compare short-term mitigation policies with long-term adaptation policies.
  Emission models +Impact models
- To assess the feedback from land cover changes caused by climate change on GHG concentrations.
  Land cover model + Carbon cycle model
- To assess the feedback from economic and social impacts caused by climate change on GHG emissions.
  Impact models +Emission model

2. Emission Models

2.1 GHG Emission Projections

A variety of global and regional assumptions about population, economic trends, as well as government policies are entered into the AIM model for scenario evaluation. These assumptions interact with the regional and country models to provide estimates of energy consumption, land-use changes, etc. which ultimately give predictions of greenhouse gas emissions.

Figure E-1-1 presents world population estimates that have been calculated and used in the scenarios. If the 1990 world population of about 5.3 billion is taken as the reference point, estimates for 2100 range from 3.6 billion to 109.4 billion. The low estimate assumes an increasing death rate caused by environmental pollution. The highest estimate assumes that the total fertility rate in the early 21st century would remain as it is now.

The economic activity scenarios used in GHG emission models project increases in economic activity by the end of the next century by a factor of three to 25 times (Figure E-1-2), equivalent to annual growth rates of 1.1% to 3.0%. As most of the scenarios assume a population growth rate of 0.7%, the gross GDP per capita growth rate in these projections is in the range 0.4% to 2.3%. The past GDP and per capita GDP growth rates from 1960 to 1990 were 4.0% and 2.1%, respectively. Most of these scenarios assume gradual decreases in economic growth rates.

However the global average does not reflect the vastly different economic contributions of various regions, differences which will grow even larger in the years ahead. For example, the IPCC reference scenario which was established from UN data in 1992 suggested that the Asian economies would grow much faster than those in other regions, with the Asian-Pacific share of global GNP increasing from the current 20% to 30% by 2025. The World Bank also predicts a much more important role in global economic growth for the developing economies of East and South Asia. Over the next ten years, the East and South Asian economies are projected to grow at 7.7% and 5.4% annual rates, respectively, in contrast to the global projection of 2.8%

Other important factors affecting global environmental change include technological innovation and patterns of energy use. Two particularly important technological areas relevant to global change analysis are those for energy and agriculture. The impact of energy technology innovation can be quantitatively estimated by changes in energy intensity, an index of energy efficiency, which is defined as energy consumption divided by GDP. All of the energy intensity indices projected by the various greenhouse gas emission models (Figure E-1-3) are based on the assumption that energy efficiency will be improved by 40% to 80% over the course of the next century through technological innovation. This improvement is equivalent to an annual increase in efficiency of 0.5% to 1.5%. This range includes the observed world average efficiency increase of 0.7% for the period from 1960 to 1990.

In addition to energy use efficiency, changes in the pattern of energy use have a very significant global impact on the environment. The pattern of energy use with respect to carbon emissions is indicated by carbon intensity which is defined as carbon emissions divided by energy consumption. The range of carbon intensities projected for 2100 (Figure E-1-4; normalized to 1990 levels) is much wider than that projected for energy intensity (Figure E-1-5). Some models estimate a constant carbon intensity because of projected increases in coal use. Other models project rapidly decreasing energy intensity due to the rapid adoption of nuclear and biomass energy technologies. The model projecting the lowest carbon intensity predicts a value at the end of the next century of only 10% of the current level. This wide range of projections leaves us with a great deal of uncertainty about future carbon intensities. Assuming the socioeconomic scenarios described above, the AIM model has been used to project future climate change, acid precipitation, deforestation and other environmental changes.

First of all, the AIM simulations of future carbon dioxide emissions from fossil fuel combustion are compared with other emission scenarios (Figure E-1-5). 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.

A countrywide comparison of carbon dioxide emissions (Figure E-1-6) reveals that China will become the top emitter before 2025. India will become the fourth largest emitter, exceeding the emissions of Japan. As a result, the Asian Pacific share of global carbon dioxide emissions, currently 25%, will reach 36% by 2025 and 50% by the end of the next century.

Figure E-1-7 shows CO_2 emission intensities in the Asian-Pacific region at 1985, 2025 and 2100, respectively. When these three figures are compared, the areas where major increases in CO_2 emission will occur can be easily identified. They include Korea, China, Thailand, Malaysia, India, and Bangladesh.

Other GHGs are also predicted to rise rapidly as a result of economic growth. The emissions of CO, NO_x, N_2O, CH_4 and SO_2 from fuel combustion and biomass burning, as well as CH_4 and N_2O 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.

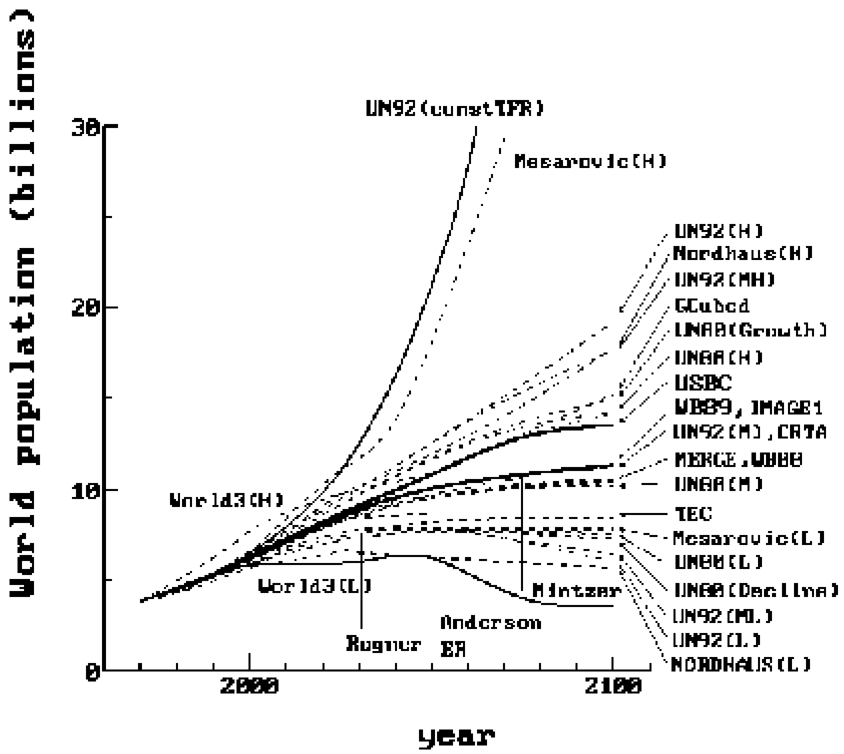

Figure E-1-1 Future world population assumptions.

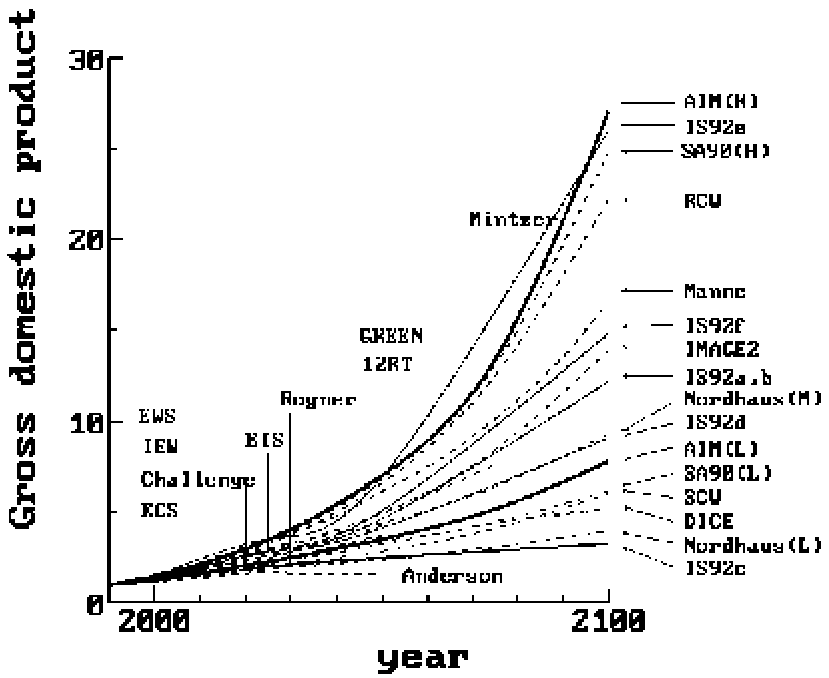

Figure E-1-2 Economic growth scenarios assumed by the GHG emission models.

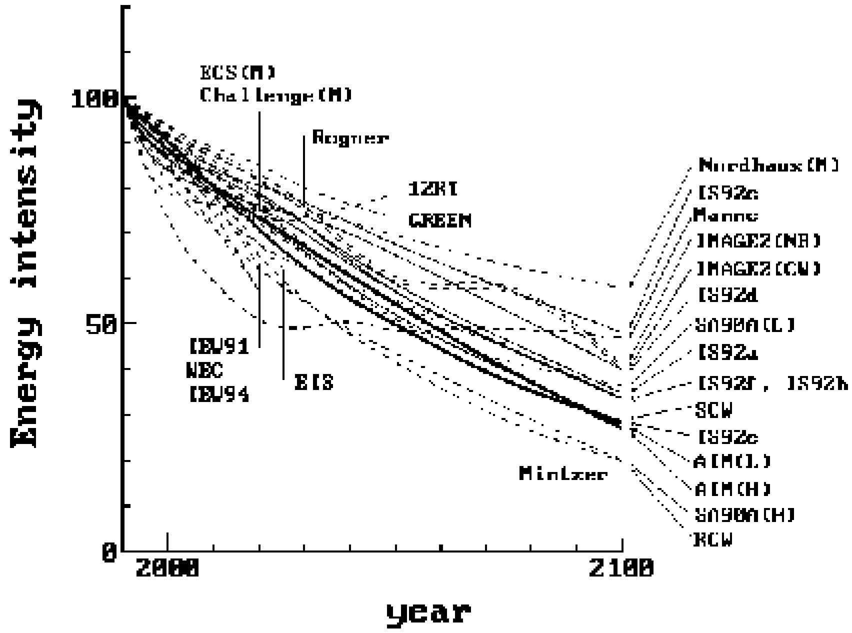

Figure E-1-3 Scenarios of energy intensity changes.

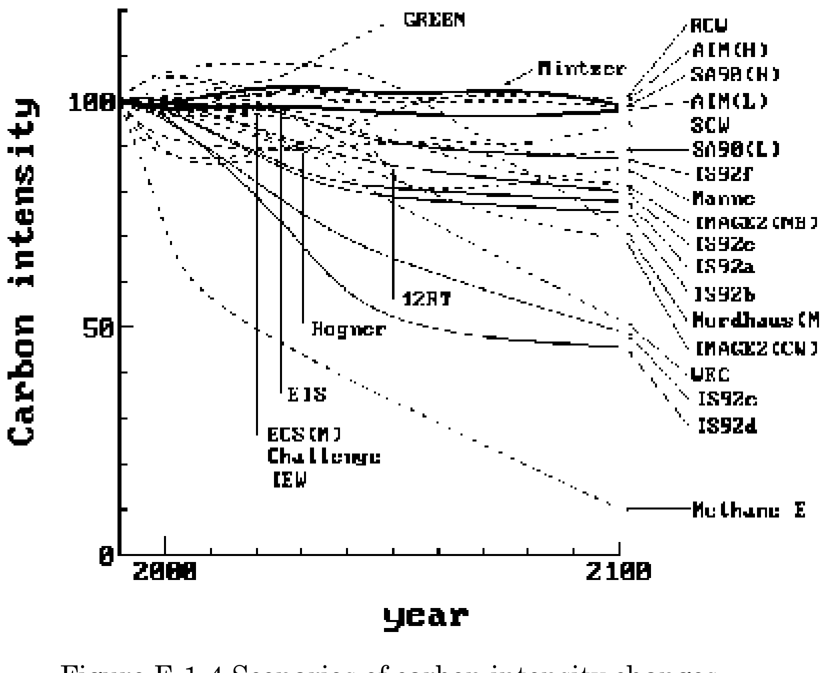

Figure E-1-4 Scenarios of carbon intensity changes.

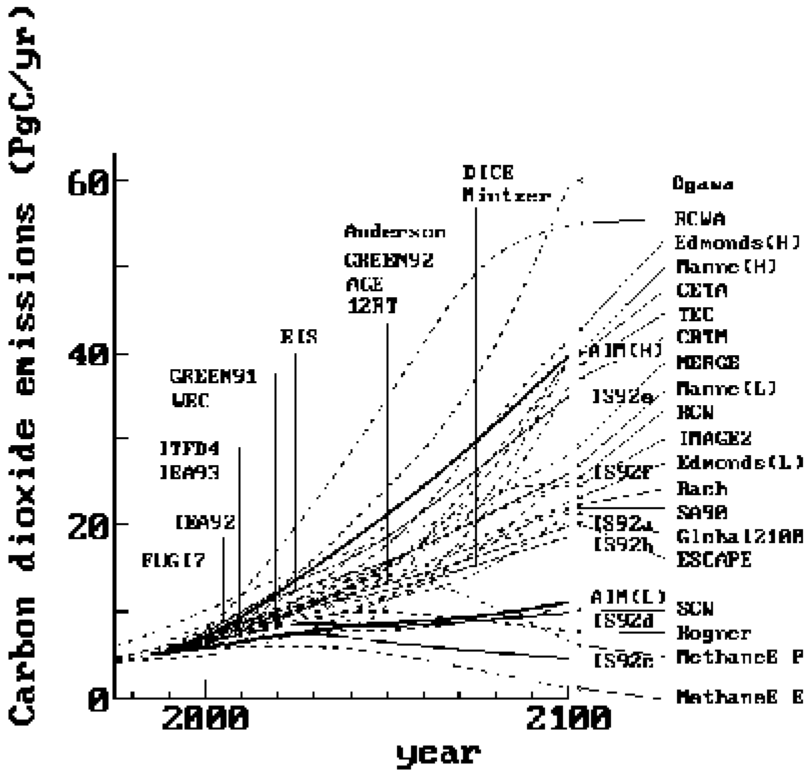

Figure E-1-5 Scenarios of carbon dioxide emissions from fossil fuel burning.

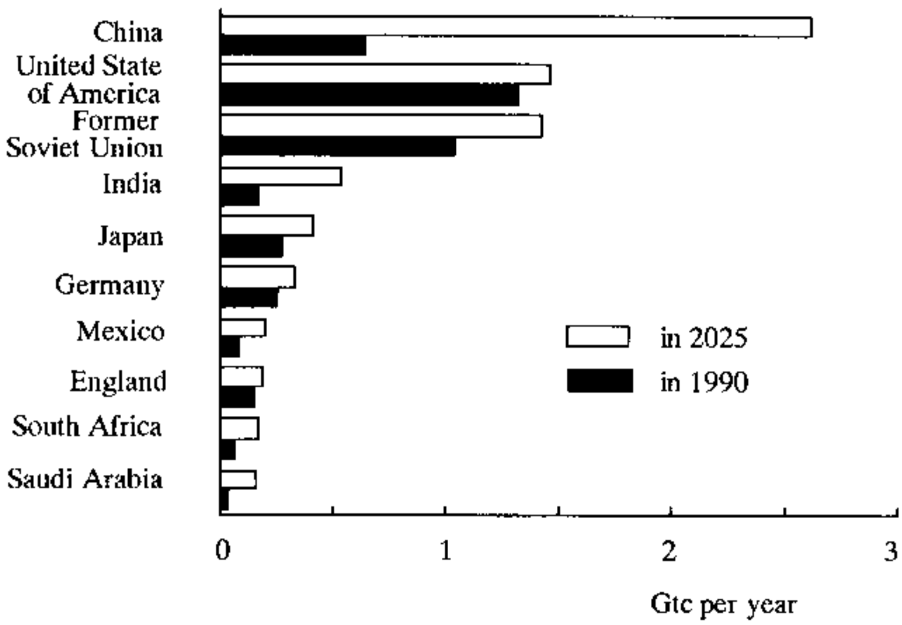

Figure E-1-6 Top ten emitters of carbon dioxide of fossil fuel origin in 2025.

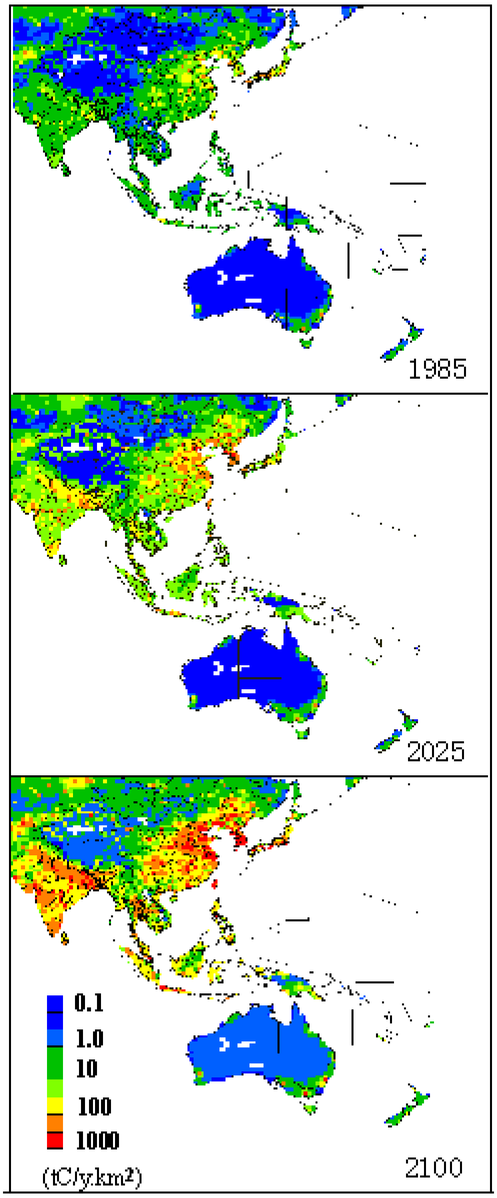

Figure E-1-7 CO2 emission intensity in 1985, 2025 and 2100.

2.2 End-use Energy Demand Model

A number of energy consumption-based GHG emission models have been developed and they can be classified into 2 types; "gtop-down models" and "gbottom-up models". Top-down models start with an economic model and represent the relationships between energy consumption and national products by using prices 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". Figure E-2-2 shows the relation between the top-down model and bottom-up models in the AIM/emission model. The top-down world model 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 E-2-3. 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 'ethe 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.

An example of the technology selection module is shown in Figure E-2-1. This figure shows the structure of the Japanese iron and steel industry model. This model considers three types of steel-making processes; the blast furnace process, the electric arc furnace process and the smelting reduction process.

The system comprises three elements; energy resources (or materials), energy services, and service devices. A service device performs an energy service by consuming energy. The problem is to select energy devices (or technologies) for supplying energy service demand under several constraints. Then energy consumption is calculated based on the selected energy technologies.

The most important judgment made in the end-use model is that of selecting technologies. There are several available technologies to produce the same service. The criteria used for technology selection depend on whether the technology has reached its scheduled replacement time or not. If a current device has reached its scheduled replacement time, a decision must be made on what kind of technology should be introduced: a conventional technology or a more expensive energy-saving technology. Technologies are selected based on purchase prices and fuel costs. If a current technology is to be replaced before the scheduled replacement time, it is replaced and/or upgraded only when the total cost of replacement and/or improvement is less than the fuel cost saved by a new technology. Another case to select technologies occurs when service demands increase. New technologies must be introduced to meet the service demands increased. Which technologies-conventional or energy-saving should be introduced is decided based on total costs.

The AIM/end-use model can calculate the changes in energy consumption from technological substitution caused by changes in energy prices, using its bottom-up structure. Thus, it is possible to evaluate not only the efficiency of each individual policy, but also the effect when various policies are combined. By linking the technology selection module with the energy demand module, it is possible to estimate energy efficiency improvements based on the actual situation for each technology. Also, because this model can be linked to the AIM world model, analyses of the effects of international factors and analyses that consider the impacts of the effects of international cooperation will be possible in the future.

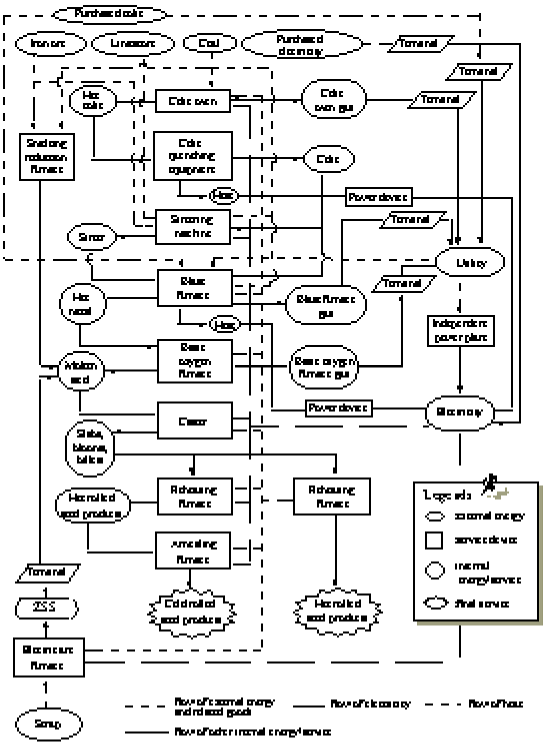

Figure E-2-1 Energy end-use model in the Japanese steel industry.

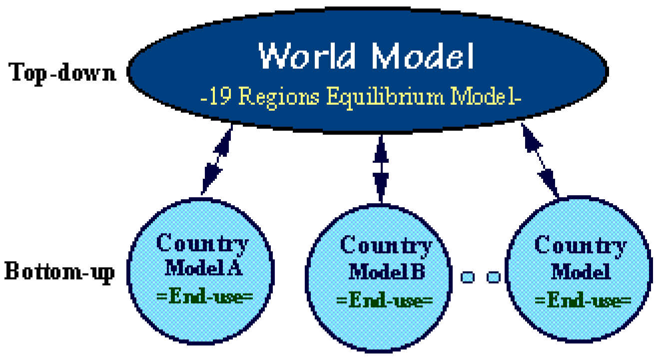

Figure E-2-2 Structure of AIM/emission model.

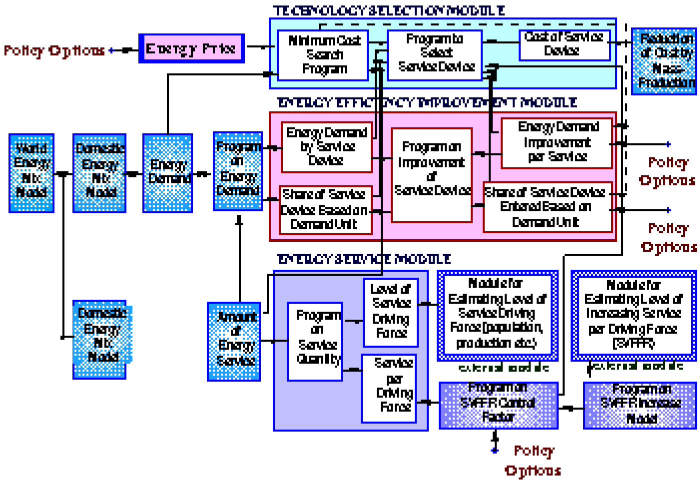

Figure E-2-3 Structure of AIM end-use model.

2.3 CO2 Emission Model in Japan

Carbon dioxide emissions in Japan have been analyzed, using the Japanese-module of the AIM end-use model. The module originally was used to examine the effects of various policies to reduce CO2 emissions to the year 2010. Table E-3-1 presents the sectors and sub-sectors represented in the model. In each sub-sector, 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. Figure E-3-1 shows the Japanese CO2 emission projections simulated by the model. In the business as usual case, the increase in emissions is only gradual, as a result of the introduction of improved technologies, even in the absence of a carbon tax. However, the CO2 emissions over the next decade are difficult to stabilize without the introduction of policies.

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 emissions.

The materialistic scenario without intervention predicts a 17% rise in CO2 emissions by 2030, whereas, the creative scenario with intervention predicts a 15% 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, which are listed in Table E-3-2. The direct cost of these policies was estimated to be approximated 1 trillion yen per annum around the turn of the century. This represents substan-tial new markets for advanced technologies and related employ-ment opportunities. These results suggested that changes in the nation's dominant life style could be very beneficial in terms of decreasing carbon dioxideemissions.

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.

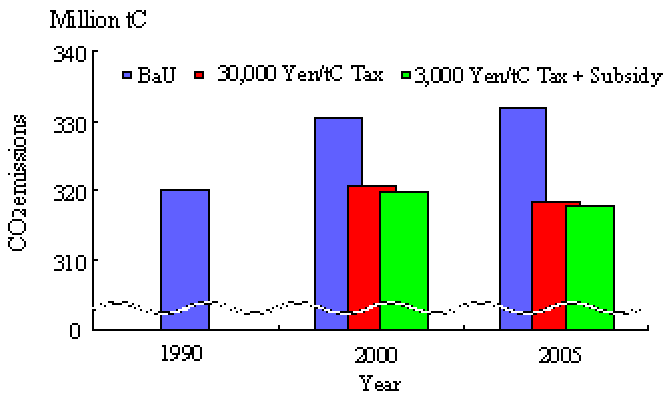

Figure E-3-1 Japan's stabilization scenarios of CO2 emissions.

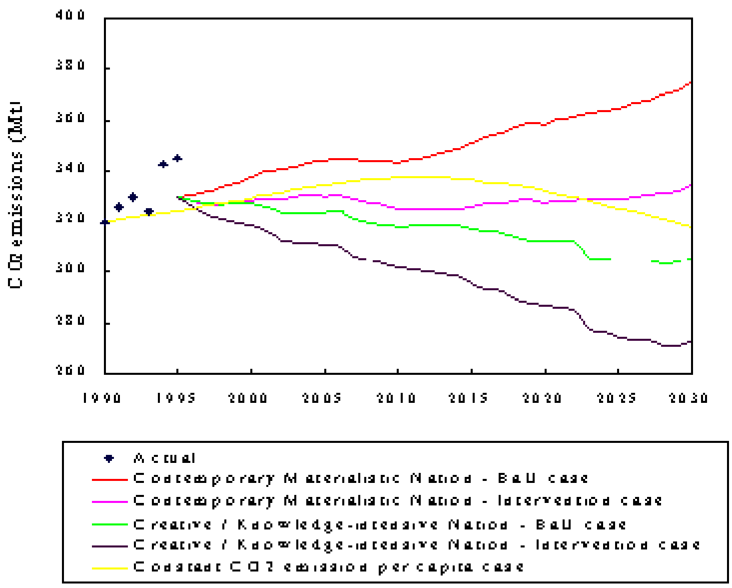

Figure E-3-2 Forecasts of Japanese CO2 emissions during 1990-2030.

Table E-3-1 Sectors and fields incorporated in the AIM/Japan model

Sectors	Fields
Industrial sector	Iron and Steel Cement Petrochemical Paper and Pulp Other Industries
Residential sector	Air Conditioner Hot Water Lighting Cooking Electric Appliance
Commercial sector	Air Conditioner Hot Water Lighting Cooking Electric Appliance
Transportation Sector	Passenger Transport Freight Transport
Power Plant	Thermal Plant Hydro Plant Nuclear Plant New Energy

Table E-3-2 Intervention scenarios for CO_2 reduction.

Electric Utilities -Coal electric power plant : Pressurized fluidized bed combined cycles (thermal efficiency = 42%) are all introduced. -LNG electric power plant : Advanced combined cycles (thermal efficiency = 50%) are introduced. -Alternative : Fuel cell, Waste power generation, Biomass generation, are all introduced. -Nuclear power plant : Change of output standard, Shortening the duration of regular inspection, Extending the period of continuous operation. Industrial sector -Energy conservation technologies without economic efficiency are introduced by political measures. steel industry : Coke wet adjustment equipment cement industry : High efficiency clinker cooler, Power plant by waste heat etc. petrochemical industry : High performance Polypropylene manufacturing device paper & pulp sector : Pre-filtration continuous cooking device, Defuser bleaching device, High performance pulp washing device, High performance vapor drum etc. -Steel industry : Extension of electric furnace -Cement industry : Extension of blast furnace cement and fry ash cement -Paper & pulp industry : Extension of waste paper Residential sector -Energy conservation technologies without economic efficiency are introduced by political measures. high adiabatic and airtight house (67% by the year 2030) Photovoltanic power generation (50% by the year 2030) Latent heat recovery type water heater (100% the year 2030) -Reduction of leakage of electricity from electric household appliances Commercial sector -Energy conservation technologies without economic efficiency are introduced by political measures. Photovoltanic power generation (50% by the year 2030) Adiabatic material (100% by the year 2030) Lighting equipment with sensor (100% by the year 2030) Latent heat recovery type water heater (100% by the year 2030) Transport sector -Energy conservation technologies without economic efficiency are introduced by political measures. Electric vehicle (30% by the year 2030) Hybrid powered bus (30% by the year 2030) -Modal shift

2.4 CO2 Emission Model in China

China is one of the world's largest countries of energy consumption and production. Continued rapid economic development will increase GHGs emission. Current CO2 emissions in China account for 9% of the world total and this share is expected to rise. As a result, the identification, evaluation and adoption of suitable policies to reduce GHG emissions in China is an important research topic to support policy making in China. From 1994, with the collaborative research with NIES of Japan, the Energy Research Institute of China decided the AIM/emission for China project was initiated as a component of "the Asia-Pacific Integrated Model for Evaluating Policy Options to Reduce Greenhouse Gas Emissions and Global Warming Impacts(AIM)". The preliminary results of the energy consumption forecast and CO2 emission analysis based on several policy options are presented below (China AIM Project Team, 1996; AIM Project Team, 1996).

The AIM/emission for China project analyzed the future trend of energy consumption in China. 1990 was taken as the base year and projections were then calculated for the year 2000 and 2010. Table E-4-1 lists the sectors, subsectors and products used in the model. These sectors and subsectors cover the energy intensive portion of the economy. More than 300 major technologies were included in the evaluation.

The policy options included for the evaluation were: 1)Carbon tax; 2) Carbon tax and extension of pay back period. The Carbon tax is introduced in the year 2000 in this analysis. Two reference cases were induced: 1) Without technological progress, assumes that future technology remains at 1990 level. These cases used for comparative analysis; 2) Technology progress case, assume that technology improves and can be regarded as a no intervention case.

Table E-4-2 gives the major input variables for the simulation. It reflects the major economic development indicators in China. Figure E-4-1 and Figure E-4-2 present the results from this analysis. The results demonstrate that: 1) Rapid economic development will increase energy consumption and CO2 emissions. All four cases show this trend; 2)Technology progress will play an important role to reduce CO2 emissions in China; 3) The carbon tax and Pay back period extension policies are effective way to reduce CO2 emissions.

Industry will keep its position as the biggest energy consumption sector because of the first stage of industrialized economic development pattern in China with its emphasis on heavy industry. Energy intensive production will continually take large part of total industry output. However energy use efficiency in Industry will increase faster than in other sectors. 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.

The project is ongoing and the analysis is being improved with more information being collected and the analysis refined. Considering the future demand for energy and the expected environmental condition, the following targets were set for future model development: 1) Cost analysis for GHG emission abatement in China; 2) SO2 emission forecast and evaluation of policy options; 3) Collect and include data for more technologies for the simulation; 4) Add more policy options to widen the scope of analysis; 5) If possible, simulation will be conducted for 2030, and 2050.

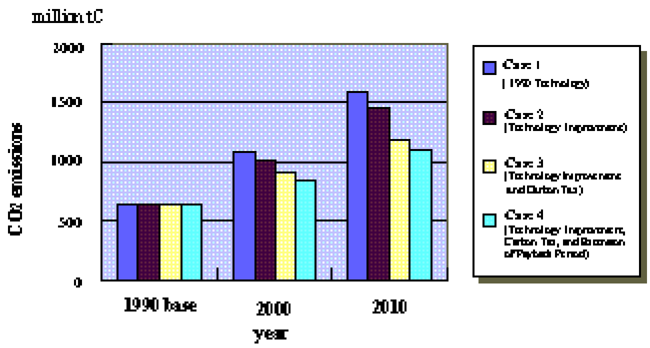

Figure E-4-1 Forecast of CO2 emissions in China.

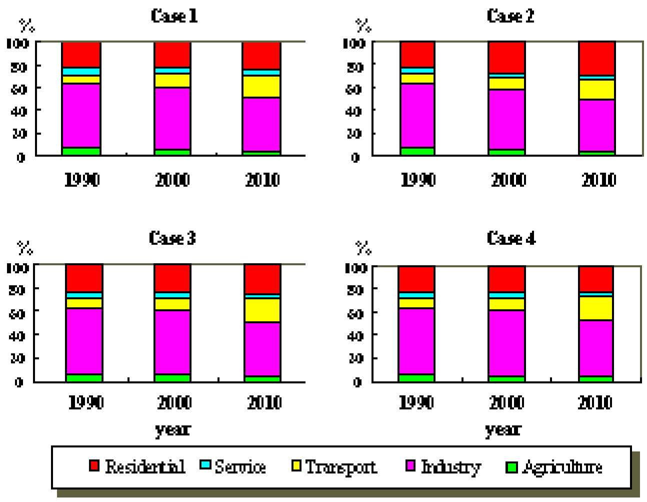

Figure E-4-2 Share of CO2 emissions by sector.

Table E-4-1 Sectors of AIM./Emission for China

Sector	Products or Processes
Agriculture	By Production Mode
Industry	Steel and Iron, Cement, Glass, Brick, Lime, Synthetic Ammonia, Caustic Soda, Soda Ash, Calcium Carbine, Fertilizer, Aluminium, Copper, Zinc &Lead, Oil Refinery, Ethane, Paper Making, Textile, Ingot Process, Forging Process, Heat Process, Cutting Process, Other Industry
Transport	By Transport Mode
Commerce	By Service
Resident	Towns and Cities, Rural

Table E-4-2 Major Energy Service Forecast

Sector	Service	1990	2000	2010
Agriculture	Irrigation land(M ha)	47.4	49.32	50
	Cultivated Land(M ha)	433	433	433
	Agriculture Products Processing(Mt)	125.6	207	314
Industry	Steel(Mt)	66.35	120	140
	Copper(kt)	550	800	950
	Aluminum(kt)	850	2100	3000
	Ethylene(Mt)	1.57	4	6
	Synthetic Ammonia(Mt)	21.29	28	38
	Fertilizer(Mt)	18.8	22.3	26.5
	Cement(Mt)	210	495	604
	Brick(G pieces)	4790	6430	8640
	Flat Glass(M heavy cases)	80.7	157	284
	Chemical Fiber(Mt)	1.65	3	5
	Paper(Mt)	1.06	4.35	10.5
Transport	Steam Locomotive(Freight, billion ton.km)	494	0	0
	Steam Locomotive(Passenger, billion passenger.km)	67.2	0	0
	Diesel Locomotive(Freight, billion ton.km)	411	907	1140
	Diesel Locomotive(Passenger, billion passenger.km)	614	1110	1300
	Electric Locomotive(Freight, billion ton.km)	290	879	1120
	Electric Locomotive(Passenger, billion passenger.km)	51.3	220	438
	Aviation(Freight, billion ton.km)	8.18	89.6	434
	Aviation(Passenger, billion passenger.km)	23	252	1210
	Private Car(Passenger, billion passenger.km)	0.525	10.4	143
	Large Truck(Freight, billion ton.km)	235	404	686
Commercial	Space Heating Area(billion m2)	0.85	1.04	1.33
	Space Cooling Area(billion m2)	0.18	0.35	0.47
	Illumination Area(billion m2)	1.42	1.9	2.81
Urban	Household(M)	79.45	116.21	156.14
Household	Change in Cooling Intensity	1	1.2	1.36
	Change in Space Heating Intensity	1	1.25	1.3
Rural	Possessing rate of Refrigerator(Set/100HH)	42.33	63	82
Househo	Possessing rate of Washing Machine(Set/100HH)	78.4	83	86
	Household(M)	193.43	227.24	232.64
	Change in Cooling Intensity	1	1.3	1.52
	Change in Space Heating Intensity	1	1.15	1.2
	Possessing rate of Refrigerator(Set/100HH)	1.22	8	15
	Possessing rate of Washing Machine(Set/100HH)	9.12	20	30

2.5 CO2 Emission Model in Korea

The Korea Energy Economics Institute (KEEI) has finished the research report "National Reports for Korean Government" related to UN FCCC. According to this report, the business-as-usual energy demand for Korea will increase at relatively rapid growth rates until year 2010. In particular, energy demand by the transportation and transformation (electricity, town gas, etc.) sector will increase remarkably, as personal income is increased. The share of energy demand by the industrial sector will decrease, even though the absolute amount of energy demand by this sector continues to increase. Population growth is more or less stabilized, by the year 2020, but per capita energy demand and the derived CO2 emissions will continue to increase. However, efforts to save energy and improve efficiency are expected in every sector, even in the BAU scenario, this implies that energy efficiency will be drastically improved. Therefore, it is very important to implement energy efficiency improvement programs, specific programs energy saving programs and fuel switching in every sector to minimize the economic impact of mitigating greenhouse gas emissions (Table E-5-1).

AIM/KOREA module produces preliminary simulation results for the alternative policy scenarios. This analysis has been under taken for the residential, transportation, and industrial (steel industry) sectors.

In the residential sector, it is found that there are many opportunities to save energy. The pattern of energy usage in this sector, heavily depends on the weather conditions in winter and summer. The main source of energy demand in this sector are heating and hot water. Also energy efficiency improvements in lighting and other home appliances are recommended. Since the marginal costs of reducing CO2 emissions in this sector are relatively low, compared with other options in other sectors, it is concluded that we focus on feasible mitigating programs in this sector. Therefore, policy measures, such as an energy labeling system, rebates, and other incentives to encourage energy saving are recommend. Another scenario assumes that the payback period for energy efficient appliances is extended to a maximum of 20 years with personal financial burdens reduced by the use of soft loans. As a result, as shown in Figure E-5-1, it might be possible to stabilize CO2 emissions in 2010 at the 1990 level.

In the steel industry it is very difficult to reduce CO2 emissions, as long as the share of electric furnace and integrated steel mills is not changed. The only way is to reduce steel production itself, but this is not acceptable, considering the economic impact of this industry. However, if new technology such as COREX, is utilized, it becomes possible to reduce CO2 emissions in steel industry. Also, potential efficiency improvements in each process and increased recycling can reduce the overall CO2 emissions in this industry.

In the transportation sector, the demand for vehicles, especially passenger cars, has increased rapidly, as per capita income has increased. It is projected that the saturation of the passenger car market will occur around 2010. Therefore, fuel substitution from carbon intensive to less intensive fuels is an important option. This option depends on how much subsidy can be made for the fixed cost of new technologies, such as hybrid and CNG cars. Policy options, such as driving restrictions, toll systems and energy price increases are considered and some of which are already implemented. Also the secondary benefits of reducing CO2 emissions in this sector are important, since by reducing CO2 emissions, we improve air quality, reduce congestion, and lower social costs. For example, if the driving restriction system (prohibition of driving on the days when the last digit of the vehicle license plate is the same as that of the date) is implemented nationally, then total CO2 emission in 2010 could be reduced by 12.6% (Figure E-5-2) while 4% reduction is possible if the system is implemented only in Seoul alone.

For further studies, we will calibrate the AIM/KOREA module. More advanced and new technology options will be introduced in each sector and the effects of these options analyzed. Further investigation into the major parameters in the AIM model will be conducted to reflect conditions in Korea. Based on the improved model, more reasonable scenarios will be set up for energy saving programs in each sector in order to derive practical policy measures. To meet this goal, the study of costs benefits and economic impacts of each policy measure will be cautiously examined. Also, it is necessary to link the AIM model, with its bottom-up approach structure to comprehensive top-down model to integrate the overall impact of mitigating greenhouse gas emissions, within a broader policy context.

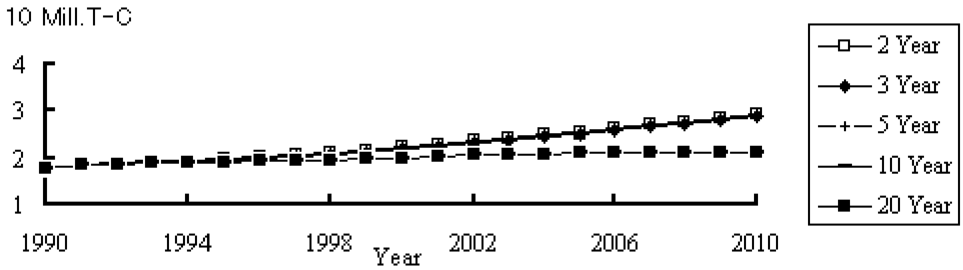

Figure E-5-1 CO2 Emissions based on payback periods in the Residential Sector.

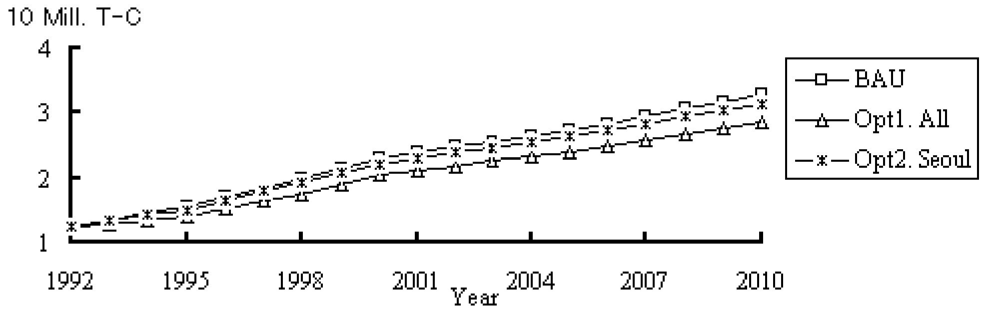

Figure E-5-2 CO2 Emissions based on effects of the Driving Restriction System in Transportation Sector.

Table E-5-1 Major Index for Energy Demand Projection.

BAU	1990	2000	2010	2020	2030
Energy (Mill TOE)	93.2	210.4	328.1	434.3	559.9
GDP ('90, Trill. Won)	179.5	361.3	617	917.2	1357.7
Population (Mill.)	42.9	46.8	49.7	50.6	50.6
CO2 (Mill. T-C)	65.2	140.7	202.5	259.3	319.9
TOE/Mill. Won	0.52	0.58	0.53	0.47	0.41
TOE/POP	2.17	4.5	6.6	8.58	11.07
CO2/POP	1.52	3.01	4.08	5.13	6.32
CO2/TOE	0.7	0.67	0.62	0.6	0.57
Energy Elasticity	-	1.17	0.83	0.7	0.64
CO2 Elasticity	-	1.1	0.67	0.62	0.53

2.6 CO2 Emission Model in India

The AIM/Enduse model for India (Shukla, 1996) has been set up for forty years horizon from 1995 to 2035. The focus of the model is the analysis of end-use demand sectors. The energy consumptions discussed below refer to the end-use sectors alone and not supply sectors (e.g. electricity). However in reporting the carbon emissions, the contribution from supply sectors is accounted. The objective of the exercise is minimization of discounted energy system costs at end-use sub-sector levels over next forty years. It 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, aluminium, cement, paper, brick, caustic soda, soda ash, sugar, cotton textiles, fertilizer, and other industries. Each sub-sectoral model contains detailed technological specifications. For instance, there are thirty technologies in steel, ten in aluminium, twenty five in transport, and twenty in urban residential sector. The entire model is specified with 250 different demand technologies.

Technological progress is represented by AEEI for each existing technology, introducing new retrofit technology options and future technologies. Technology mix in the model is influenced by the trajectory of shares of old technologies and economics of retrofit and future technologies. The Indian AIM/Enduse model is specified to capture the developing country realities. For instance, a separate representation is made of the traditional biomass fuels for cooking and kerosene for lighting in the rural households and brick kilns in the industrial sector.

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 E-6-1 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.

Among end-use sectors, the highest growth in primary energy consumption is observed in transport. Its share in primary energy increases from fourteen to thirty five percent. Share of industry increases from twenty three to twenty nine percent, while that of households declines from fifty eight to thirty one percent due to fuel switch from inefficient biomass to more efficient LPG and kerosene.

The high growth of electricity consumption results from the shift in end-use technology mix from coal and oil based technologies to electric equipments and processes. Under the BAU, the sectoral shares of electricity consumption changes as follows: commercial sector from twelve to fifteen percent, residential sector from twenty to twenty six percent, agriculture from twelve to eight percent and industry from fifty three to forty eight percent. In the rural residential sector, the electricity use increases sharply due to switch from kerosene to electric lighting. In general, the shift from fossil fuels to electricity using equipments and processes is observed in most sectors. Although, the irrigation in future shall use more electric pumps replacing diesel pumps, the share of agriculture in electricity is expected to decline due to lower growth of the sector.

Figure E-6-2 shows the changing energy consumption mix in the Indian steel industry. The peta-calories of electricity consumed is taken as equivalent to the energy of coal replaced at electricity generation. Coal and coke are gradually substituted by electricity and natural gas as the shares of electric arc furnace and gas based sponge iron technology increases. As a result, the energy intensity of steel industry declines from 7.4 Gcal/t in 1995 to 5.3Gcal/t in 2025. Carbon intensity declined from 0.58 tC/t to 0.32 tC/t.

A great advantage of the AIM/Enduse model is the detailed specification of technologies at a sub-sectoral level. The model is thus 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 E-6-3) For instance, the carbon emission from Indian steel industry in the year 2035 declines by fifteen percent under such a tax. The AIM/Enduse model results also provide very useful inputs on the demand side to the integrated bottom-up energy systems models such as MARKAL and provide very good bench marks to validate the aggregate models.

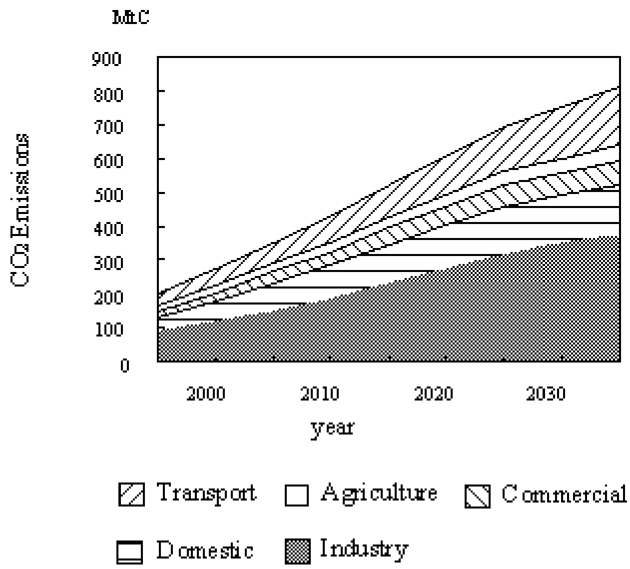

Figure E-6-1 Total CO2 emissions in India by sector.

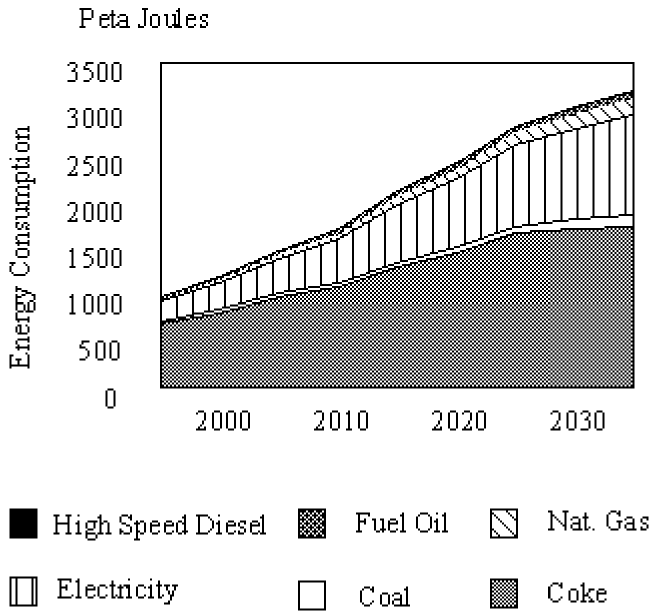

Figure E-6-2 Fuelwise energy consumption in the steel industry.

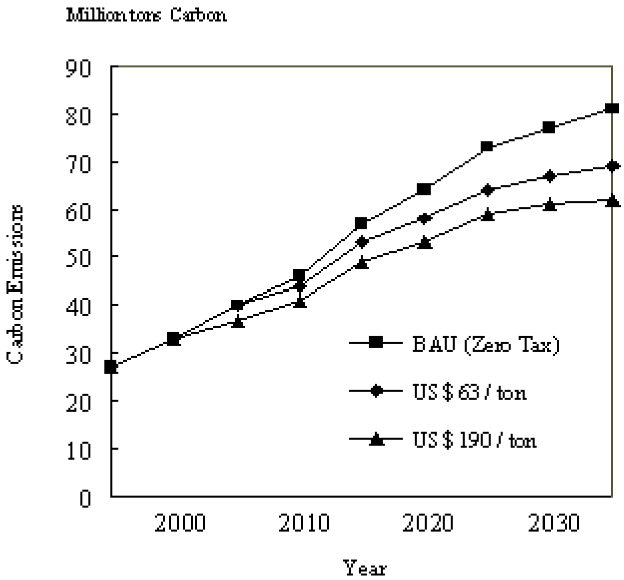

Figure E-6-3 Carbon emissions from Indian steel industry under tax scenarios.

2.7 CO2 Flux from Tropical Deforestation

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.

Many studies about changes in tropical land-use have been conducted since the last century. Studies which tried to quantify social and economic causes include Houghton (1988) and IMAGE2 (Alcamo et al., 1994). Among these many approaches, the parameter with the strongest correlation to forest area is population density. There are a number of conjectures about the relationship between the increase in population density, and the decrease of forest area. Among them, the main cause of deforestation is thought to be the expansion of cultivated land in response to increasing population.

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. Figure E-7-1 displays the comparison of coverage forest and population density in 1880 and 1980 for 105 states in 13 tropical Asian countries. This relationship may change in the future, but at present, we believe that an extrapolation of current trends is a valid method to represent environmental change.

1980 is the base year for calculating annual coverage for each country using FAO's 1980 tropical forest resource assessment (FAO/UNEP, 1981) and the interim report values of the 1990 assessment (FAO,1988). To estimate the carbon stored in vegetation per unit of forest area, we used a biomass value for each country based on FAO's 1990 tropical forest study. The amount of carbon is calculated from biomass estimates using the factor 0.45 (Whittaker, 1975).

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.

Figure E-7-2 shows the forest area for the medium range estimate of population. The rate of deforestation reaches a maximum in 2010 of 13.8 million ha per year, and declines thereafter. Tropical forests decrease by 990 million ha, and 53% of the global forests in 1980 are expected to disappear during the 120 years from 1980 to 2100. The actual forest area cleared in Latin America is the largest, but Africa (62%) shows the largest percentage decrease, followed by Latin America (50%), and the Asian region (45%). Asia and Latin America experience their peak rate of forest loss during the 1980s and 1990s. In Africa, the rate of forest clearing is highest in the decade 2010 - 2020.

Table E-7-1 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 beginning of the next century and then decline. Overall 91.6 billion tC is released during the 120 years from 1980 to 2100.

This model assumed the deforestation rate is directly connected with population change. There are some problems with using population change to describe trends in forest area. First, there are various cause-and-effect processes by which population growth leads to deforestation, and the degree of their effects on forests varies widely. For example, depending on whether an increase in food production comes about from an increase in shifting cultivation, or from an increase in settled cultivation, the impact on forests is vastly different. Second, results will depend on the extent to which factors other than population are considered, such as national development policies, land use rights, commercial logging, and the demand for timber. Third, current trends show a decrease of forest area due to population increase, but a halt or reversal of these trends would affect forecasts. For example, in the middle latitudes, many countries have experienced periods of rapid exploitation of national forests and land resources. Mediterranean countries and England did not see a drop in deforestation until almost all forests had disappeared. However the trend reversed in Japan and the United States when the amount of surviving forest cover was still high. The other versions of AIM deforestation model are now take into account these consideration.

A number of studies have attempted to estimate carbon flux resulting from future tropical deforestation, assuming no aggressive reforestation occurs. These forecasts about tropical forests, this on included, predict that between fifty and one hundred percent of remaining forests will be cleared by the end of the next century. For example, Myers (1983) estimated tropical forest loss at the beginning of the 1980s as 24.5 million ha/y, and predicted that as that rate tropical forests would disappear within 38 years. Houghton (1988), IS92, and this study shows nearly the same results, the implications of them should be addressed as real issues.

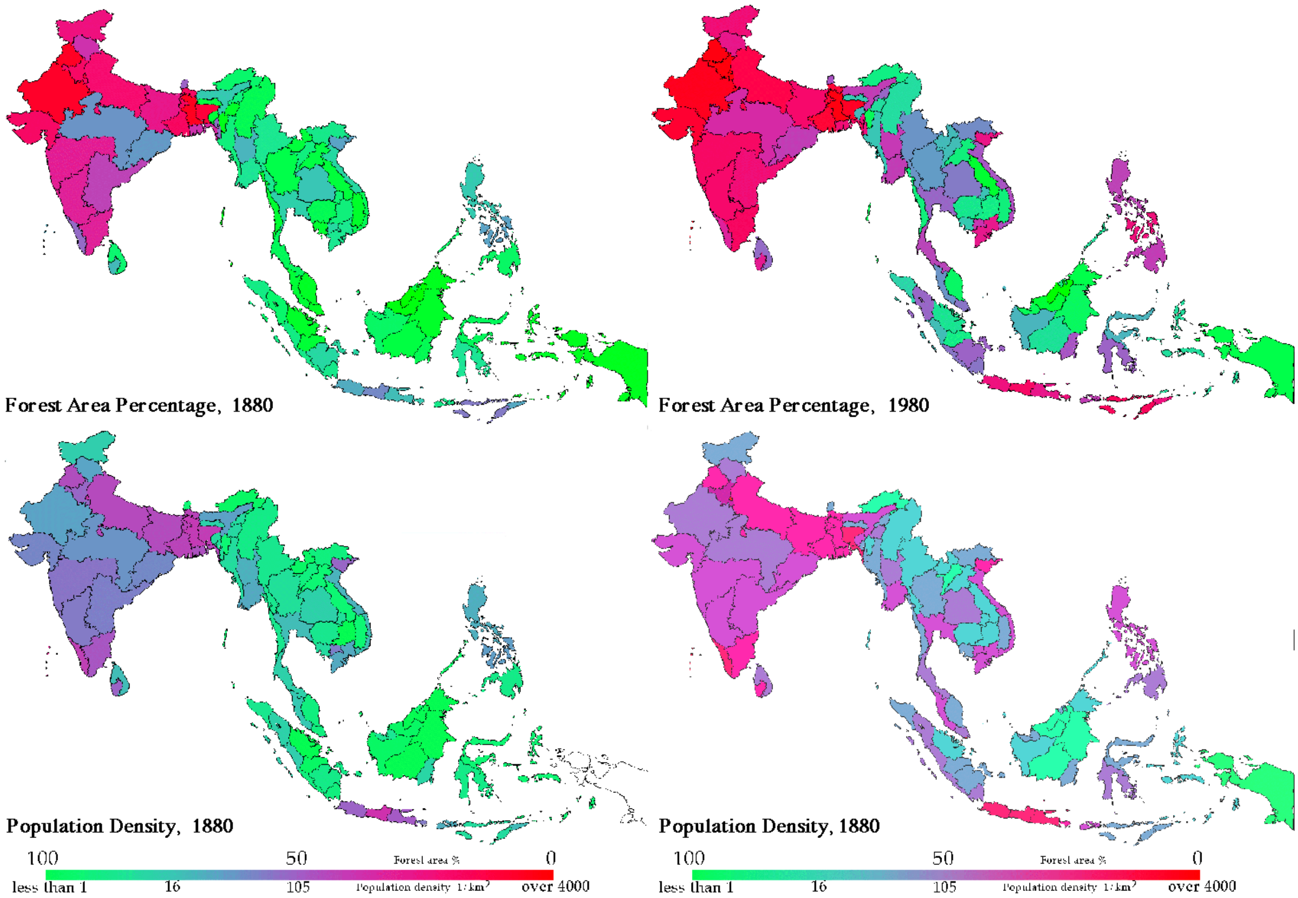

Figure E-7-1 Forest area percentage (%) and population density (persons/km2).

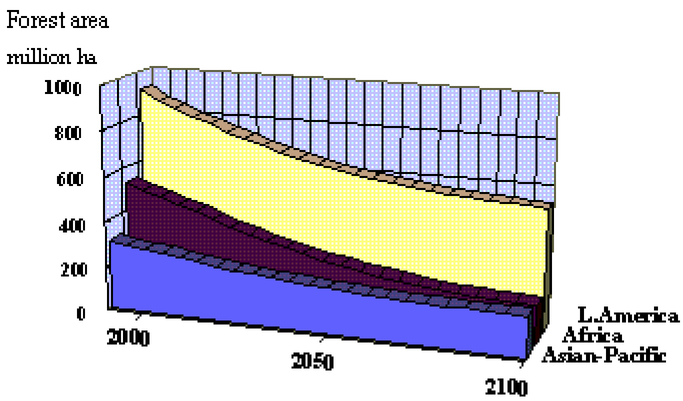

Figure E-7-2 Estimation of regional forest area.

Table E-7-1

	Medium		Medium-high		Medium-low	
year	Area	CO2	Area	CO2	Area	CO2
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
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	

2.8 SO2 Emission and Deposition

Figure E-8-1 explains the framework of the SO2 emission and deposition module in AIM. The amount of anthropogenic SO2 emissions are estimated under several alternative scenarios. Coupling the degree of dissemination of reduction countermeasures with energy scenarios, we projected future SO2 emissions as presented in the table E-8-1. In addition, the natural emission of SO2 is assumed to be 22 TgS/y and to remain constant. The regional distribution of the anthropogenic emissions expected in the year 2100 is given in Figure E-8-2.

The long-distance transport of SO2 emissions are calculated with a 2-dimensional diffusion model incorporating 2 vertical layers along with simple chemical reactions and deposition. Using ECMWF wind velocity and precipitation data in 0.5x0.5 degree resolutions and 3 hour time intervals, lower layer sulfate concentration as well as dry and wet deposition rates are estimated. Figure E-8-3 shows the annual averaged deposition rate for sulfur in 2025. Sulfur depositions are calculated under several emission scenarios for the period 1960 to year 2100. Their environmental impacts are estimated as well.

One example of these impact assessments is the depletion of the available exchangeable bases from top soil. This index used as a measure of significant impacts from acid rain is the year in which 50% of the 1960 stock of bases is depleted. Figure E-8-4 shows the spatial pattern under the medium population and economic growth scenario with 10 mol/(ha・y・cm) buffer rate. An estimated 7% of terrestrial area is affected by 2050, and 12% by 2100. The calculated sulfate emissions / concentrations are also used for estimating cooling effect of the climate.

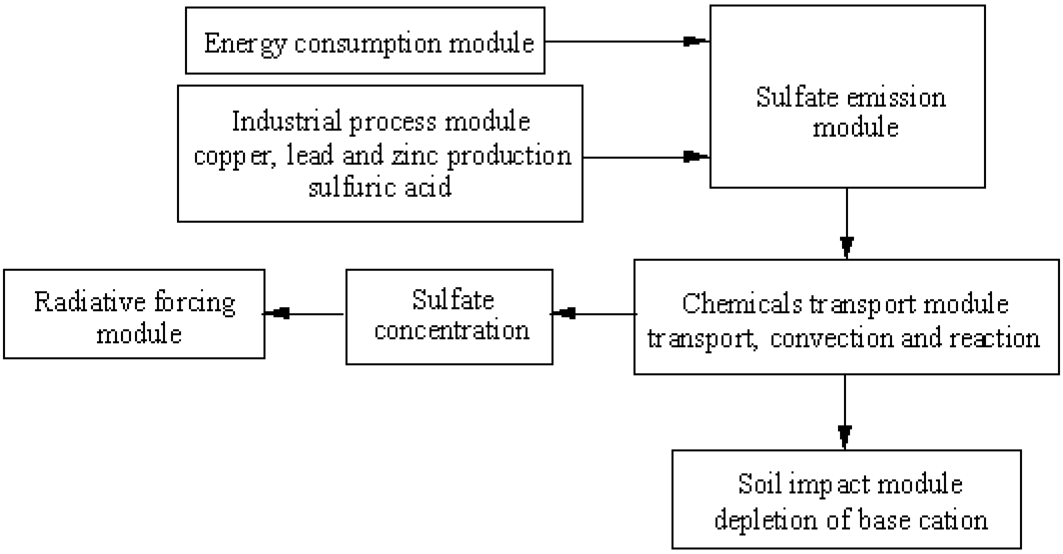

Figure E-8-1 Framework of sulfur emission and deposition modele.

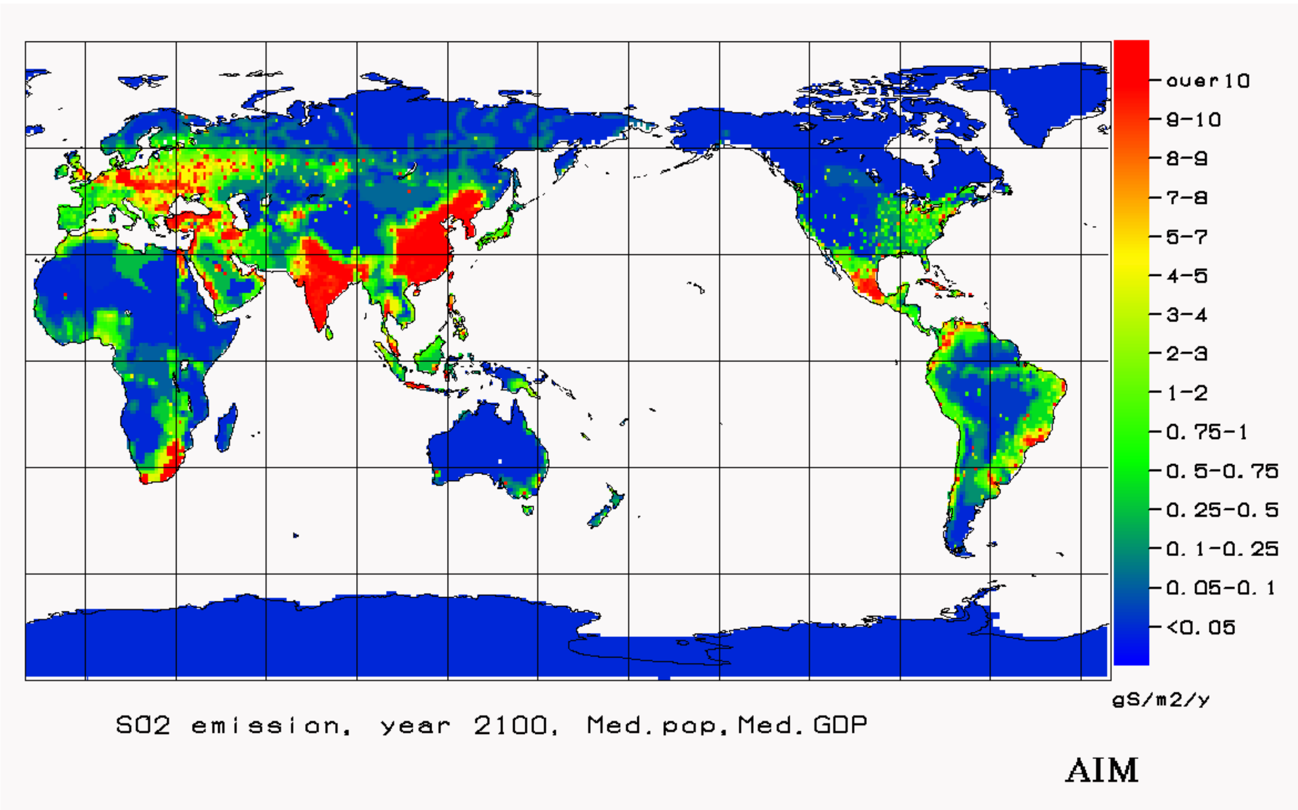

Figure E-8-2 Distribution of sulfur dioxide emissions in 2100.

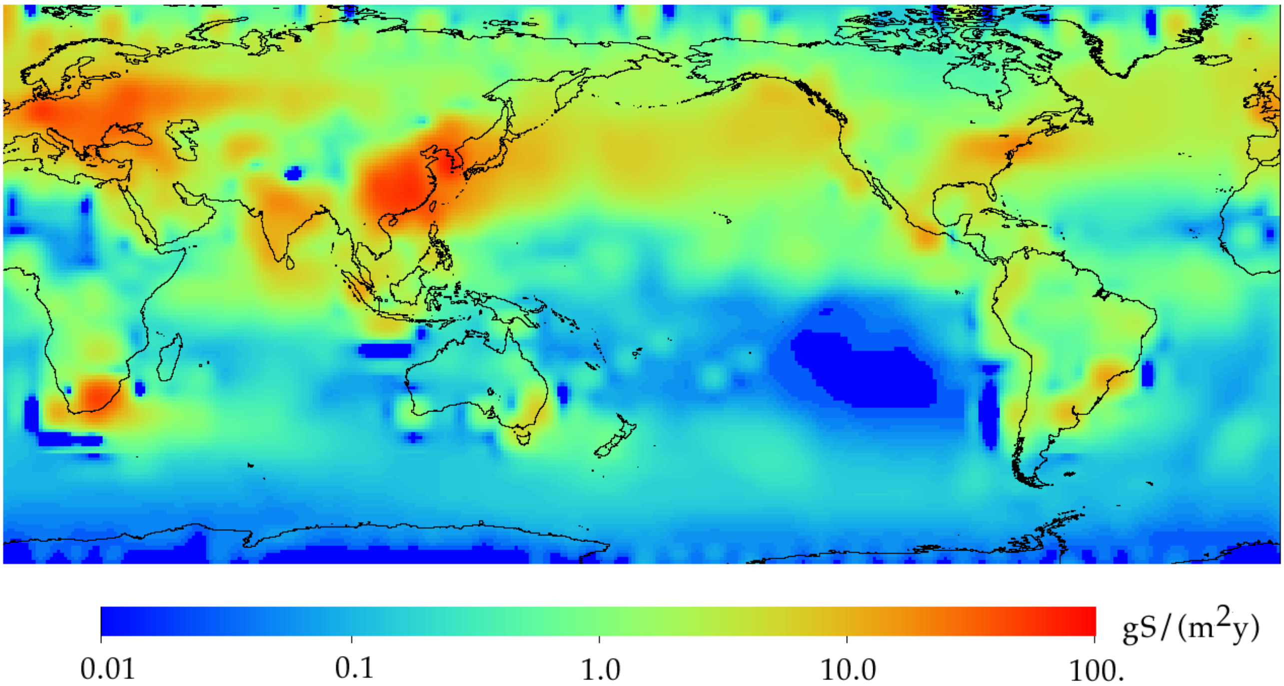

Figure E-8-3 Distribution of sulfur deposition in 2025.

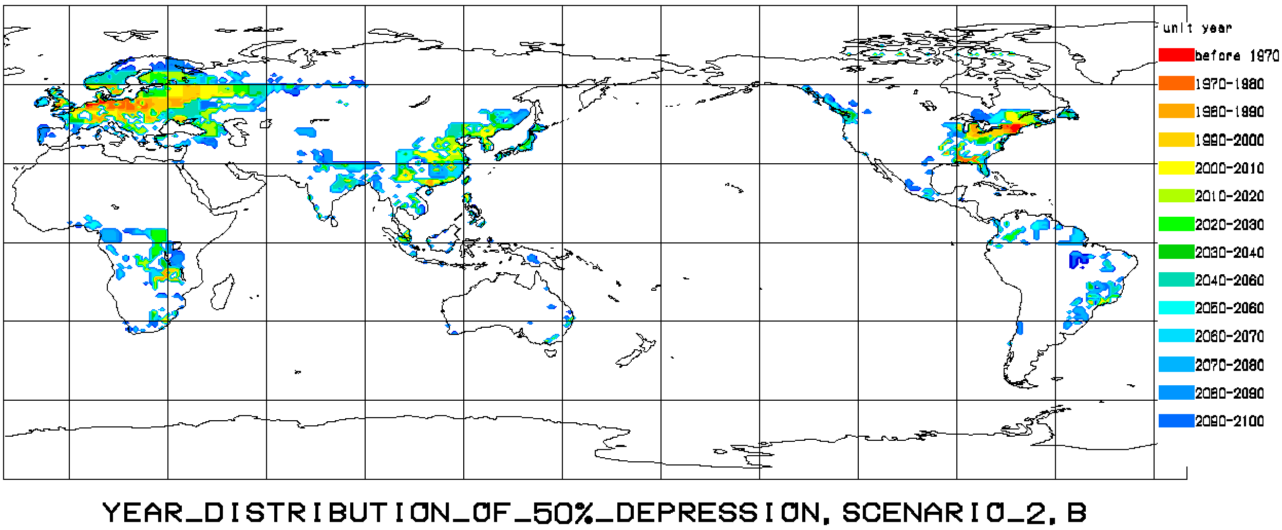

Figure E-8-4 Year of soil acidification due to acid precipitation.

Table E-8-1 Emissions of SO2 from anthropogenic sources (TgS/year)

scenario	1985	1990	1995	2000	2005	2010
so2g1p13	66.41	60.74	70.83	83.08	99.48	119.89
so2g2p23	66.41	58.14	64.95	72.52	82.43	94.81
so2g3p33	66.41	63.57	77.5	95.76	119.77	150.68
so2aeeih	66.41	61.08	70.75	82.92	98.49	117.8
so2aeeil	66.41	64.91	79.56	98.55	122.83	153.75
so2highr	66.41	60.55	70	81.43	96.97	117.66
so21owrs	66.41	61.52	72.13	85	100.75	121.08
so2glpl2	66.41	63.05	74	87.39	92.54	72.71
so2glpl4	66.41	55.21	65.65	78.41	76.64	34.24

scenario	2015	2020	2025	2050	2075	2100
so2g1p13	141.68	168.7	200.75	290.99	352.67	385.24
so2g2p23	106.86	120.44	137.42	159.28	154.32	132.35
so2g3p33	188.92	238.58	297.5	529.19	775.86	742.94
so2aeeih	138.2	162.7	192.38	275.01	338.31	377.48
so2aeeil	185.66	226.18	274.86	456.62	641.44	797.88
so2highr	139.96	167.41	200.35	292.64	354.73	386.3
so21owrs	142.73	169.4	201.96	290.14	352.35	383.87
so2glpl2	83.9	97.73	113.41	150.13	152.26	136.61
so2glpl4	39.19	45.4	52	64.02	56.43	52.42

so2g1p13:Medium population increase, Medium GDP growth rate
so2g2p23:Low population increase, Low GDP growth rate
so2g3p33:High population increase, High GDP growth rate
so2aeeih
so2aeeil:Low energy efficiency improvement
so2highr:Low fossil fuel resource estimation
so21owrs:High fossil fuel resource estimation
so2glpl2:Medium population growth, Medium GDP growth, Mild mitigation
so2glpl4:Medium population growth, Medium GDP growth, Strict mitigation

2.9 Desulfurization in the Asia-Pacific Region

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 E-9-1 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 E-9-2 and E-9-3 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 E-9-2 indicates that Korean investment in these technologies is expected to rise in the mid 1990s whereas Figure E-9-3 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.

Predictions of SO2 emissions are also important because of the cooling effect that these aerosols have in the atmosphere. The distribution of SO2 emissions varies greatly among regions and is expected to have a very significant effect on regional climate change impacts. This cooling effect should not be over-estimated by the simple extrapolation of past emission trends. Emissions will be the function of many factors, including the energy mix and technology selection processes, as well as the increased recognition of the local damage caused by emissions as rising incomes enable choices to made to reduce these costs.

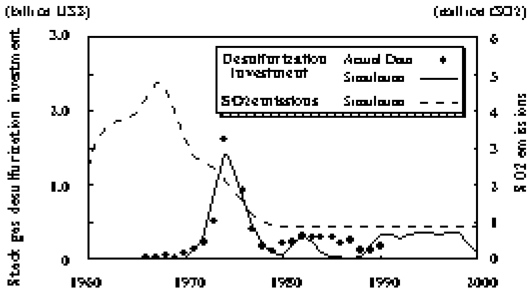

Figure E-9-1 A desulfurization simulation for Japan

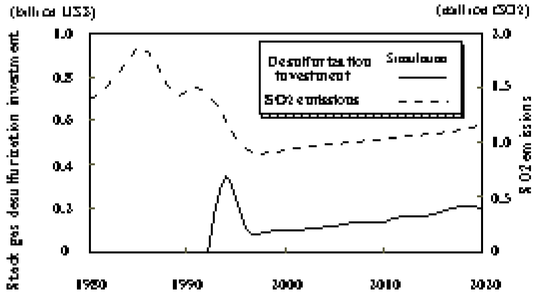

Figure E-9-2 A desulfurization simulation for Korea

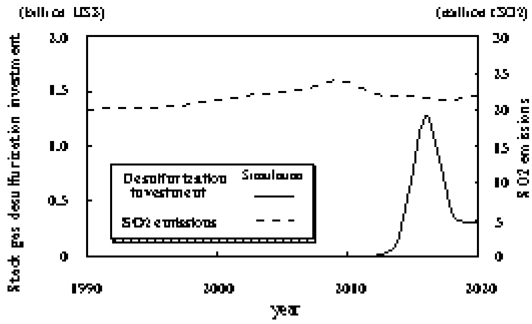

Figure E-9-3 A desulfurization simulation for China

2.10 World Population

The population growth model that was developed and used in AIM is based on the cohort component method. This method has been adopted by many nations and international organizations such as the United Nations Population Division, and the World Bank, and is the most widely-used population-estimation methodology. In this method, the age group population distribution in any chosen year is calculated using the age group population distribution in the base year of the forecast period, a model life table, a model table of fertility-age distribution, and the birth-sex ratio, with changes in the average life expectancy at birth, change in fertility, and migration rate taken as exogenous variables.

In our model, we used 5-year internal estimates and divided the age distribution into 17 groups, each of 5-years. Also we used several kinds of model life tables, fertility-age distributions and model tables of total fertility rates (TFR). Estimates of future populations are based on expected death rates, fertility rates and migration. Countries and cultures generally wish to reduce their death rate and extend the average life expectancy at birth. The main problem is to estimate future trends and changes in the fertility rate.

The Total Fertility Rate (TFR) expresses the number of children a woman is likely to have during her life-time, and is used as an input parameter in this model: the index of fertility. TFR is linked to many social and economical factors. Let us examine the significance of this relation. In Figure E-10-1, each country's and region's TFR from 1950 to 1985 (U.N.,1990) is on the vertical axis, and Per Capita GNP is on the horizontal axis. The open circles in the figure show Japan's TFR values from 1925 to 1990. The trend to lower fertility rates with increasing income, which has been reported repeatedly, can be seen. The relationship between socioeconomic activity and fertility is represented in the following formula:

$\Delta TFR = -\alpha \Delta \ln(\text{Per Capita GNP})$ ...(1)

In this formula, Δ is the size of the change over a certain period. α is the rate of change observed in Figure E-10-1, approximately 1.3. Assuming that this fertility trend continues along with the increasing life expectancy, future population can be calculated using the economic growth rate as an independent variable.

How great is the significance of the above equation on the global environment? Figure E-10-2 presents the projections in 2050 and 2100, with Per Capita GNP growth on the horizontal axis and estimated CO_2 emissions by AIM on the vertical axis. The upper boundary of the shaded area shows the case where equation (1) is assumed. The lower boundary shows the case where a 0.13 per year lowering of the TFR (a rate often observed in demographic transition) is assumed in countries and regions where it is above the replacement level. According to these results, if economic growth is assumed to be 0, emissions will be 3 - 7.47 billion tC in 2025, and 2.64 - 31.1 billion tC in 2100. The difference between the two values is from population changes. The two black circles in the middle of the figure are values from IS92a emission scenario for 2050 and 2100.

Increasing incomes, raising the level of education, lowering infant mortality, elevating the status of women and promoting intensive family planning contribute significantly to lowering the TFR. When estimates of how much these factors affect future global populations (Bongaarts et al., 1990) are reviewed, the population of developing regions in 2100 could range from 10.0 billion under a reference scenario, to 14.6 billion without family planning, or 7.8 billion with the promotion of family planning. The population of developed countries in 2100 will be between 1 and 1.5 billion. Even though the global population would be significantly lower with family planning than without it, its impact is not sufficient to reach the bottom of the gray area in Figure E-10-2.

Also, in AIM, we use this population module in order to calculate the population density in arbitrary year by multiplying present spatial population distribution profile and country population estimates. Figure E-10-3 and E-10-4 are the estimated population densities in the year 1990 and 2100, which have 5.3 billion and 11 billion people respectively. These information serves as a basic element which supports emission and impact modules of the AIM.

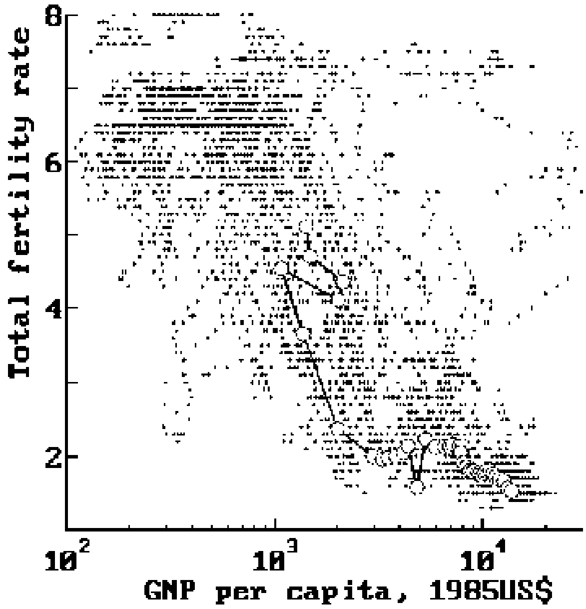

Figure E-10-1 Historical trend between TFR and Per Capita GNP (Open circles. denote the locus of Japan.)

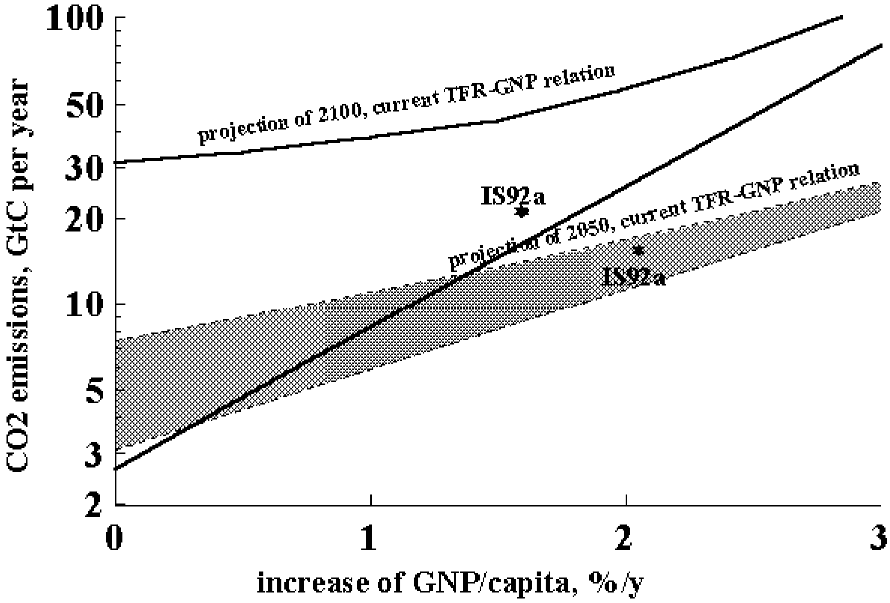

Figure E-10-2 Growth of per capita GNP and CO2 emissions.

Figure E-10-2 Growth of Per Capita GNP and CO2 emissions.

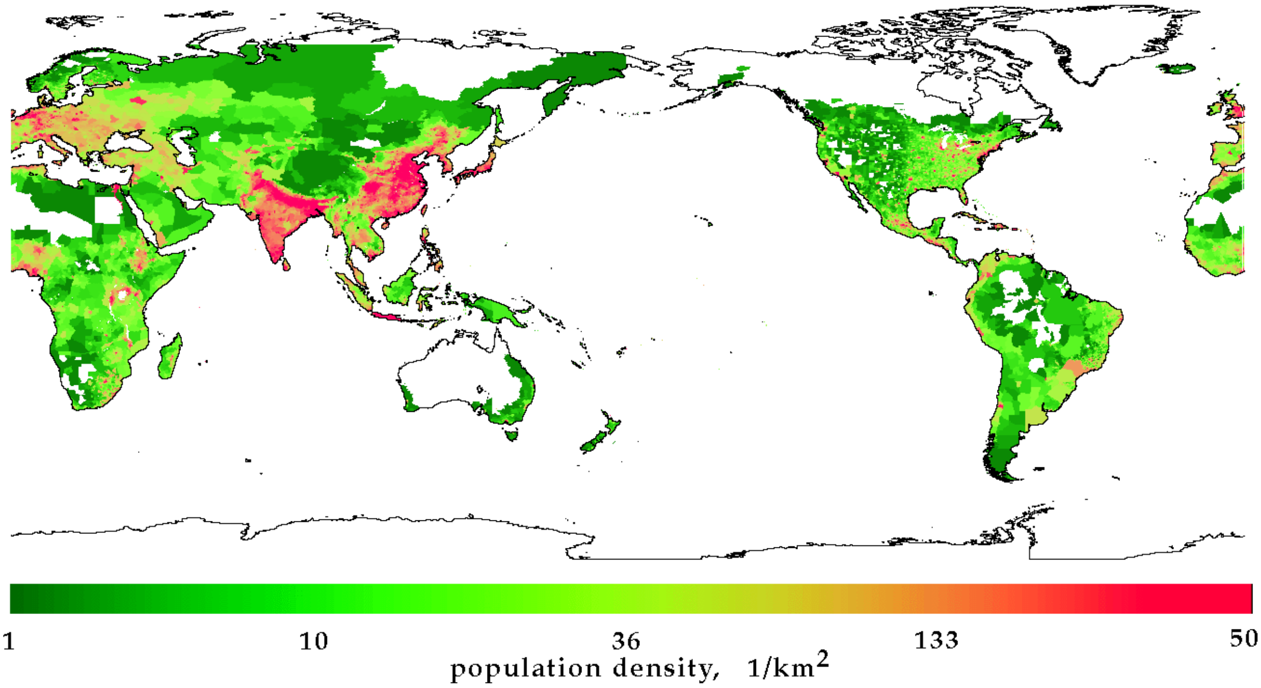

Figure E-10-3 Population density in1990.

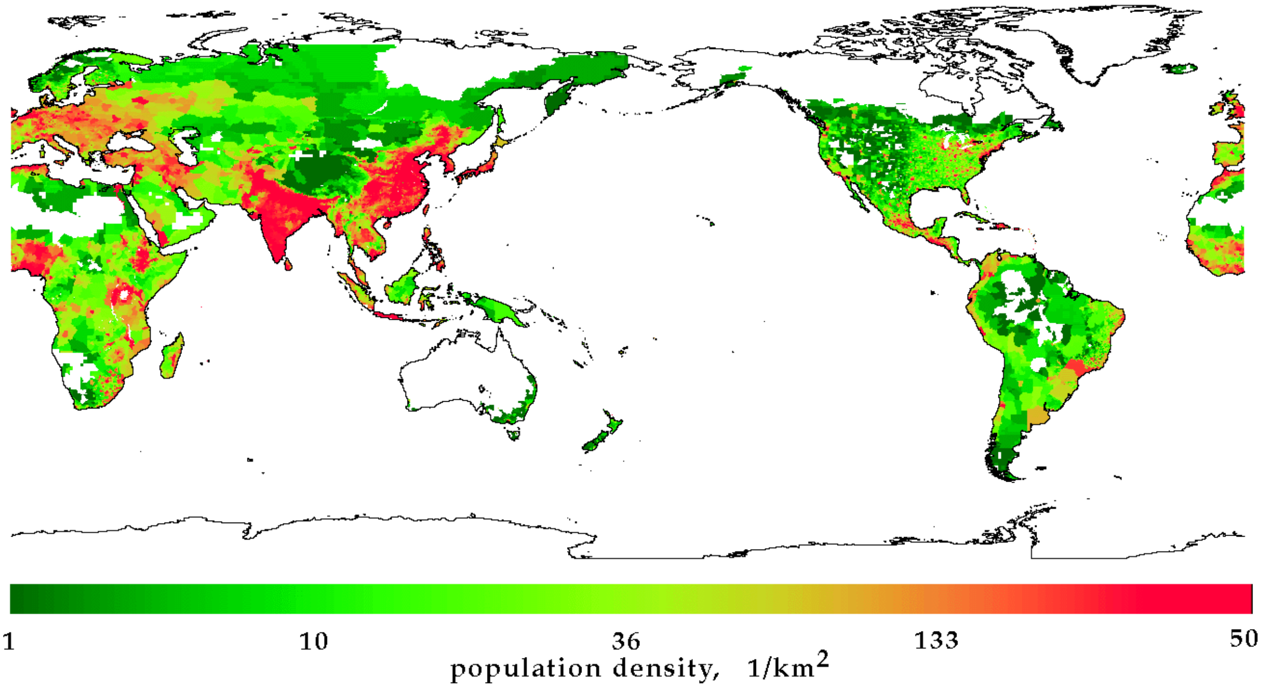

Figure E-10-4 Population density in 2100.

3. Climate Change Models

3.1 Climate Change

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 C-1-1.

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 be 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, 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.

The relationship between radiative forcing ΔQ and the increase in temperature, ΔT, is expressed by the following equation:

$$C_m \frac{d\Delta Tm}{dt} = \Delta Q - \lambda \Delta T_m - (1-f) \cdot (\Delta F_{m,d} + \Delta F_p)$$

In this equation, t is time, and the subscript m represents the upper mixing layer of oceans. Cm expresses the apparent thermal capacity, and λ is the climate sensitivity. $\Delta F_{m,d}$ is heat flux to the intermediate ocean layer, ΔF_p is the thermal flux which enters into deep oceans in the high latitudes, and f is the ratio of ocean to land surface. Flux transfer from the mixing layer to deeper layers is calculated with the one dimensional diffusion and upwelling model. The land is assumed to be in equilibrium with the upper mixing layer.

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 contribution from ice-melting is calculated using the equations by Wigley et al.(1993). To estimate the expansion, we divided the oceans into 20 degree latitude belts and calculated the increased volume of sea-water.

Figure C-1-2 is the result when climate sensitivity λ is set at 1.748 W/(m2 K), which is equivalent to an equilibrium temperature increase when CO2 levels have doubled ($\Delta T_{2\times CO2}$). 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.

Research on climate change impact requires spatial data of future climate. To consider the spatial distribution of future climate, we use the outputs from the climate model which were calculated using various General Circulation Models (GCMs). For example, Figures C-1-3 and C-1-4 show the GCMs outputs for temperature and precipitation. Since the spatial resolution of GCMs is not fine enough for direct use in impact studies, the output is interpolated spatially to generate values at a finer resolution. GCM outputs can thus generate spatial future climate data using the global mean temperature increase in the following equations.

For temperature,

$$T(t) = T(base) + \Delta T_{2\times CO2} \times \frac{T_{mean}(t) - T_{mean}(base)}{T_{mean}(2\times CO2) - T_{mean}(1\times CO2)}$$

For precipitation,

$$\log P(t) = \log P(base) + \frac{T_{mean}(t) - T_{mean}(base)}{T_{mean}(2\times CO2) - T_{mean}(1\times CO2)} \times \log \frac{P(2\times CO2)}{P(1\times CO2)}$$

Here, T(t) and P(t) are the temperature and the precipitation in year t respectively. $\Delta T_{2\times CO2}$ is the temperature difference and P(2xCO2) / P(1xCO2) is the precipitation ratio between 2xCO2 and 1xCO2 values for each cell of the spatial grid as calculated by GCMs. Tmean(t)-Tmean(base) is the global annual mean temperature increase between the base year and year t, which is calculated in the climate change model.

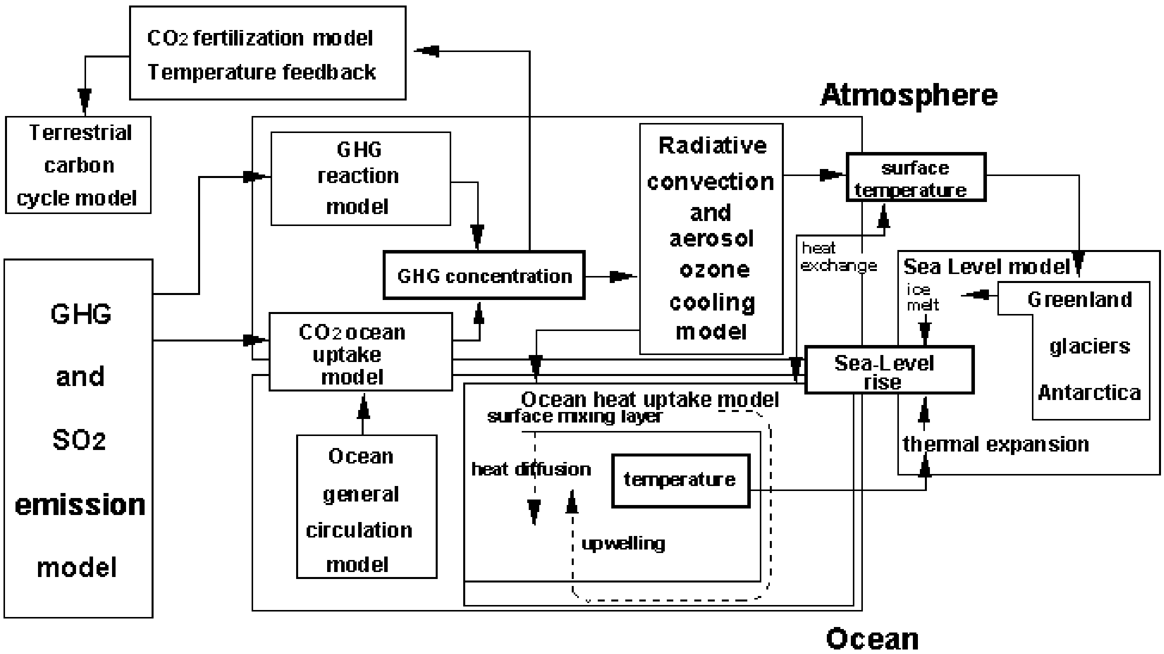

Figure C-1-1 Outline of AIM climate change model.

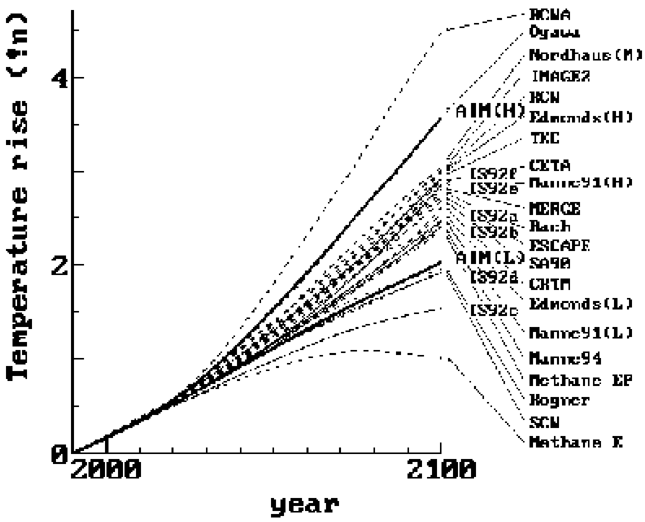

Figure C-1-2 Estimated temperature rise under various scenarios ($\Delta T_{2\times CO2}$=2.5℃).

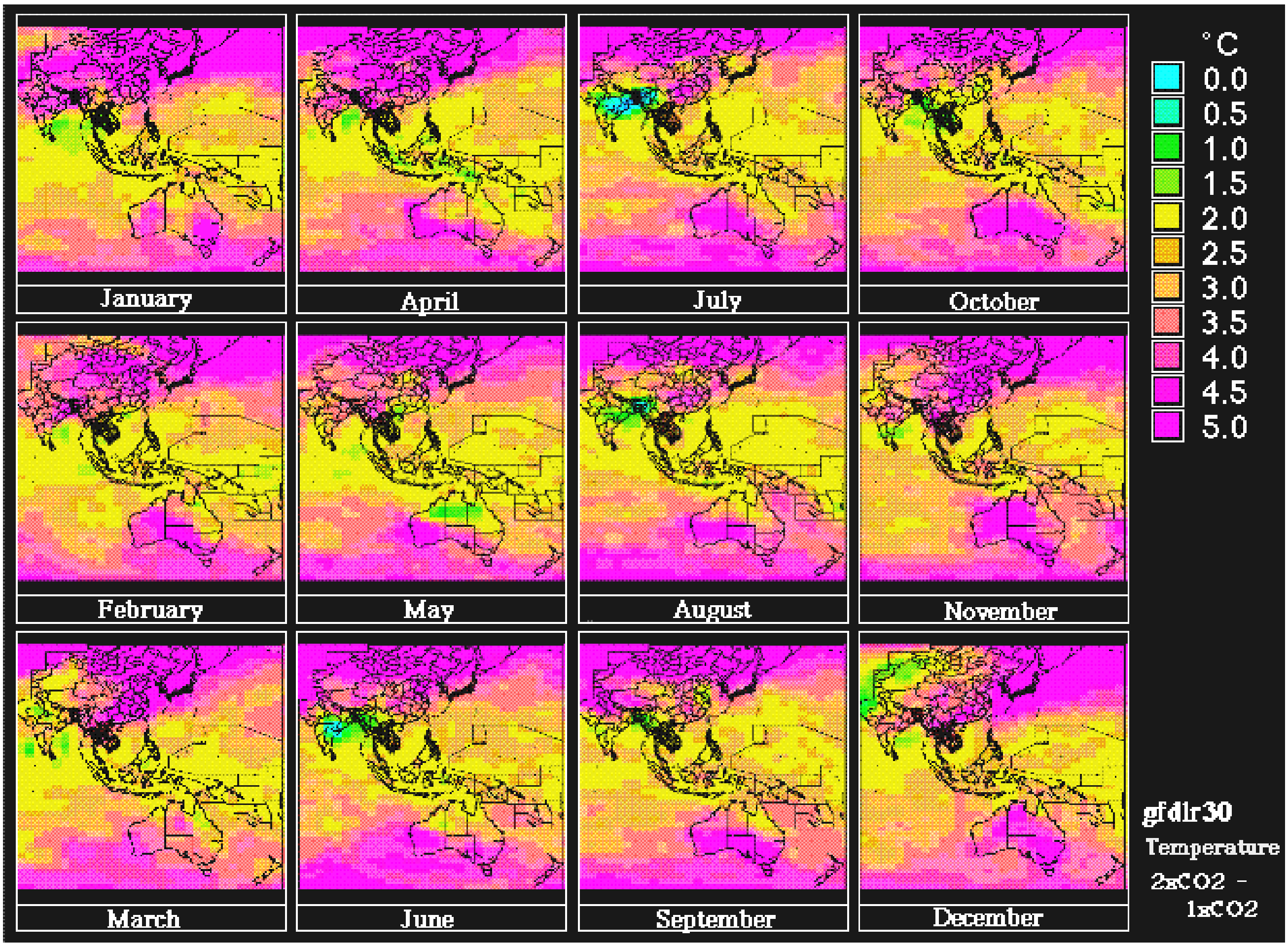

Figure C-1-3 Estimated temperature by GCM (2×CO2-1×CO2).

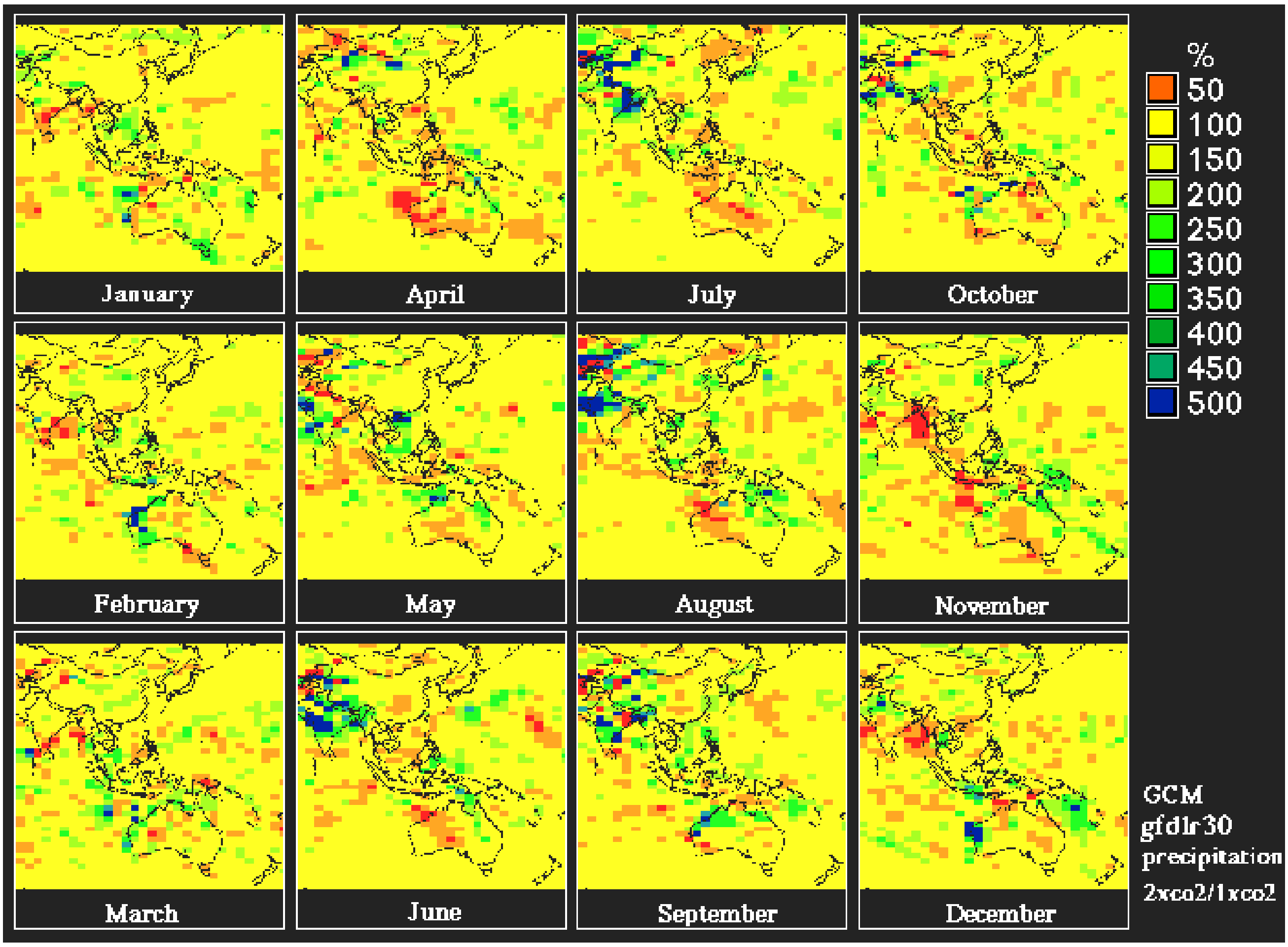

Figure C-1-4 Estimated precipitation by GCM (2×CO2/1×CO2).

3.2 Global Carbon Cycle

The main function of the carbon cycle model is to geographically evaluate the terrestrial CO2 absorption and storage in response to CO2 emissions (Figure C-2-1). 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 (Maier-Reimer et al., 1987). It operates on a 0.5x0.5 degree gridded earth, whose land cover is provided by Olson's World Major Ecosystem Complex map (1985). 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 humify (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 modelled as 1st order kinetic reactions.

Since ecosystem-level fertilization exper-iments are impossible, results from small-scale fertilization experiments are adopted in the simulation of Carbon Cycle Model fertilization mechanisms. Plants respond in a variety of ways, depending on, C3 or C4 photosynthetic paths, water and nutrient availability, elevation, etc. Fertilization is materialised in the core formula of Net Primary Productivity, which is based on the assumption that a relative change in atmospheric carbon dioxide leads to a relative change in Net Primary Productivity proportional to the former:

$$NPP = NPPI\left\{1 + log\left(\frac{pCO2(t)}{pCO2(0)}\right)\right\}$$

in which NPPI is the unfertilized Net Primary Productivity at t=0 year, a characteristic of the land-cover-type of each grid cell, and pCO2 is the atmospheric carbon dioxide content. The factors limiting fertilization are described as a function of altitude, dominant species, soil, and water use efficiency characteristics.

Assuming a steady state of the carbon pools in the year 1850 (net bioflux=0), carbon dioxide is injected into the atmosphere following the historical emission trajectory. This raises the Net Primary Productivity of every land grid-cell, either finding its way back into the air (through decay) or joining the carbon pools. One measure of this carbon storage is Net Ecosystem Productivity, which equals Net Primary Productivity minus the flux into the atmosphere. The Figure C-2-2 presents the Net Ecosystem Productivity for the year 1990.

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 C-2-1 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 centry. 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.

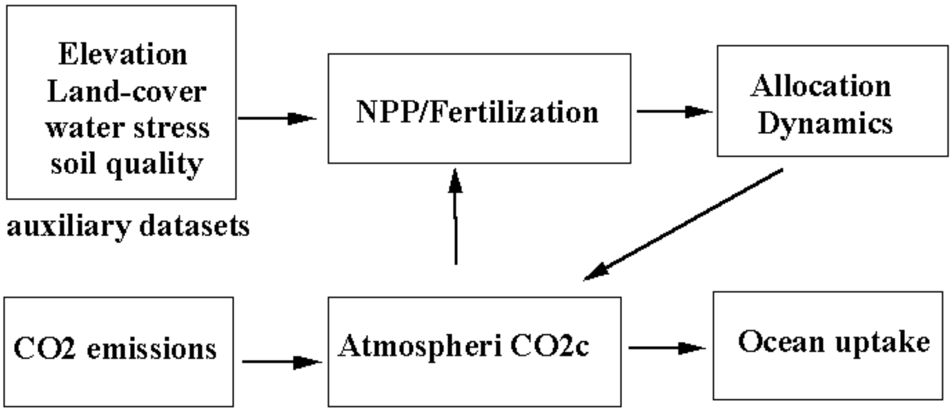

Figure C-2-1 Framework of net ecosystem productivity estimation.

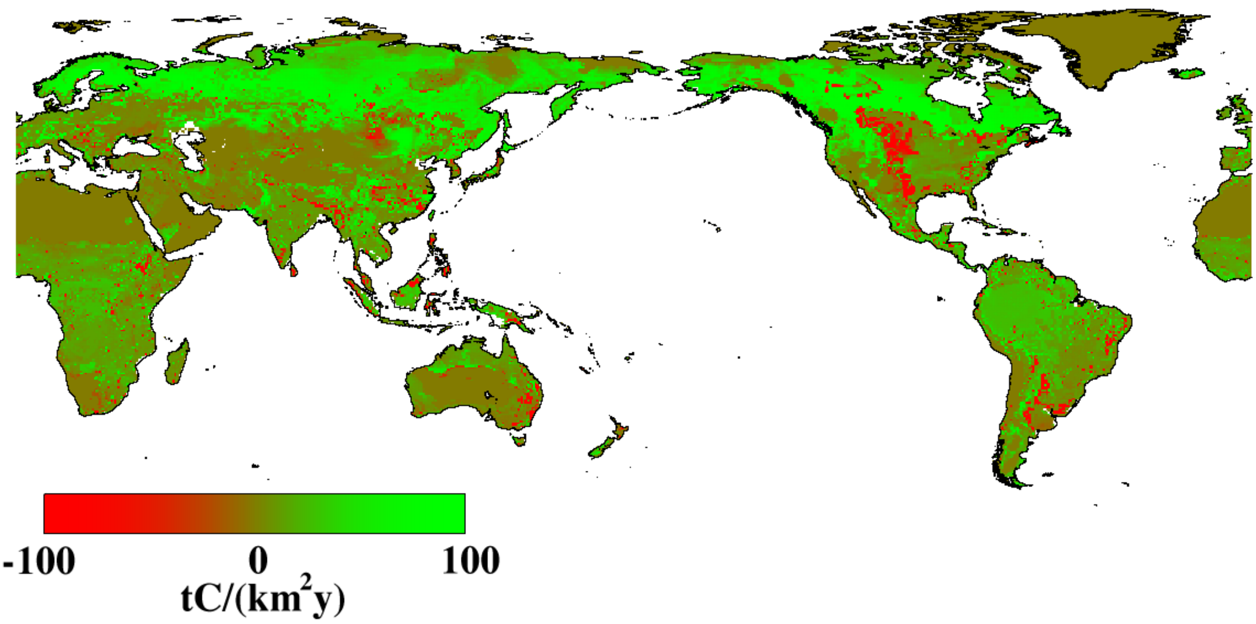

Figure C-2-2 Net ecosystem productivity in 1990.

Table C-2-1 Global carbon balances among sources and sinks (GtC)

scenario	anthropogenic emission	ocean	terrestrial	residual in atmosphere
		uptake	uptake	
1860-1989	336	119.8	55	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
IS92d	980	255.5	145.1	579.3
IS92e	2190	1012.4	179.6	998
IS92f	1830	802.9	170.4	856.7

4. Impact Models

4.1 Water Resources

Hydrological impacts are one of the most important aspects of the coming climate change. Changes in the magnitude, frequency and duration of hydrological factors influence the availability of water resources, flooding intensity as well as agricultural and natural terrestrial ecosystems. A rainfall-runoff process submodel was developed as one of the basic submodules of the AIM/impact model. This submodule consists of water balance and water transport components, and it is intended to provide basic hydrologic information to the impacts models of other sectors. Specifically, it creates gridded high resolution datasets of surface runoff, soil moisture, evapotranspiration and river discharge.

The major parameters of the hydrological model are elevation, soils, vegetation as well as precipitation, temperature, and potential evapotranspiration. Except for the first three, these parameters are endogenous variables of the total AIM system. As the coupling of the total system is not complete, we set soil and vegetation characteristics as well as elevation conditions at their current value.

The water balance component of the model is based primary on the models of Thornthwaite and Mather (1955) and their successors. The water balance among precipitation, snowmelt, evapotranspiration and streamflow is calculated for each grid cell in the simulation region. A number of climatological and geographical data sets were prepared from various sources. Precipitation and temperature values were taken from interpolated results of GCM experiments by several institutes. Soil moisture capacities were estimated using current vegetation classes and soil textures (Vorosmarty et al., 1989, Webb et al., 1993).

In the water transport component, the network topology of streams was determined from digital elevation data and modified with various hydrological maps of the analyzed regions. (See Figure M-1-1). Modelling of surface water retention time in each cell followed Vorosmarty's model (1989). The calculation was conducted with 1/4 degree grid cells. Current climate data are taken from anywhere with high spatial resolution.

Using this model as the base module, we then applied outcomes of GCM experiments (e.g. GFDL Q-flux experiment as the perturbed climate scenario), which provide precipitation and temperature. These experiments are based on a future CO2 level which is twice that of the current level. After interpolating spatially the results of the GCM experiment, so they could be overlaid with current climatic pattern which has a higher resolution than GCM outputs, these input conditions were used to prepare simulations of variability in the water discharge of each river basin. These simulations were conducted for a 10 year period after a 2 year initial simulation under each condition, and then the probability distributions of the monthly simulated discharges were identified in each grid cell. Based on these distributions, we estimated flood and drought severity with 10 year return period in the 2×CO2 condition.

Figure M-1-2 shows an output of such a simulation for flood discharge. The red indicates the area where the highest monthly discharges during a 10 year return period may be expected to exceed twice the current maximum monthly flow. Parts of India, China, and Japan could experience much higher flood levels.

Figure M-1-3 shows the changes in low flow conditions with 10 year return period. The red indicates areas where the lowest flow levels decrease by 40 or 50%. As shown in the figure, large areas of the region are forecasted to experience much drier periods. The spatial pattern of influence was not sensitive to the selection of a return period. Table M-1-1 presents estimates of the area affected by drought in Asian countries. Some South-East Asian countries are expected to suffer severe drought. Intensification of floods does not mean relief from drought. In fact, an increase in the incidence of both events is anticipated for some regions.

In order to assess the more direct impact of hydrological changes on the human dimension, we have to consider the effect of water control and management devices, as well as the intensity and style of water consumption. So far, we have estimated only population weighted average values of drought and flood intensities(Figure M-1-4). More information is required to comprehend the overall impacts of hydrological changes on human society. To clarify these impacts, we are now accumulating information about vulnerabilities to water related factors at the regional and subcountry levels.

Table M-1-1 Area affected by drought, percent of total area.

	No change	mild	severe		No change	mild	severe
Bangladesh	0	100	100	Lao PDR	33.3	59.5	7.2
Bhutan	0	100	0	Macao	100	0	0
Brunei	16.7	83.3	0	Malaysia	24.3	20.9	54.8
Burma	53.2	41.5	5.3	Mongolia	19.3	79.7	1
China	34.4	48.3	17.3	Nepal	0	100	0
Hong Kong	100	0	0	Pakistan	0	18.2	81.8
India	56.6	40.4	3	Philippines	91.6	0	8.4
Indonesia	24.6	32.7	42.7	Singapore	0	0	100
Japan	81.4	18.6	0	Sri Lanka	0	28.7	71.3
Kampuchea	84.8	15.2	0	Taiwan	100	0	0
Korea-PDR	65.6	30.5	3.9	Thailand	16.8	76	7.2
Korea-Rep	100	0	0	Vietnam	35.1	31.6	33.3

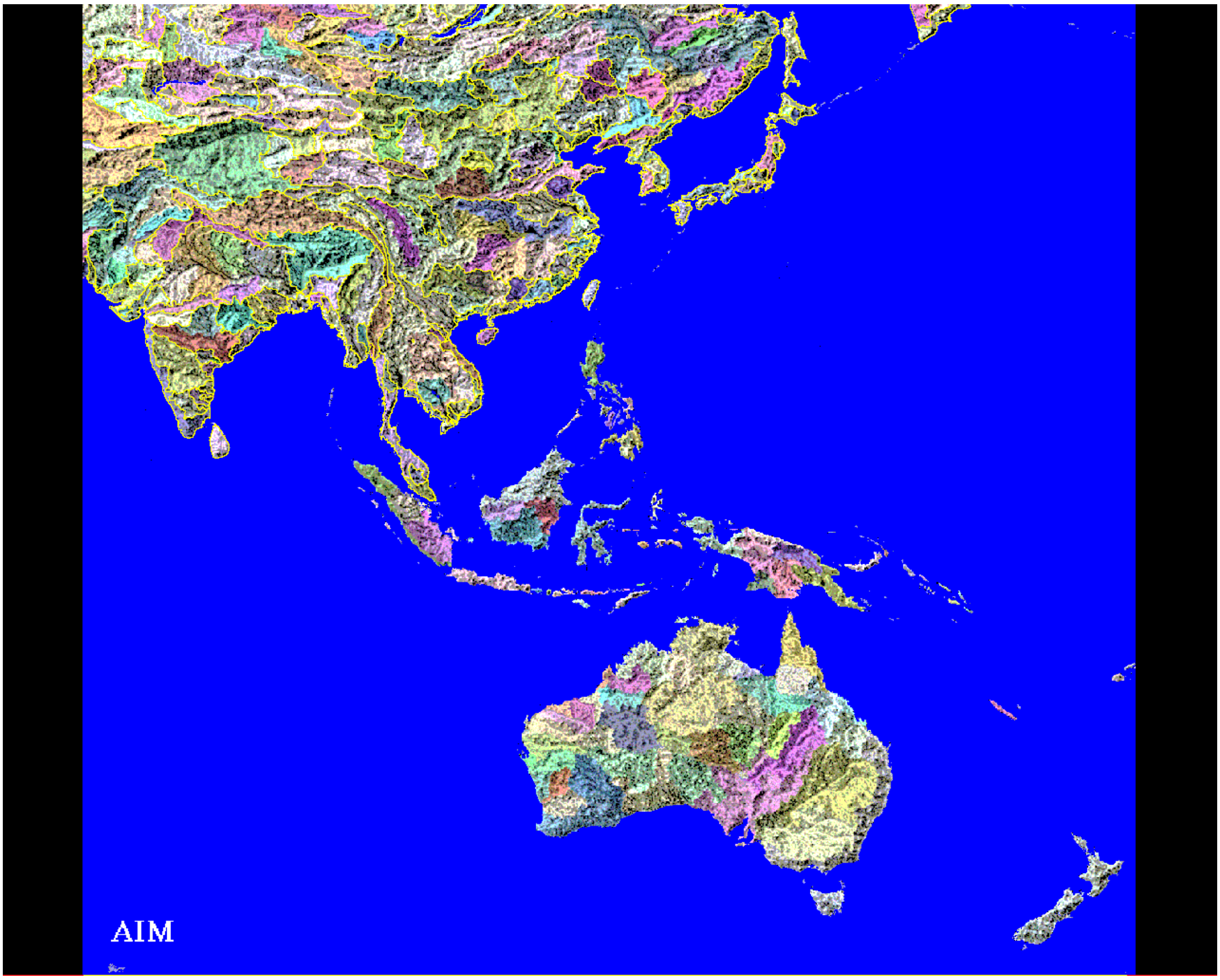

Figure M-1-1 Major watershed basins of the AIM study area.

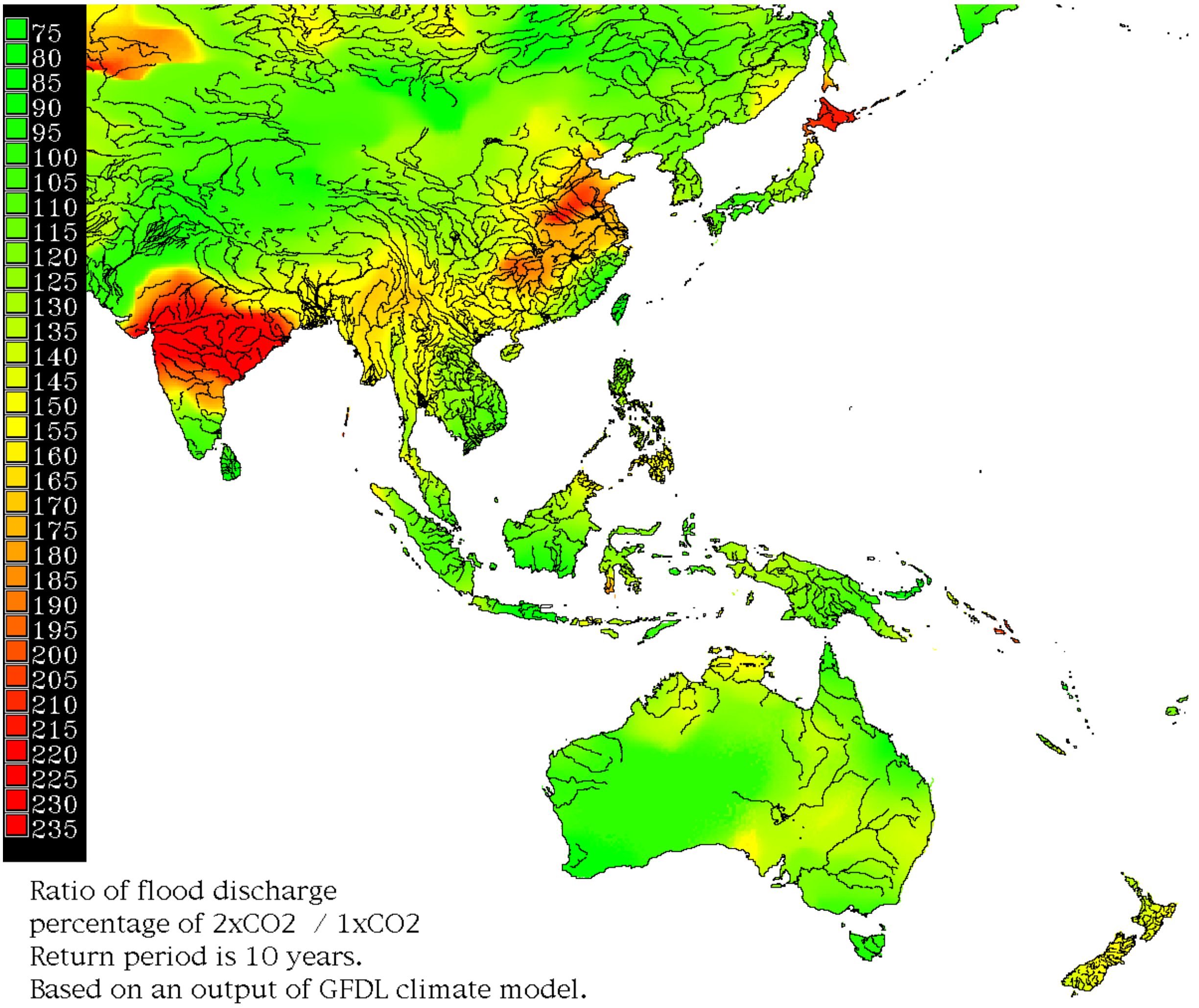

Figure M-1-2 Increase of flood discharge by climate change (%, Return period is 10 years.)

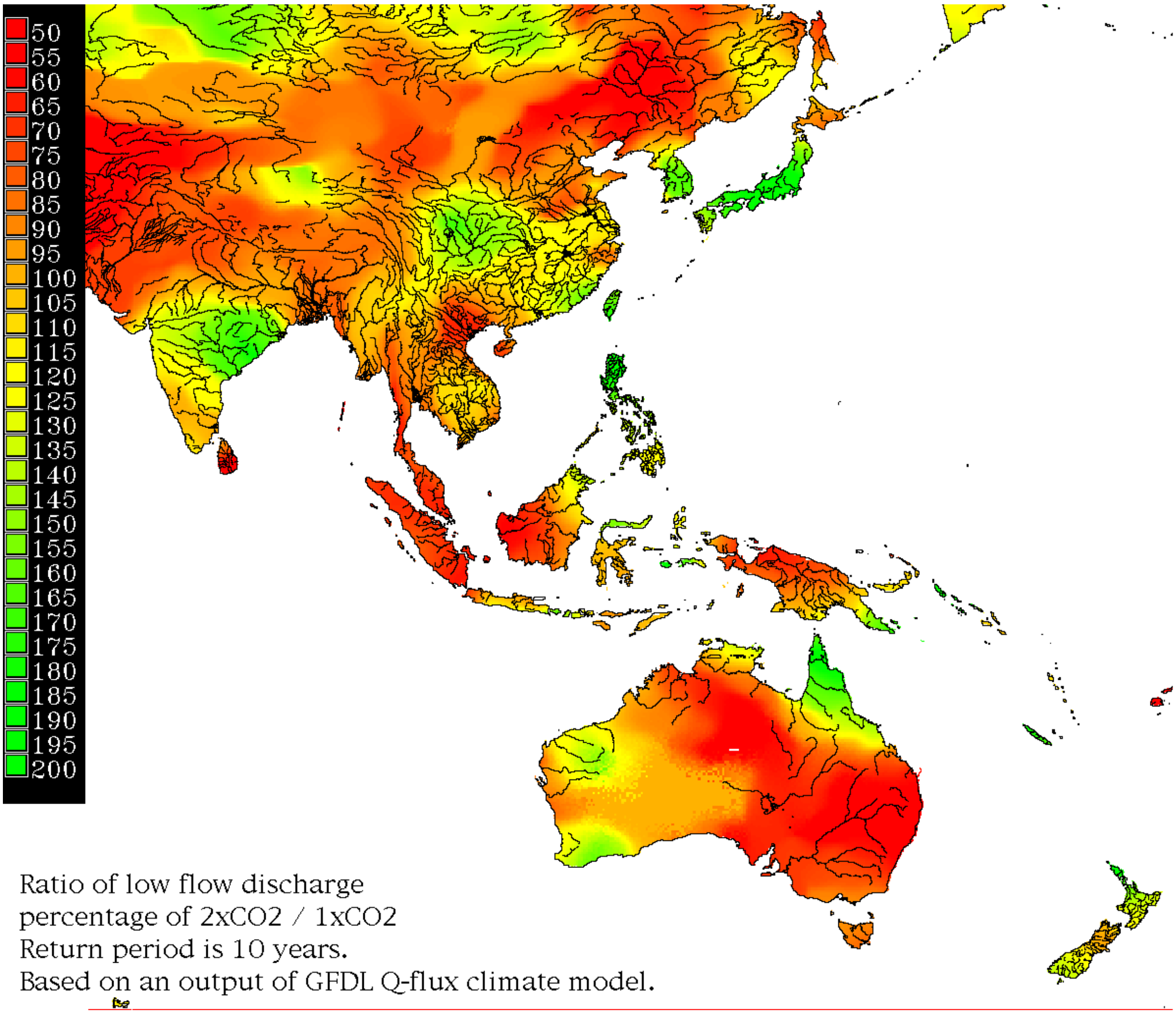

Figure M-1-3 Drought intensified by reduced minimum flows under climate change conditions, 2xCO_2 scenario. (% change, 10 year return period.)

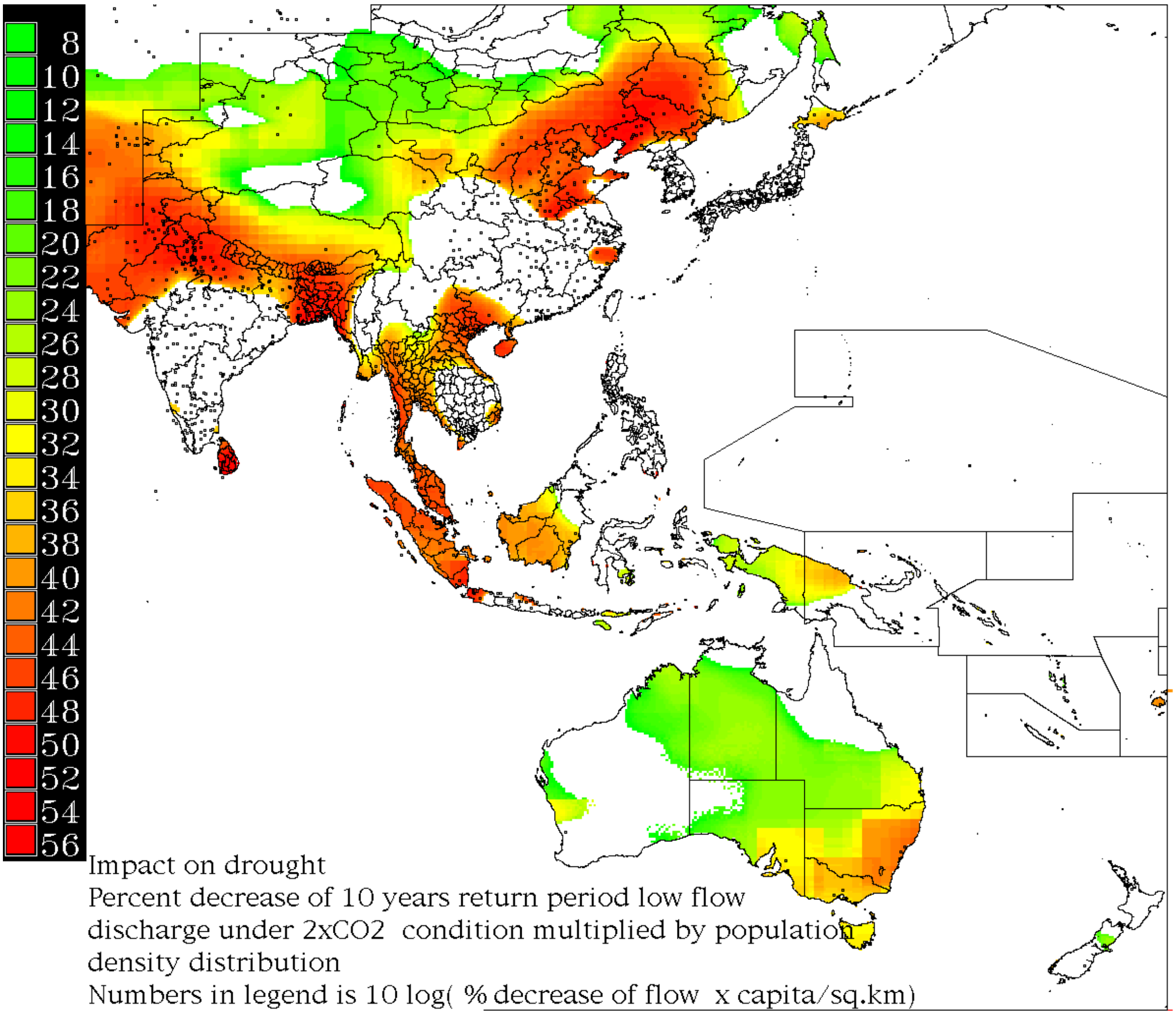

Figure M-1-4 Climate change drought impact on population.

4.2 Impact on Natural Ecosystems

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 which 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.

Holdridge (1947) developed a climatic division using two ecoclimatic indices, bio-temperature and annual precipitation. Bio-temperature is defined as the summation of average mean monthly temperature greater than 0℃ divided by 12. This boundary temperature, 0℃, assumes that a plant usually grows very slowly below the boundary. He classified climate into 7 divisions by this biotemperature. Then he used the ratio between annual precipitation and biotemperature to classify these 7 divisions further into 39 divisions by water requirement of plants. To make the interpretation of results easier, we reclassified these divisions after the example of Cramer and Leemans (1993).

The classification we adopted is shown in Table M-2-1.

We implemented this classification with the current climate conditions based on monthly average climate data sets of Legates and Willmott (1989) using 0.5 degree grid cells. As for the future climate pattern, 7 equilibrium GCM outputs (Table M-2-2) were interpolated into 0.5 degree grid cells, modified to have the global-averaged temperature estimated under the assumed socio-economic scenario (IS92a) and the medium climatic sensitivity (2.5℃), and overlaid with the current climate pattern.

The change of classification between current and 2100 can be seen from Figure M-2-1. The increase of tropical and subtropical forest in the Indian subcontinent and the transformation from cool forest to temperate forest in Eastern Europe can be observed. In the western part of North America, the dry area expands.

Table M-2-3 shows the ratio for each climate division under the current climate and the future climate estimated with each GCM output.

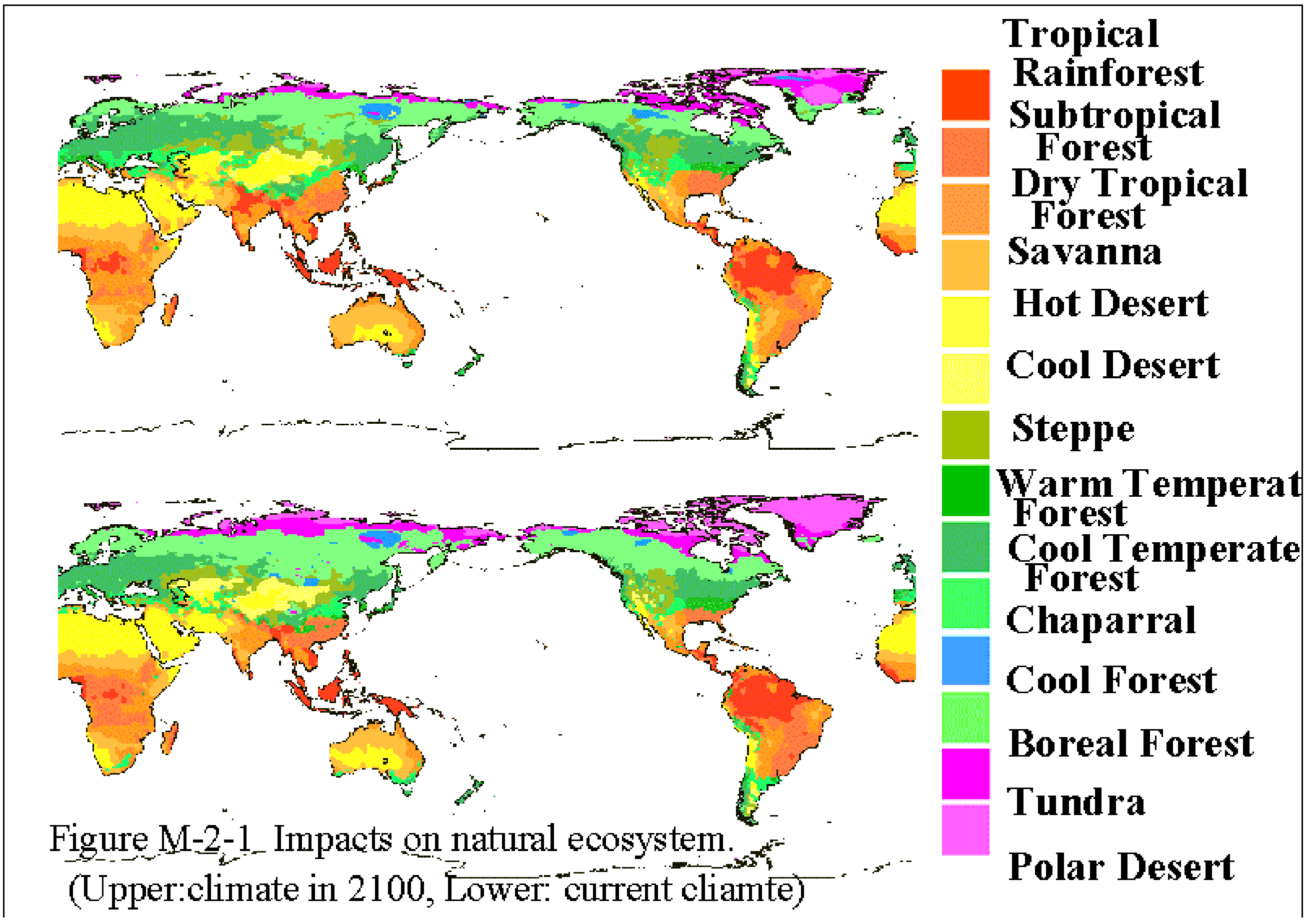

Figure M-2-1 Impacts on natural ecosystem (Upper:climate in 2100, Lower: current climate).

Table M-2-1 Climate classification used in this study.

	Classification adopted in this study
TRF	Tropical rainforest
StF	Subtropical forest
DTF	Dry tropical forest
Svn	Savanna
HtD	Hot desert
ClD	Cool desert
Stp	Steppe
WTF	Warm temperate forest
CTF	Cool temperate forest
Chp	Chaparral
Clf	Cool forest
Bof	Boreal forest
Tun	Tundra
Pld	Polar desert

Table M-2-2 General circulation model results used for classification of future climate.

GCMs	Date calculated	Resolution lat×long	1CO2 (ppm)
CCC	Nov.1989	3.75×3.75	330
GFDL	1984-85	4.44×7.50	300
GFDL Q-flux	Feb.1988	4.44×7.50	300
GFDL R-30	May.1989	2.22×3.75	300
GISS	1982	7.83×10.0	315
OSU	1984-85	4.00×5.00	326
UKMO	Jun. 1986	5.00×7.50	320

Table M-2-3 Ratio of each classification divisions in current and 2100 (7GCMs cases).

	Current Climate	CCC	GFDL	GFDL Q-FLUX	GFDL R30	GISS	OSU	UKMO	Average
TRF	8.26	9.39	11.69	11.14	17.61	13.18	16.07	10.3	11.93
StF	10.87	7.25	8.48	8.23	9.09	7.22	7.44	8.38	8.01
DTF	12.31	17.43	14.46	14.95	14.14	14.24	12.21	15.94	14.77
Svn	9.43	12.98	11.38	11.11	10.85	12.35	10.85	11.7	11.6
HtD	14.48	14.47	14.36	14.57	13.7	12.54	13.67	14.3	13.94
ClD	2.8	1.26	1.66	1.86	1.6	1.76	1.77	1.41	1.62
Stp	4.7	4.87	7.01	5.23	5.22	3.85	5.47	4.96	5.23
WTF	2.05	1.76	2.23	2.38	2.41	2.16	2.08	2.44	2.21
CTF	10.01	12.04	12.71	12.73	13.82	12.88	12.15	12.1	12.63
Chp	3.62	4.28	4.1	3.52	3.83	3.56	3.69	4.2	3.88
Clf	0.73	0.63	0.6	0.49	0.36	0.46	0.63	0.37	0.51
Bof	14.13	10.05	7.44	9.48	9.21	11.35	9.74	9.42	9.53
Tun	3.3	2.43	2.18	2.38	2.34	2.21	2.23	2.29	2.29
Pld	3.32	1.16	1.7	1.94	1.68	2.25	2	2.19	2.85
Total	100	100	100	100	100	100	100	100	100

4.3 Impacts on Malaria

Air and water pollution, as well as solid and hazardous wastes, affect human health directly. Global climate changes will also affect human health in the future in many ways. For example, global warming will result in increasing temperature and changing vegetation close to the ground. This will allow the habitat of the Anopheles mosquito, which is the malaria vector, to expand. In addition, the development period of the malaria protozoan will shorten and its reproductive potential will increase. As a result, it is predicted that the global malaria risk will increase. In order to estimate the risk quantitatively a sub-model has been developed for the AIM/impact. (Matsuoka et al., 1995)

Figure M-3-1 shows the assessment framework used in this study. The major components of the framework are the relationship between sporogony and temperature, and the eco-climatic index model which shows the climatic response of vectors. These components are complimented with soil moisture sub-module and outputs from the equilibrium experiments of GCMs. The primary climatic variables of this framework are surface temperature and precipitation distributed spatially and temporally for both the current situation and that expected under 2xCO2 climate conditions. (AIM Project Team, 1994)

Figure M-3-2 shows the calculated malaria potential under current and expected future climate conditions. The yellow indicates areas where the risk of malaria is mesoendemic and the red highlights areas where it is hyperendemic. Table M-3-1 shows the predicted expansion of the population living under endemic malaria when atmospheric CO2 doubles. The malarial risk in China, Indonesia and India increases due to this environmental change. It was concluded that the population at risk of infection with malaria will increase due to this environmental change. The population expected to be at risk of malaria infection will increase by 30% in the Asia-Pacific region.

Table M-3-1 An estimate of malaria risks caused by climate change,

Population at risk (million)	eported values		Present climate		after climate change	
Country	country population	malarious area	low risk	high risk	low risk	high risk
Afghanistan	18.14	10.39	3.65	0.00	18.14	0.00
Bangladesh	98.66	2.29	64.16	64.16	64.16	64.16
Bhutan	1.42	0.18	0.79	0.73	0.79	0.79
Cambodia	7.28	2.36	5.76	5.76	5.76	5.76
China	1059.52	975.82	646.93	54.60	807.30	132.33
India	750.90	728.33	721.40	522.31	731.45	648.04
Indonesia	163.39	155.63	122.00	74.76	138.17	107.62
Iran	44.21	34.83	12.92	0.00	29.76	0.00
Iraq	15.90	15.90	9.39	0.00	15.90	0.00
Laos	4.12	3.30	3.79	3.64	3.79	3.79
Malaysia	15.56	15.44	13.14	12.16	13.14	12.16
Myanmar	37.15	33.22	30.93	23.25	36.06	29.39
Nepal	16.63	10.76	14.09	4.76	14.95	10.22
Oman	1.24	1.24	0.92	0.00	0.48	0.00
Pakistan	96.18	96.18	91.89	0.00	95.86	0.00
Philippines	54.38	16.82	30.55	30.55	30.55	30.55
Saudi Arabia	11.54	4.51	8.68	0.00	7.97	0.00
Sri Lanka	15.84	11.51	12.67	9.17	12.67	12.67
Syria	10.27	6.38	1.91	0.00	10.27	0.00
Thailand	51.30	46.09	44.61	43.98	44.61	43.98
Turkey	49.27	49.27	14.78	0.00	49.27	0.00
U.A.E.	1.33	1.33	1.07	0.00	1.07	0.00
Viet Nam	59.61	44.03	45.96	41.37	45.96	45.96
Yemen	6.85	3.01	1.08	0.00	2.38	0.00
Papua	3.33	3.33	2.97	2.14	3.15	2.81
Solomon Is.	0.27	0.27	0.08	0.00	0.00	0.00
Vanuatu	0.14	-	0.00	0.00	0.00	0.00
total	2594.43	2272.42	1906.12	893.34	2183.61	1150.23

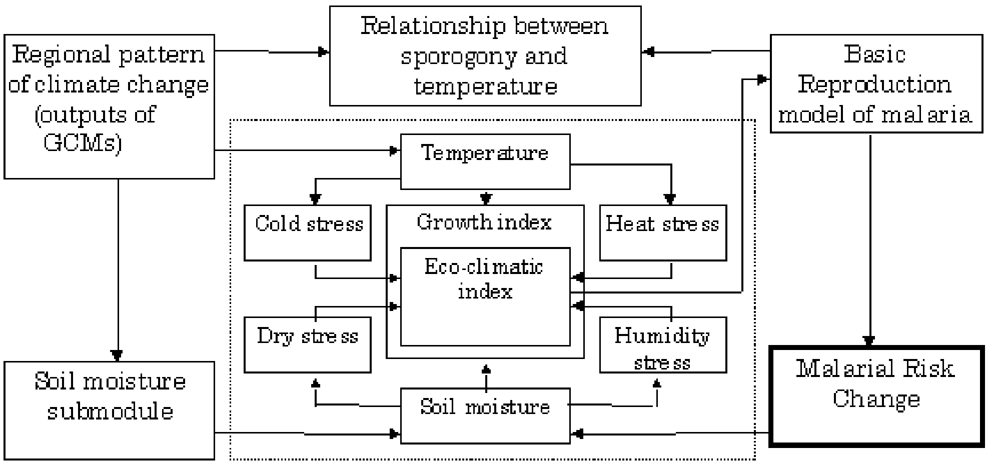

Figure M-3-1 The framework for estimation of climate change impacts on malaria infection.

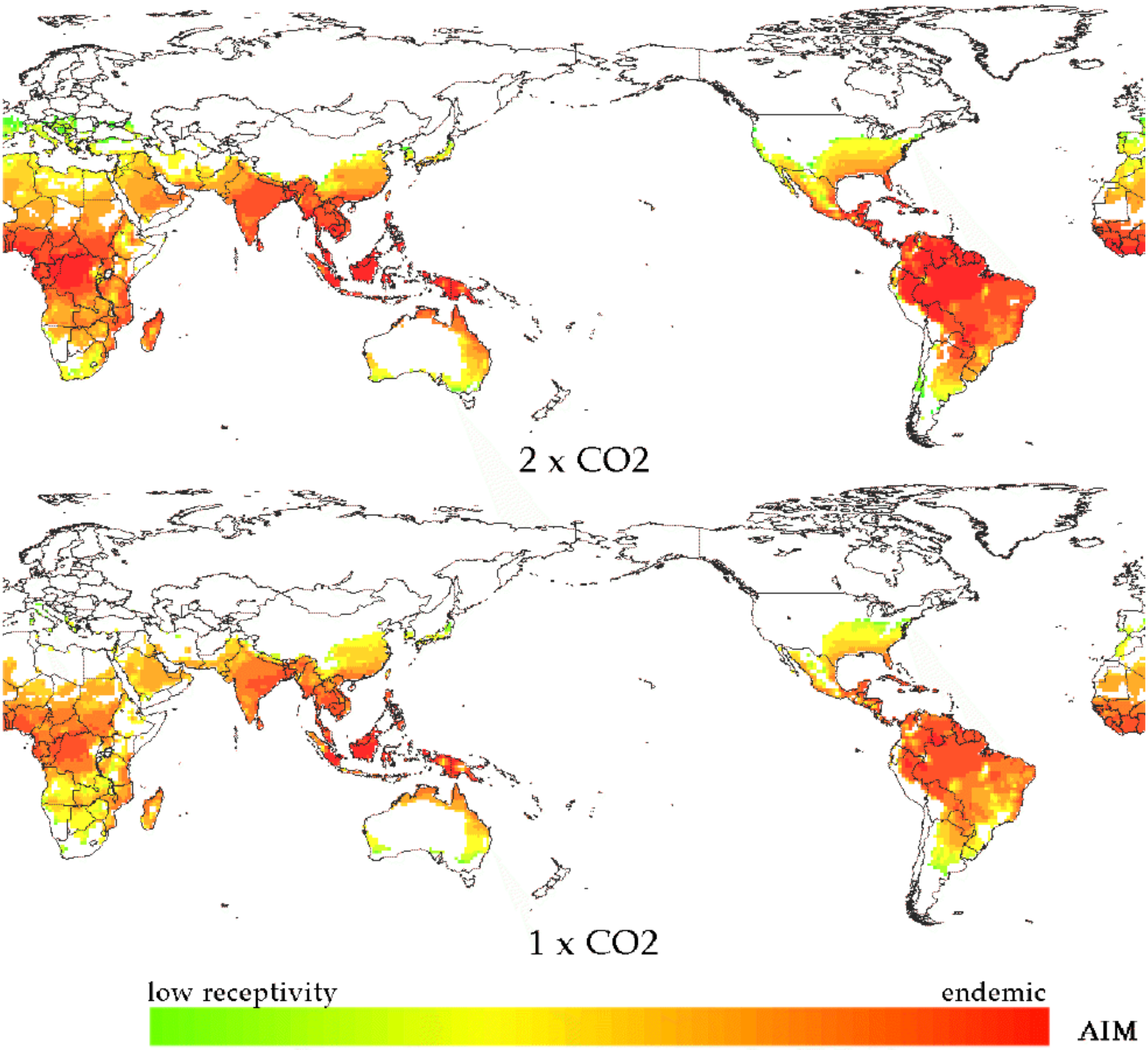

Figure M-3-2 Increase in area affected by malaria (Upper:2xCO2 climate change, Lower: current climate).

4.4 Agricultural Production

The productivity of crop land is strongly controlled by forthcoming environment changes. For example, future climate changes should have profound impacts on the potential yields of crops, and as a result, influence the distribution of cropping patterns in the Asia-Pacific area.

In order to evaluate the climatic change impact on agriculture, we need to undertake a study based on a framework which can evaluate related direct and indirect effects. Figure M-4-1 shows the framework of our agricultural impact study. The basic assumptions of this figure are (1) climatic change will directly affect land and water resources (primary effect), and (2) changes in land and water resources will affect economic activities (secondary effect).

As a preliminary assessment of this impact, we established a potential crop production model coupled with regional climate and soil environment data (AIM Project Team, 1996). The method of potential agricultural productivity estimation is based on that used by the Food and Agriculture Organization (FAO, 1978-1981). Days suitable for crop cultivation (growing period) are counted using climate data, then the crop growth during the growing period is simulated biophisically according to the growth characteristic parameters of each crops. The direct impact of CO2 concentration on crop growth (CO2 fertilization) is not considered in this study.

Rice and wheat are important staple crops throughout much of Asia so changes in their future productivity were calculated. Figure M-4-2 and figure M-4-3 shows the change of potential productivity of winter wheat and rice caused by climate change under the medium socio-economic scenario (IS92a) and the medium climatic sensitivity (2.5). Green indicates areas where increase of potential productivity is expected and red indicates decrease. The calculation was conducted with 5 minutes grid cells. For current, climate data were taken from the monthly average data sets of Legates and Willmott (Legates et al., 1989) with 0.5 degree grid cells. As for the future (2100) climate pattern, the equilibrium GCM output of Canadian Climate Center was interpolated into 0.5 degree grid cells, adjusted to have the globally averaged temperature estimated under the assumed scenario and overlaid with Legates'. Soil characteristics data were taken from Soil Map of the World (FAO/Unesco, 1994) with 5 minutes grid cells. As for rice, the northern portion of Asia can expect an increase in production, while the reverse is expected in central China and northern India.

Table M-4-1 shows the aggregated pattern of productivity changes among the major producing countries in Asia. The numbers in this table indicate the future percentage change compared with that in 1990. China, one of the major wheat producers in the world, will suffer from a yield decrease of 15 % for winter wheat, and 21 % for spring wheat. India, another major area producing 10 % of the world's wheat, is expected to suffer a 55 % decrease in the yield. Such potential yield changes, coupled with the increase in population density and the change in eating habits, will influence the global and regional food problem in a very complicated fashion.

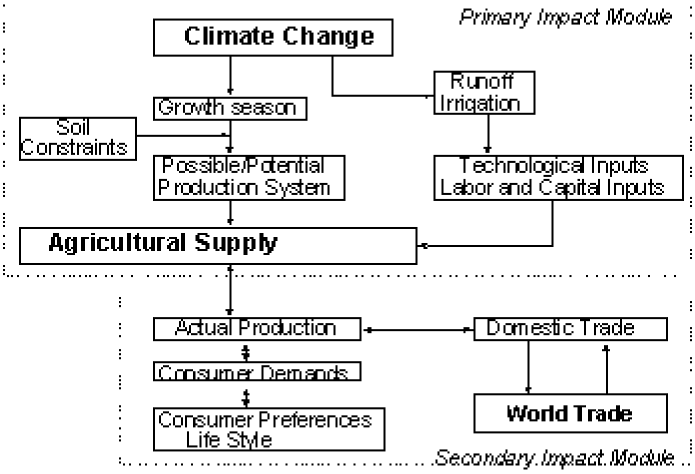

Figure M-4-1 The framework for an estimation of climatic change impact on agriculture.

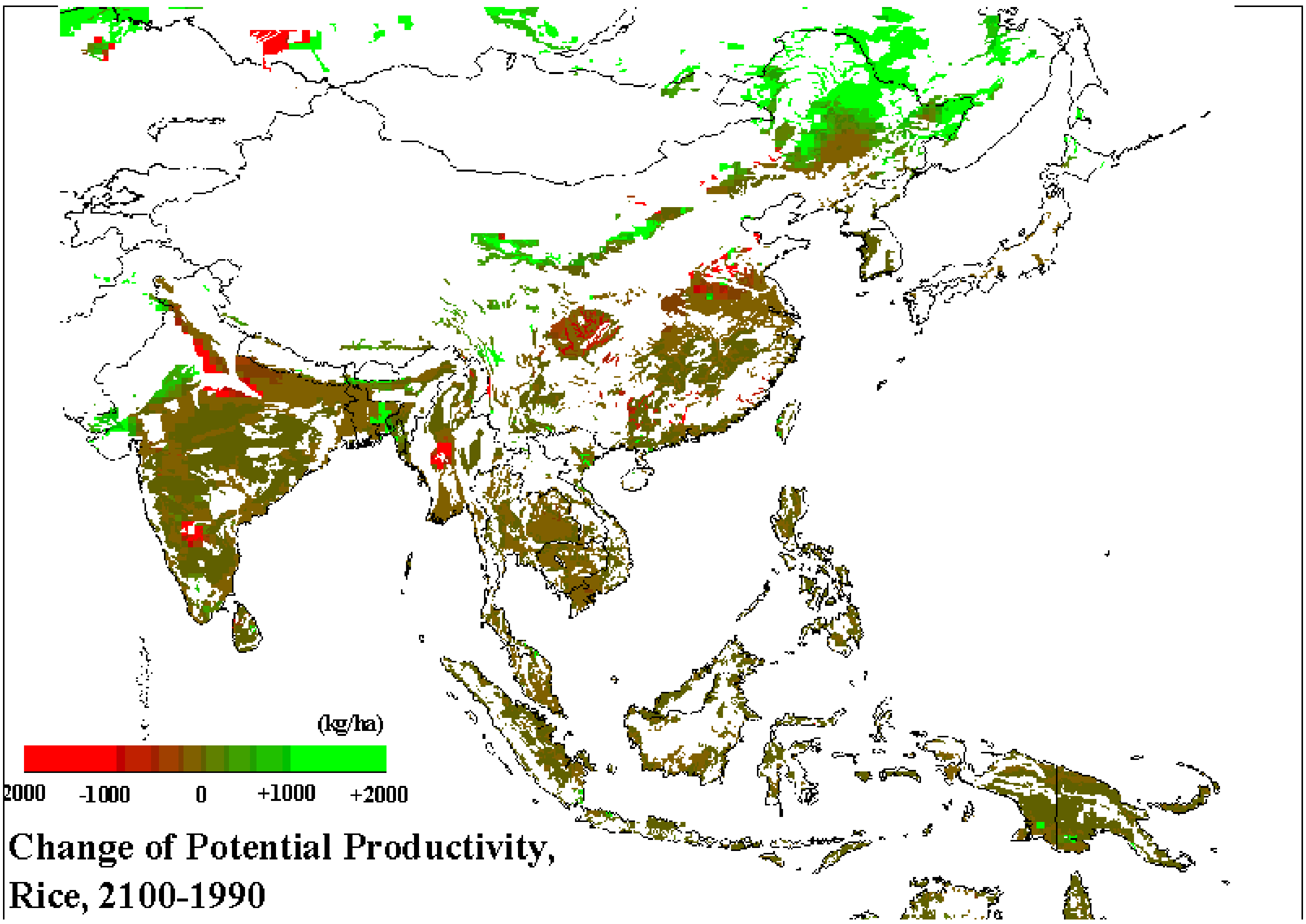

Figure M-4-2 Change in potential productivity of rice between 1990 and 2100.

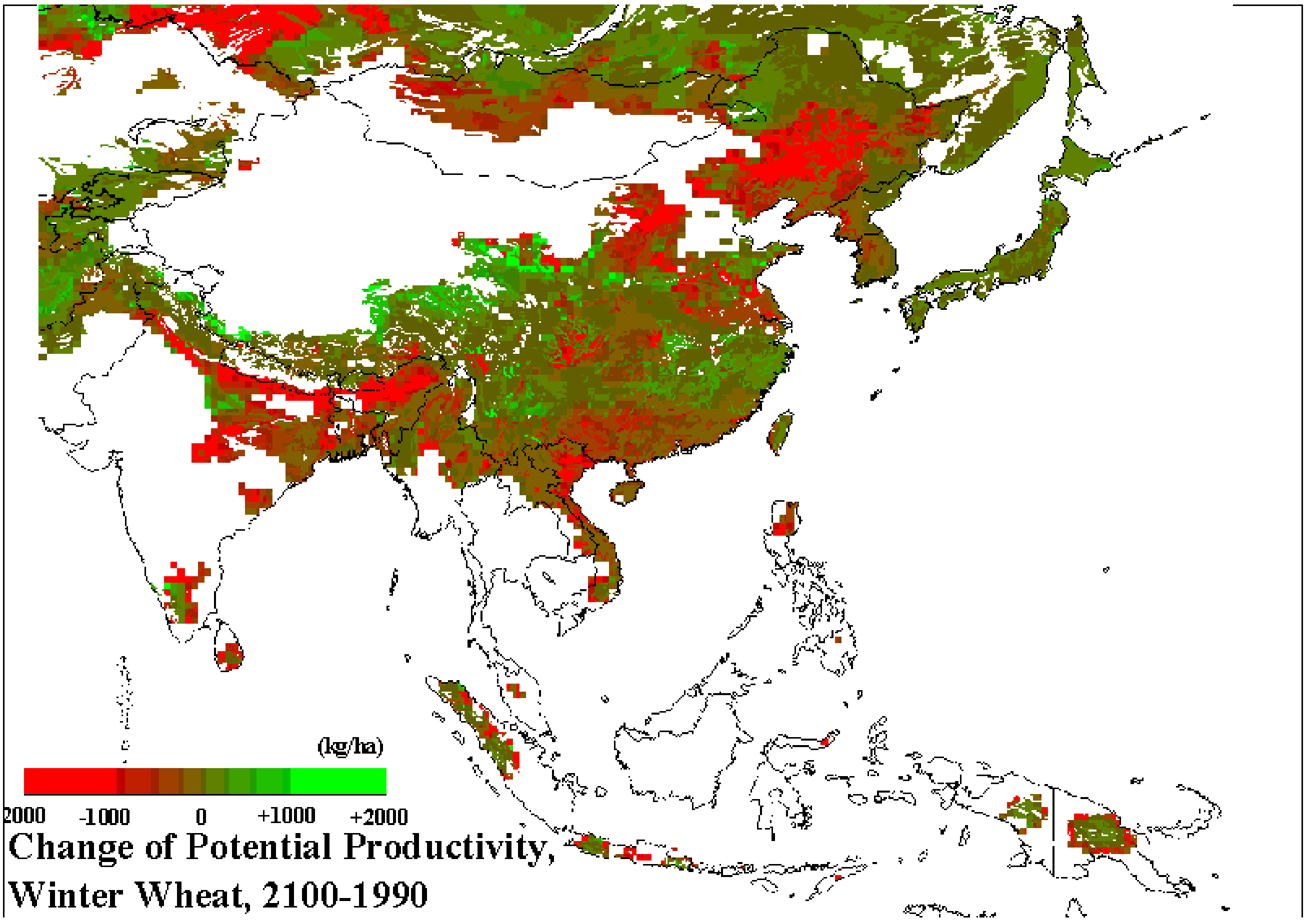

Figure M-4-3 Change in potential productivity of winter wheat between 1990 and 2100.

Table M-4-1 An estimate of potential crop production change caused by global warming in the Asia-Pacific region compared with 1990 and 2100 (%)

Country	rice	winter wheat	spring wheat	maize	sorghum	cassava	white potato
Bangladesh	3	-87					
China	10	-15	-21	-40	-54	28	-7
India	-3	-55					
Indonesia	-2						
Japan	3	5	-3	-51	9		
North Korea	0	-19	-6	-70	-87		-6
South Korea	-3	-13	-4				
Thailand	-4					-24	
Vietnam	0						

5. Collaboration Program

5.1 International Collaboration program

In 1994 the AIM project introduced an international collaboration program to further develop the AIM model and to make it available as a common analytical tool for policy studies in the region. This program consisted of three steps. First, support was provided to collaborative institutes to collect national data. Second, collaborative development of the country models was undertaken. Third, the model and database were transferred to the collaborative institutes for further use and development to meet their own needs.

In order to promote this collaboration program, the Environment Agency of Japan offered research funds and Eco-Frontier Fellowships to researchers for data collection and model development. In addition to these Environment Agency sources of support, researchers have been awarded Science and Technology Agency Fellowships, Ministry of Education Scholarships, Japan Foundation Fellowships, United Nations University Internships and other bilateral scholarships.

Collaborative research agreements have been arranged with the seven Asian research institutes shown in Figure F-1-1: Commission for Integrated Survey of Natural Resources and Energy Research Institute in China, Indian Institute of Management and Indira Gandhi Institute of Development Research in India, Korea Energy Economics Institute and Sangmyung University in Korea, and Ministry of State for Environment in Indonesia.

In addition to the seven institutes in Asia, the AIM team made contracts with American and European research institutes: specifically, the National Pacific North-West Laboratory in Washington and the International Institute of Applied Systems Analysis in Vienna. This facilitated the exchange of data and researchers. These exchanges enabled the best models from each group to be linked to those of the other institutes. Another partner is the United Nations University which promotes the development of the research network with Asian developing countries.

The AIM project team holds an annual workshop to present and discuss the latest research results from each collaborative institute and to set priorities for further work. A strong communication network and frequent collaborative activities have resulted from these initiatives.

Plans are being made to establish a training program to extend and enhance AIM objectives. It is hoped to enable new researchers in the partner countries to join the AIM team to gain modeling and analytical skills. These skills can then be used to direct the model to evaluate a wide range of policies in each country.

The AIM project has developed its models to a stage where greater emphasis can be placed on policy evaluation. Future workshops and conferences may be used to provide opportunities for greater dialogue between scientists and policymakers.

The AIM project team welcomes the addition of new collaborators to enable the project to address the policy needs of other countries and/or environmental issues.

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