2. Long-term Scenarios based on AIM Model

Tsuneyuki Morita[1], Kejun Jiang[2], Toshihiko Masui[1], Yuzuru Matsuoka[3], and Ashish Rana[1]

Summary. In order to respond to climate change, it is essential to describe possible future trajectories of greenhouse gas (GHG) emissions in terms of both nonintervention and intervention strategies. This chapter analyzes long-term GHG emissions scenarios according to alternative development paths for the world and major regions, based on the nonintervention emissions scenarios quantified by the Asian-Pacific Integrated Model (AIM). AIM has been revised and applied to the quantification of story lines for scenarios of socioeconomic development, and GHG emissions from energy use, land use changes, and industrial production processes are simulated. A wide range of mitigation policies have been adopted as responses to climate change. The results show that to achieve stabilization at a different GHG concentration level, it is essential to have a policy package to reach the target concentration level, rather than a single policy. Energy efficiency improvements and renewable energy introduction make a key contribution to the reduction of GHG emissions as a result of such a policy package. The mitigation costs could be small without a significant reduction in economic growth. The developing world could substantially reduce GHG emissions compared with nonintervention scenarios with sufficient knowledge transfer from the developed countries.

2.1 Introduction

The Asia-Pacific region, which covers Asia plus the Oceania region, excluding the Middle East, has half the world's population and is experiencing high economic growth, making it a major growth center in the global economy. Many countries in the region share problems that arise from rapid industrialization, population growth, and the increasing concentration of people in cities. With energy consumption increasing rapidly, the region is a major and growing driver of climate change. On the other hand, the region will suffer significant damage from climate change in terms of its impact on water resources, agriculture, ecosystems, and natural disasters. The Asia-Pacific region has been emerging as a dominant force for human responses to climate change.

To enable the Asia-Pacific region to respond to the climate change issue, the first step is to forecast the regional scenarios for greenhouse gas emissions in

[1] National Institute for Environmental Studies, Tsukuba 305-8506, Japan
[2] Energy Research Institute, State Development Planning Commission, Guohong Building, A-11 Muxidi Beili, Xicheng District, Beijing 100038, China
[3] Kyoto University, Kyoto 606-8501, Japan

relation to world emissions. Future emissions scenarios are mostly dependent on regional development patterns, and this region has a wide range of options for its development path. This means that future GHG emissions could be diverse, depending on the future development path. The recognition of such diverse non-intervention scenarios is very important in assessing the policy options for responding to climate change, since any reduction in the level of GHG emissions depends not only on the target climatic stabilization level, but also on the rate of increase in GHG emissions in a baseline non-intervention scenario.

It is known that a lot of emissions scenarios have already been quantified or published, including ones for the Asia-Pacific region. The most popular scenarios are the IS92 scenarios published by the IPCC in 1992 (IPCC 1992), and the number of other quantified scenarios comes to more than 150 for China, 30 for India, and 20 for South Asia (Morita *et al.* 1994; Morita and Lee 1998). However, none of these scenarios was explicitly analyzed from the viewpoint of future alternative paths for development in the Asia-Pacific region. Only some scenarios clarified the relationship between development patterns and emissions at the global level (Lashof and Tirpak 1990; WEC 1993). The IPCC activities for the Special Report on Emissions Scenarios (SRES) (Nakicenovic *et al.* 2000) gave us an opportunity to analyze the Asia-Pacific emissions scenarios with explicit consideration of the regional paths for future development.

This chapter presents some results from the AIM model simulations for emissions scenarios for the Developing Asia-Pacific countries and the world with and without climate change policies. In the next section, SRES scenarios are briefly introduced. This is followed by a description of the model. Following this, the results, findings and conclusions are given.

2.2 SRES Scenarios

Each scenario links one of four “story lines” with one particular quantitative model interpretation. All the scenarios based on a specific story line constitute a scenario “family.” The following paragraph describes four story lines, driving forces of the SRES scenarios and their relationships. Each story line represents the playing out of different social, economic, technological and environmental developments (or paradigms), which may be viewed positively by some people and negatively by others. Possible “surprise” and “disaster” scenarios were excluded.

The main characteristics of the four SRES story lines and scenario families are:

- The A1 story line and scenario family describes a future world of very rapid economic growth, low population growth and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among the regions, capacity building and increased cultural and social interaction, with a substantial reduction in regional disparities in per capita income.
  Scenarios in the A1 family were categorized into four groups according to their technological emphasis—on coal (A1C), oil and gas (A1G), non-fossil fuel

energy sources (A1T) or a balanced mix of all three (A1B). The last group, a balanced mix, is simply noted in this chapter as "A1".

- The A2 story line and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, resulting in high population growth. Economic development is primarily regionally oriented, and per capita economic growth and technological change are more fragmented and slow compared to other story lines.
- The B1 story line and scenario family describes a convergent world with rapid change in economic structures toward a service and information economy, reduction in materials intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions for economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.
- The B2 story line and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with less rapid, and more diverse technological change, but with a strong emphasis on community initiatives and social innovation to find local and regional solutions. While policies are also oriented towards environmental protection and social equity, they are focused on the local and regional levels.

2.3 Model Description

In order to quantify GHG emissions from various sources, a new linkage module of the integrated assessment model was developed and comprehensive storylines of development were established. Future projections were made using the integrated assessment model for energy use, energy production, industrial processes, land-use changes, agricultural production, livestock, etc. from 1990 to 2100 according to the storylines. These projections were finally converted to the GHG emissions scenarios.

A model framework called the AIM/Emission-Linkage model was developed for this emissions scenario study. It links several models to calibrate the data and perform scenario quantification. An important point to note is that the development pattern of the developing Asia-Pacific region should be analyzed in relation to the global regime since international issues will strongly influence the region's future environment, economy, and energy activities. Scenarios for the developing Asia-Pacific region should also be closely related to scenarios for other regions. Hence, the model framework adopted was a global model divided into key regions.

Major emission sources including energy activities, industries, land use, agriculture, and forests can be simulated in the model framework. The structure of the AIM/Emission-Linkage model comprises two kinds of top-down models – energy and land-use – and a set of bottom-up models as shown in Fig. 1. The GHG emissions from energy consumption and energy production are simulated by

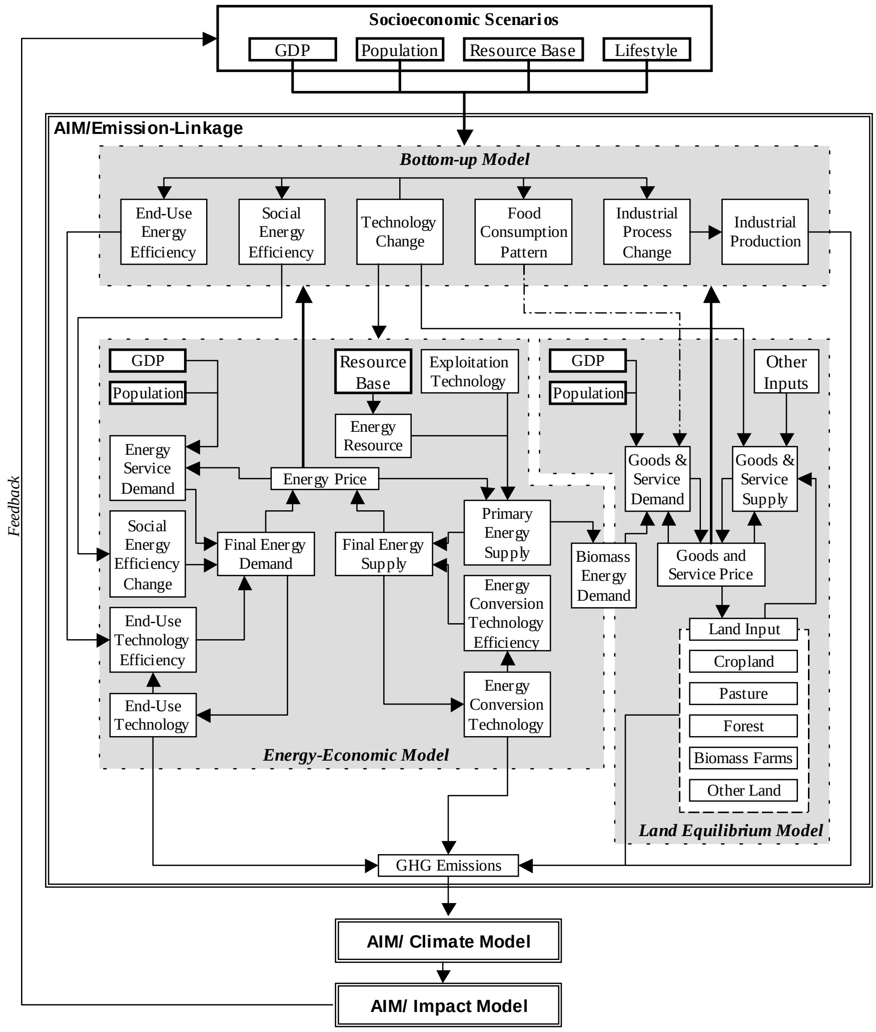

Fig. 1. Outline of the AIM/Emission-Linkage model

the energy model. GHG emissions from land use are derived from the land use model, while GHGs from other emission sources are calculated by simplified industry process models that describe the relationship between GDP per capita and industrial product outputs.

The energy sector top-down module was developed based on the revised Edmonds-Reilly-Barns (ERB) model (Edmonds *et al.* 1983; Edmonds *et al.* 1995), which is widely used for the analysis of emissions. The top-down model for the energy sector provides a consistent, conditional representation of economic, demographic, technical, and policy factors as they affect energy use and production. It is a macroeconomic partial-equilibrium model that deals with energy activities and forecasts energy demand over the long term. It uses the gross domestic product (GDP) and population as future development drivers, combined with other energy-related parameters to forecast energy demand based on the supply and demand balance. Three end use sectors—industrial, residential and transportation—and one energy conversion sector— the power generation sector—are specified in the model. Energy efficiency is described by both technology efficiency and social efficiency improvements. A number of technologies in these four sectors are listed in the model to present different possibilities of technological progress. A link between the bottom-up energy model and the top-down energy model has been developed. A detailed energy use analysis for the developing Asia-Pacific region from the bottom-up model drives the energy use pathway before 2030, while a simplified linkage is presented for other regions in the model. The linked AIM/Enduse model and the energy top-down model comprise the energy model in the model framework.

The top-down land use model is based on the Global Trade Analysis Project (GTAP), which was established in 1992 (Hertel 1997). This model is an applied general-equilibrium model that divides the world into multiple regions. For the sake of this analysis, the land uses for agriculture, livestock, and forests are considered, and the biomass energy demand is considered exogenously. It is designed to explicitly model agriculture and land use, endogenously determine emissions resulting from land use changes, and explore the use of biomass as an element of a strategy for anthropogenic carbon emissions.

The bottom-up models were prepared using the original AIM bottom-up components, which can reproduce detailed processes of energy consumption, industrial production, land use changes, and waste management as well as technology development and social demand changes. The AIM/Enduse model is part of the Asian-Pacific Integrated Model (AIM), which was developed by the National Institute for Environmental Studies (NIES) and Kyoto University (AIM Project Team 1996; Hibino *et al.* 1996). It is a bottom-up, energy technology model. Based on detailed descriptions of energy services and technologies, it calculates the total energy consumption and production in a bottom-up manner. This model has been used to analyze several key countries in the Asian region, including China, India, Indonesia, and Japan. AIM/Enduse models for key Asian developing countries have been constructed, and the results of analyses using this model have been reported (Jiang *et al.* 1998; Hu *et al.* 1996). Among the advantages of bottom-up models, the most important is that their results can be interpreted clearly because they are based on detailed descriptions of changes in human activities and technologies.

The AIM/Emission-Linkage model combines these various components to calculate future GHG emissions in a relatively wide ranging analysis. For the purpose of the model, the world is divided into nine regions: USA, Western Europe, OECD countries and Canada, Pacific OECD, Eastern Europe and the former Soviet Union, Centrally Planned Asia and China, South and East Asia, the Middle East, Africa, and Central and South America. The model has a time horizon extending from 1990 to 2100. The time steps are in units of 5 years up to 2030, followed by time steps at 2050, 2075, and 2100. The GHGs covered in the nonintervention emissions scenarios are CO_2, N_2O, CO, NO_x, and CH_4. Since SO_2 has a strong influence on climate change and is an important pollutant in local areas (Gan 1998; Qi *et al.* 1995), it is also included. CO_2 emissions are analyzed in the intervention scenarios.

2.4 Emissions Scenarios without Climate Change Policies

2.4.1 Assumptions

The data has been compiled from several sources. Based on the descriptions of development patterns (story lines), the quantified key scenario drivers for each scenario used in our model for the Developing Asia-Pacific and the world are listed in Table 1.

The population data resources include estimations by the United Nations and IIASA. There are three patterns for population growth: low (for scenarios A1 and B1), medium (for scenario B2), and high (for scenario A2). The high and low

Table 1. Key scenario drivers assumed for the Developing Asia-Pacific countries and the World

	A1	A2	B1	B2
Developing Asia-Pacific population	4.2 billion in 2050; 2.9 billion in 2100	5.8 billion in 2050; 7.3 billion in 2100	4.2 billion in 2050; 2.9 billion in 2100	4.7 billion in 2050; 5.0 billion in 2100
Developing Asia-Pacific GDP growth rate	6.4% from 1990 to 2050, 4.6% from 1990 to 2100	3.9% from 1990 to 2050, 3.4% from 1990 to 2100	5.6% from 1990 to 2050, 4.0% from 1990 to 2100	5.7% from 1990 to 2050, 3.8% from 1990 to 2100
World population	9 billion in 2050; 7 billion in 2100	15 billion in 2100, Higher growth in non-OECD countries	9 billion in 2050; 7 billion in 2100	11.7 billion in 2100
World GDP	$550 trillion in 2100, High growth in non-OECD countries	$250 trillion in 2100	$350 trillion in 2100	$250 trillion in 2100
GDP/capita trends	OECD: more than $100,000 by 2100; Non-Annex I: >$70,000 by 2100, $14,000 by 2040	Lower growth in non-OECD countries Disparity rises.	Annex-I: more than $90,000 by 2100; Non-Annex-I: >$30,000 by 2100; Global $40,000	Disparity remains; GDP/capita of OECD is 7 times that of non-OECD (now 13 times).
AEEI	1.2%-1.6%	0.8%-1.0%	1.6%-1.8%	1.0%-1.2%
International trade	High trade Low trade cost	Low trade across regions, high trade within regions; High trade cost	High trade Low trade cost	Low trade across regions High trade cost
Urbanization	Rapid increase	Increase in non-OECD Decrease in OECD	Increase	Decrease

population assumptions were adopted from the research output of IIASA, while the medium population assumptions were taken from the medium case of the World Bank population forecast.

Energy resources in the model include not only conventional energy such as coal, crude oil and natural gas, but also unconventional sources of oil and gas. The energy resources in the simulation are ultimately the recoverable reserves. The energy reserves available for exploitation are determined by progress in energy production technologies, which are described in the story lines. For example, in the A1 scenario, available energy reserves are taken to be plentiful by assuming high levels of improvements in the efficiency of energy exploitation technologies that will make unconventional forms of energy available. Due to the large volume of energy supply, several sub-scenarios were defined according to this possible pathway of energy supply. The A1C scenario describes large amounts of available coal reserves. Oil and gas supply is high in the A1G scenario, while the A1T scenario assumes progress in high technology for renewable energy. A1B is a balanced scenario taking elements from these A1 scenarios. Energy resource availability in Scenario A2 mainly relies on energy resources distribution among the regions. The low technological progress assumption for energy production in scenario A2 means that energy exploitation mainly relies on conventional energy. Due to concern for environment, energy resource pressure is not so great for the B1 and B2 scenarios.

The grades of energy resources used in the model differ on the basis of exploitation costs. When combined with the level of improvements in exploitation technology efficiency (expressed as the rate of improvement in the marginal cost of producing energy), the graded energy resource exploitation cost determines the primary energy production cost (price). Table 2 shows the total for the energy resources assumed in the model.

Improvements in energy efficiency mainly rely on the parameters of social efficiency improvements and technological efficiency improvements based on the energy market. Social efficiency improvements were determined according to factors such as changes in the economic structure, the trend toward dematerialization, patterns in people's lifestyles, transportation, etc. Technological efficiency improvements were set up according to the introduction of different technologies. For example, on the demand side, efficiency was assumed to be

Table 2. Assumed total energy resources

	Conventional oil	Conventional gas	Coal	Unconventional oil	Unconventional gas
OECD	1,271	2,186	56,808	12,709	73,062
CIS & EE	1606	2,679	62,439	451	36,628
Developing Asia-Pacific	912	657	20,385	556	9,379
ROW	7,325	3,449	3,368	4,403	45,026
World	11,114	8,971	143,000	18,119	164,095

Unit: Exa (10^{18}) joule.

relatively low in the A1 scenarios since low energy prices provide very little incentive to improve end use energy efficiencies and high income levels will encourage people to pursue comfortable and convenient lifestyles (especially in the household, services, and transportation sectors). This will result in the consumption of much more energy. Efficient technologies are not fully introduced into the end use side, dematerialization processes in the industrial sector are not well promoted, lifestyles become energy intensive, and there is greater use of private motor vehicles in developing countries as per capita GDP increases. Thus, the final energy use in scenario A1 is much higher than in the other scenarios (A2, B1, B2), while the difference in per capita final energy use between Annex 1 countries and non-Annex 1 countries in 2100 is small. In determining energy efficiency in the Developing Asia-Pacific, attention was paid to the processes of social and economic restructuring that have been underway since the 1980s. This is a key issue for short- and medium-term analyses of the Developing Asia-Pacific countries.

2.4.2 Quantified scenarios

From the parameters used for the inputs, outputs were obtained from the model on energy use and GHG emissions.

Global primary energy use will keep increasing up to 2100, except in scenario B1, in which primary energy starts to decrease after 2075. The range for primary energy use by the end of the next century is quite large and is 6.7 times that in 1990 for A1C, while it is only 2.3 times for B1. The primary energy intensity has a similar range, which is from 2.41 GJ/MUS$ for B1 to 7.7 GJ/MUS$ for A2, while it was 16.5 GJ/MUS$ in 1990.

With regard to primary energy demand in the Developing Asia-Pacific, all of the scenarios show increases to support the demand for economic development at least up to 2075, and then a decrease is found for scenario B1. The highest primary energy demand in 2100 (scenario A1C) is 10.5 times that in 1990, while the lowest (scenario B1) is 3.7 times. The growth rate for primary energy use in the Developing Asia-Pacific is higher than the global average. Per capita primary energy use ranges from 75 to 274 GJ, compared with 181 to 403 GJ for OECD countries. A significant catch-up effect is seen in per capita primary energy use although it is still lower than that of the OECD countries. The primary energy mixes also show highly significant changes during the next century. However, the changes are quite different for each scenario, in accordance with the conditions described in the story lines. Figure 2 shows the primary energy mix for scenario A1B, in which renewable energy becomes dominant.

GHG emissions follow the pattern of energy use in the case of CO_2 and SO_2 emissions. Due to the introduction of renewable energy, CO_2 emissions reach a peak between 2030 and 2050 (Fig. 3), except for scenario A2 for the world and A2 for the Developing Asia-Pacific in which coal use will continue and renewable energy use will be limited. Per capita CO_2 emissions in the Developing Asia-Pacific rise from 0.56 tons of carbon (t-C) in 1990 to range from 0.97 to 1.9 t-C in

2030, and 0.84 to 4.8 t-C in 2100, while the corresponding data for the OECD countries are 3.34 t-C in 1990, 2.55 to 4.71 t-C in 2030, and 1.13 to 5.73 t-C in 2100. All the scenarios show that per capita CO_2 emissions do not reach the level of the OECD countries in 2100.

By the year 2100, the range of most GHG emissions scenarios expands significantly for both the world and the Developing Asia-Pacific. For example, CO_2 emissions in these scenarios for the world in 2100 range from 6.0 Giga tons of carbon (Gt-C) per year to 36.8 Gt-C per year, a factor of more than 6 (Fig. 4). They are 2.4 Gt-C, 13.9 Gt-C and 5 Gt-C for the respective scenarios for the Developing Asia-Pacific. Consequently, these results highlight how future emissions estimates can vary according to different development pathways.

Global SO_2 emissions reach a peak between 2020 and 2050, and then start to decrease (Fig. 5). The emissions fall below the 1990 level by 2050 except for scenario A1C. The global SO_2 emissions trajectory follows that of the developing countries. The Kuznets curve was introduced to calculate SO_2 and NO_x emissions. Based on the historical data, per capita GDP is a key factor in controlling the level of SO_2 emissions. Since the per capita GDP in the Developing Asia-Pacific is rapidly increasing, all SO_2 emissions decrease after 2030 (Fig. 6). Emissions are

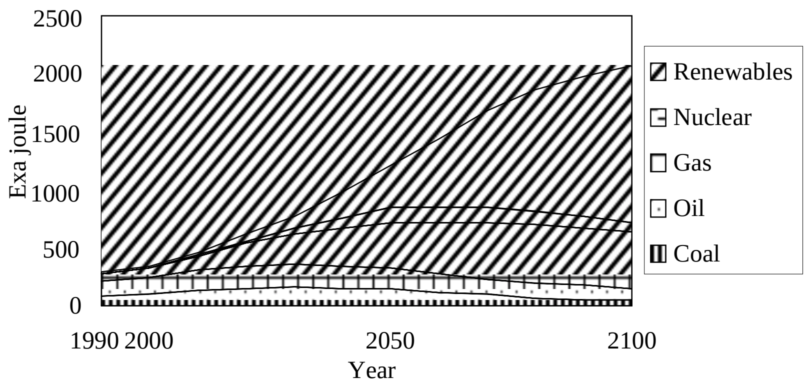

Fig. 2. Global primary energy in A1B scenario

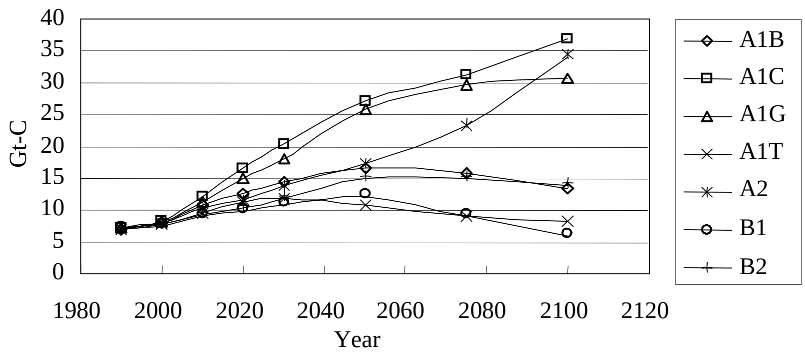

Fig. 3. Global CO_2 emissions

higher in scenario A1C due to the large amount of coal used. The range of SO_2 emissions in 2100 is relatively smaller than that of other gases. This is the result of domestic environmental policies to control pollutant emissions rather than climate change policies.

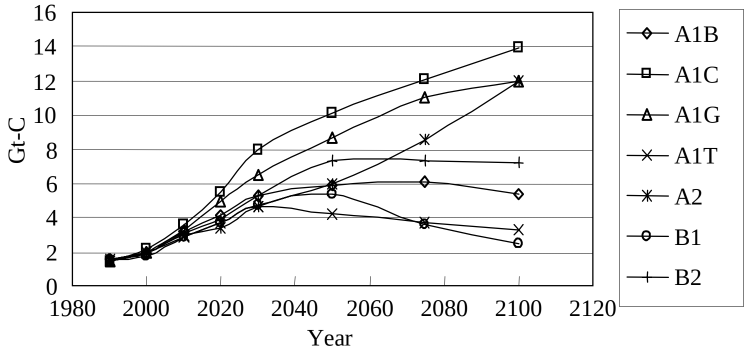

Fig. 4. CO_2 emissions in Developing Asia-Pacific

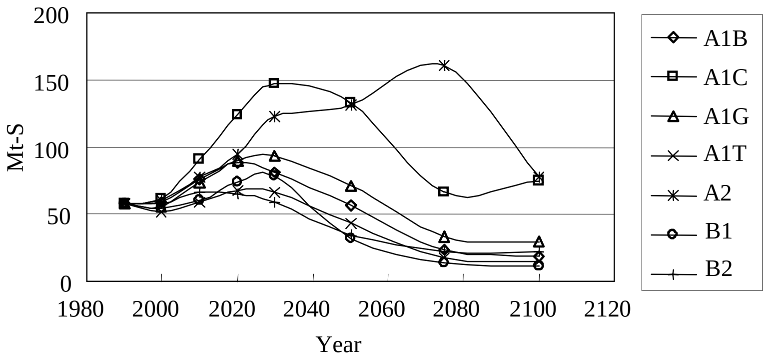

Fig. 5. Global SO_2 emissions

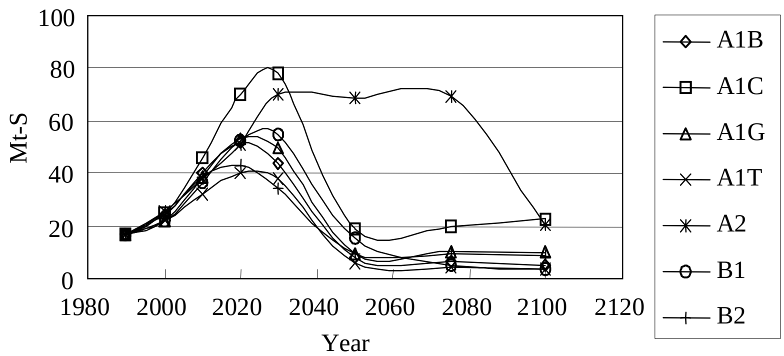

Fig. 6. SO_2 emissions in Developing Asia-Pacific

It is interesting to look at the A1 scenario emissions family. This scenario family has a quite wide diversity. Scenarios A1B and A1T have low emissions, indicating that it is possible for the Developing Asia-Pacific to maintain a high economic growth rate with low emissions. Energy end use technology improvements and large-scale renewable energy recovery will play key roles in the trajectory. Scenarios A1C and A1G have high emissions due to the huge fossil fuel consumption. Their emissions are among the highest of all the groups. If the world follows either of these paths, new technologies for emissions control and new policies will have to be introduced. The same applies to NO_x emissions.

2.5 Emissions Scenarios with Climate Policies

Scenarios in the previous section (SRES scenarios) do not include any explicit mitigation or stabilization policies or measures. As such, they include scenarios ranging from rapidly increasing to decreasing emissions over the next one hundred years. New scenarios based on the wide range of SRES scenarios were quantified as a set of mitigation (policy intervention) scenarios for stabilizing atmospheric GHG concentrations. Therefore, the policy/technology measures assumed in these scenarios are strongly affected by baseline emission trajectories of SRES scenarios as well as by their socio-economic assumptions. They describe mitigation measures and policies (the additional climate initiatives) that would have to be undertaken, in each SRES scenario "world," to achieve stabilization at different levels (450, 550, 650, and 750 ppmv). As a result, the analysis and comparison of scenarios with climate policies (AIM stabilization scenarios) can supply very systematic data to clarify the relationship between the relative contribution of the development path and climatic policy/technology measures. Knowledge of these relationships can in turn enable us to assess robust policy/technology options for different future development paths.

2.5.1 Policy package design for stabilizing global climate

The AIM stabilization scenarios were simulated to quantify the various pathways to reach the desired target for global GHG concentrations by the end of the 21^{st} century. A policy package was designed for this quantification based on the diverging baseline scenarios.

The policy package used in the AIM stabilization scenarios is as follows:

- Improved transportation efficiency. Higher transportation technology efficiency and the introduction of advanced transport technologies, such as electric vehicles and fuel cell vehicles, are included.
- Social efficiency gains. Efficiency improvements from industrial structure changes and lifestyle changes are considered.
- Improved power generation efficiency. More advanced power generation technologies are introduced.

- Improved end use efficiency. Higher end use technology efficiency improvements are adopted.
- Nuclear power progress. Advanced nuclear power generation technologies such as the fast breeder reactor (FBR) are emphasized.
- Incentives for natural gas use.
- Carbon tax. A carbon tax is levied on the basis of carbon emissions.
- Renewable energy incentives. Solar, wind, geothermal, and ocean energy will be well developed.
- Synthesized fuel production.
- Commercial biomass: early introduction, larger share. Commercial biomass will involve low cost technology to bring it to the market.
- Preference for forests.

Population and GDP growth are not designed to be reduced for mitigation, although there will be some reduction in the GDP due to the introduction of the above policies.

All these policies are incorporated in the AIM stabilization scenario analysis based on the merits of each baseline scenario. In the A1B baseline scenario, successful economic development, social prosperity, human equity, etc., are the key factors. Consequently end use technology efficiency improvements and social efficiency improvements are emphasized in the A1B stabilization scenario analysis. Intergenerational equity is considered in the A1 mitigation scenarios to avoid major pressure on CO_2 emissions reductions after 2050. In the A2 scenario failed economic development results in inequity and little improvement in technological efficiency. Hence, technological efficiency improvements, commercial renewable energy utilization, and nuclear technology incentives are adopted in the A2 stabilization scenario simulation. A neutral policy level was maintained for the stabilization scenario analysis of the B2 world, since the B2 baseline scenario already includes an understanding of the importance of human welfare and inequity, as well as environmental solutions. There is no major pressure for policies in the AIM B1 stabilization scenario for a 550 ppmv stabilization level analysis.

In the A1B stabilization scenario family, much stricter policies are required for the 450 ppmv stabilization analysis. A wider range of policies has to be introduced, and strong policies have to be considered in order to attain the large reduction in CO_2 emissions. Early reduction is essential to avoid substantial pressure on social development and technological progress in the latter part of the 21^{st} century. Investment in technology R&D will contribute to CO_2 emissions reductions over the next several decades. High carbon tax rates must also be adopted at an early stage even in the developing countries.

By examining all the policies adopted in the AIM stabilization scenario analyses, some policies such as carbon taxes, end use efficiency improvements, and renewable incentives are seen in all the stabilization scenario analyses. All these policies could be regarded as robust policies.

The quantified policies in this study are shown in Table 3 based on the model parameters.

Table 3. Policy option package for stabilization at 550 ppmv

Policy options	A1B	A2	B1	B2
Transport efficiency improvements	Vehicle fuel use efficiency improvement rate will be 0.14% higher than the BaU case for all regions, starting from 2000	Vehicle fuel use efficiency improvement rate will be 0.14% higher than the BaU case for all regions, starting from 2000	Vehicle fuel use efficiency improvement rate will be 0.1% higher than the baseline case for all regions, starting from 2000	Vehicle fuel use efficiency improvement rate will be 0.1% higher than the baseline case for all regions, starting from 2000
Other end use technology efficiency improvements	-	-	0.1% higher efficiency improvements	0.15% higher efficiency improvements
Power generation efficiency	0.13% higher efficiency improvement	0.15% higher efficiency improvement	0.1% higher efficiency improvement	0.1% higher efficiency improvement
Social efficiency improvement	0.3% higher energy efficiency improvement, additional 0.2% higher energy efficiency improvement in developing countries from 2030 to 2050	0.3% higher energy efficiency improvement, additional 0.2% higher energy efficiency improvement in developing countries from 2030 to 2050	0.1% higher energy efficiency improvement, starting from 2000; additional 0.1% higher energy efficiency improvement in developing countries from 2030 to 2075 (efficiency improvement rate will be 0.1%, 0.2%, 0.1% higher in 2000, 2030 to 2075, 2100	0.2% higher energy efficiency improvement, starting from 2000; additional 0.2% higher energy efficiency improvement in developing countries from 2030 to 2070

2.5.2 Quantified stabilization scenarios

This section presents the quantified results from AIM/Emission-Linkage for the stabilization scenarios.

Among the same target concentration level stabilization scenarios—for example, the 550 ppmv stabilization group—there is no significant difference in CO_2 emissions trajectories (Fig. 7). Rather, the CO_2 emissions reductions differ due to the different baseline emissions trajectories. They show that CO_2 emissions will increase first then start to decrease in the second half of the 21st century.

Table 3. Policy option package for stabilization at 550 ppmv (continued)

Policy options	A1B	A2	B1	B2
Carbon tax	US$50/t-C Annex 1 countries start from 2000, non-Annex 1 countries start from 2030	US$80/t-C Carbon tax starts from 2000.	US$15/t-C Annex 1 countries start from 2000, non-Annex 1 countries start from 2030	US$60/t-C Annex 1 countries start from 2000, non-Annex 1 countries start from 2030
Nuclear power incentives	-	0.5% higher marginal production cost improvement rate	-	0.2% higher marginal production cost improvement rate
Natural gas incentives	-	0.4% higher marginal production cost improvement rate	0.1% higher marginal production cost improvement rate	0.2% higher marginal production cost improvement rate
Syn-oil	0.1% higher marginal production cost improvement rate	0.15% higher marginal production cost improvement rate	0.1% higher marginal production cost improvement rate	0.15% higher marginal production cost improvement rate
Syn-gas	0.1% higher marginal production cost improvement rate	0.16% higher marginal production cost improvement rate	0.1% higher marginal production cost improvement rate	0.16% higher marginal production cost improvement rate
Biomass incentives	0.1% higher marginal production cost improvement rate	0.2% higher marginal production cost improvement rate	0.1% higher marginal production cost improvement rate	0.2% higher marginal production cost improvement rate
Solar energy	-	0.4% higher marginal production cost improvement rate (3.5 cents/kWh)	-	0.1% higher marginal production cost improvement rate

To achieve CO_2 stabilization at a given level, CO_2 abatement is mainly achieved through a mix of technological progress in the energy end use sector and supply sector, structural changes in the economy with a trend toward dematerialization and lifestyle changes. End use technology efficiency improvements and lifestyle changes are favored mitigation measures in the A1B baseline scenarios. In order to avoid possible damage from climate change to prevent a greater welfare loss, people may invest more in end use technology R&D to attain higher efficiency improvements, and give up their energy-intensive consumption patterns. Advanced energy end use technology could be introduced

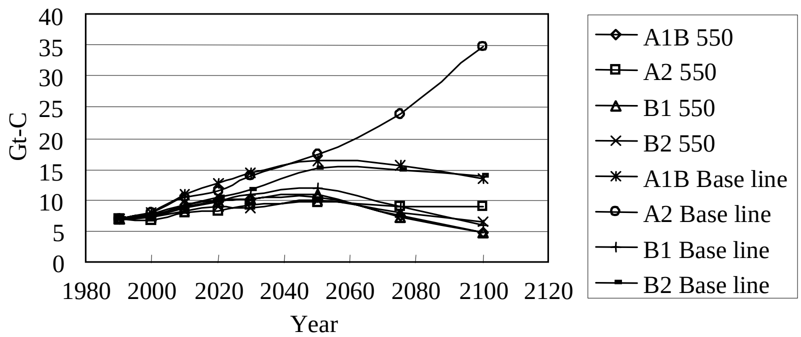

Fig. 7. Global CO_2 emissions in stabilization scenarios

to save energy, especially fossil fuels. In the A1B world, in order to reach the 450 ppmv stabilization level, early action to reduce GHG emissions becomes essential due to the large reduction needed. If the reduction of GHG emissions is delayed, there will be critical pressure for reductions in the latter half of the 21st century, which may cause social and economic losses. In the A2 baseline scenario, due to the energy resource limitations in the baseline scenarios, CO_2 abatement is mainly through progress towards zero carbon technologies such as renewable energy utilization technologies, nuclear power generation technology, etc. Fossil fuel use could be reduced due to the increase in renewable energy and nuclear energy production, when the cost of such technologies decreases as a result of the large demand for them. End use technology efficiency improvements are also a key countermeasure for CO_2 abatement. The results show that in the A2 world, early GHG emissions reduction is also essential. In the B1 baseline scenario, there is relatively little pressure for the CO_2 emissions reduction to reach the 550 ppmv stabilization level, so the target could be reached by price incentive policies, such as a carbon tax. In the B2 baseline scenario, progress in both energy end use technology and energy supply technology is emphasized.

Technological progress is thus a key issue for CO_2 emissions abatement in the AIM mitigation emissions scenarios. This is because these scenarios embrace the perspective of induced technical change; i.e., an additional environmental constraint accelerates the rates of technological change already implicit in the scenario baseline.

Examining the policies used for emissions reductions in this study, it is seen that some of them are not necessarily adopted in response to climate change, especially in developing countries. For example, technological efficiency improvements in both energy production and energy end use, social efficiency changes, and low carbon technology incentives (nuclear and renewable energy, etc.) have been widely adopted in pursuit of sustainable development, as has been the case in China.

As a result, primary energy will decrease with energy efficiency improvements and the introduction of energy price incentive policies, and the primary energy mix will tend to shift to low carbon energy sources such as natural gas, renewable energy, nuclear energy, etc. (Fig. 8).

Cost analyses were simulated by the AIM/Emission-Linkage model. Table 4 shows the GDP loss for each mitigation scenario and different target level in 2050 and 2100. The results reveal that the GDP loss ranges from 0.1% to 5.9% across the scenarios. Obviously the costs rely on the target level and baseline emissions trajectory. The largest loss occurs in the A1B-450 scenario, at 5.9%.

Applying the designed robust policies to different scenarios results in different CO_2 emissions levels (Fig. 9). Some commonly used policies in the AIM mitigation scenarios could be recommended as essential countermeasures in response to climate change, while they also have benefits unrelated to the climate change concept. Policies such as technological progress in end use and energy supply, social efficiency improvements, renewable energy incentives and carbon taxes can be regarded as robust policies.

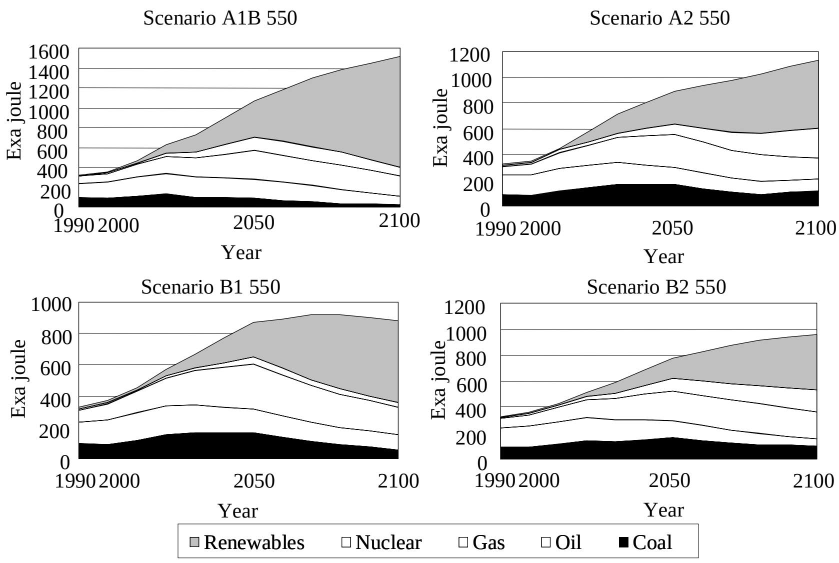

Fig. 8. Global primary energy in AIM stabilization scenarios

Table 4. GDP loss for each scenario at different target levels

	2050	2100
A1B-550	1.0%	2.0%
A1B-650	0.6%	1.0%
A1B-450	3.2%	5.9%
A2-550	1.3%	3.2%
B1-550	0.3%	0.1%
B2-550	0.9%	1.2%

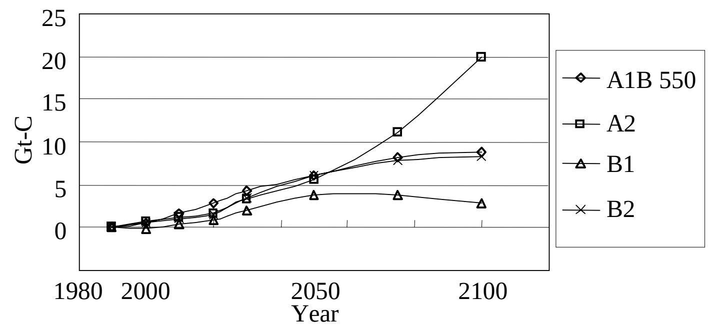

Fig. 9. CO_2 emission reductions with robust policies

2.6 Findings

In this chapter, a model framework to analyze long-term emissions scenarios for the global and the Developing Asia-Pacific was described. Four development patterns were simulated to generate scenarios. Several key findings have been obtained from the results, as follows:

1. The large range of CO_2 emissions in 2100 was simulated for the global and the Developing Asia-Pacific countries.
2. The trend in the Developing Asia-Pacific emissions is similar to that for the world, and the Asia-Pacific future would affect the global future significantly.
3. All the scenarios show that CO_2 emissions in 2100 will be above the level in 1990 for the Developing Asia-Pacific, while some scenarios present the possibility that they will be below 1990 CO_2 emissions at the global level.
4. The growth rate of GHG emissions is higher in the Developing Asia-Pacific countries than the global rate.
5. Half of the scenarios present a decrease in CO_2 emissions after 2050.
6. Technological progress will contribute substantially to low CO_2 emissions.
7. Per capita CO_2 emissions of the Developing Asia-Pacific countries will be below the level of the OECD countries over the next 100 years.
8. SO_2 and NO_x emissions of the Developing Asia-Pacific countries will decrease rapidly after 2020.
9. The high economic growth scenarios (scenarios A1) give a wider range of CO_2 emissions trajectories than for the low economic growth scenarios.
10. The global market and global governance are especially important key factors for CO_2 emissions scenarios.

Furthermore, a set of mitigation scenarios was simulated by the AIM/Emission-Linkage model based on the nonintervention emissions scenarios. Key findings from the results of this modeling are as follows:

1. The targeted stabilization levels could be reached through the adoption of various policies. All the mitigation scenarios from AIM show a trend toward various stabilization levels.
2. Wide-ranging policy packages are needed, rather than a single policy, in order to mitigate the socioeconomic effects of responses to climate change.
3. In the A1 and A2 world views as well as for 450 ppmv stabilization, an early reduction in GHG levels is essential to avoid serious pressure on social development and technological progress in the second half of the 21st century.
4. Integration between global climate policies and domestic environmental policies could effectively reduce GHG levels in the developing regions for the next two or three decades.
5. Technological progress and lower energy consumption play a very important role in stabilization.
6. Knowledge transfer to developing countries is a key issue that should be emphasized to motivate developing countries to participate in early CO_2 emissions reductions.
7. Technological efficiency improvements for both energy use technology and energy supply technology, social efficiency improvements, renewable energy incentives and the introduction of energy price incentives, such as a carbon tax, can be regarded as robust policies.
8. Robust technology/policy measures include efficiency improvements in end use technologies and social systems, as well as the introduction of renewable energy.

2.7 Conclusions

Based on the above findings, the following points form our conclusions from the Asian viewpoint:

1. The future development of the Asia-Pacific region has a significant influence on global emissions scenarios. The Developing Asia-Pacific countries will achieve a dominant position in climate change issues.
2. It is possible for the Developing Asia-Pacific to continue high economic growth while maintaining GHG emissions at a low level.
3. Technological progress and technology transfer should be emphasized to maintain low GHG emissions in the economic development of the Developing Asia-Pacific.
4. It is important for the Developing Asia-Pacific to introduce sophisticated measures to control GHG emissions before 2030.
5. Robust policy options should be designed to respond to a very wide range of alternative development paths.

From the global common viewpoint, the major conclusions can be summarized as follows:

1. Different development paths require different technology/policy measures and involve different costs of mitigation to stabilize atmospheric CO_2 concentrations at the same level.
2. Secondly, no single type of measure will be sufficient for the timely development, adoption and diffusion of mitigation options for CO_2 stabilization. Policy integration across an array of technologies, sectors and regions is the key to the successful promotion of climate change policies.
3. The level of technology/policy measures in the beginning of the 21st century will be significantly affected by the choice of the development path over the next one hundred years.
4. Several robust policy options across the different worlds are identified for stabilization. Technological efficiency improvements for both energy use technologies and energy supply technologies, social efficiency improvements, renewable energy incentives and the introduction of energy price incentives, such as a carbon tax, can be regarded as robust policies.
5. Large and continuous energy efficiency improvements and afforestation are common features of mitigation scenarios in all the different SRES worlds. The introduction of low-carbon energy is also a common feature of all scenarios, especially the introduction of biomass energy over the next one hundred years, as well as the introduction of natural gas in the first half of the 21st century.

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