Analysis of Post-Kyoto Scenarios : The AIM Model

M. Kainuma[a] Y. Matsuoka[b], and T. Morita[a]

[a] Global Environment Division, National Institute for Environmental Studies,
16-2 Onogawa, Tsukuba, 305-0053 Japan

[b] Faculty of Engineering, Kyoto University,
Yoshida-Honmachi, Sakyo-ku, Kyoto, 606-8501 Japan

Abstract

The AIM/top-down model is a recursive general equilibrium model used to analyze the post-Kyoto scenarios presented by EMF16. Differences among scenarios mainly arise from the setting of emission trading. Japan's marginal cost is the highest among the Annex I countries except New Zealand, where a relatively high emission reduction is necessary, while the highest GDP loss is observed in the USA in 2010 in the no trading case. The marginal costs will become much less in the global trading case. The countries of the Former Soviet Union sell emission rights and the USA buys the largest amount of them. Emission reductions by trading will account for a large part of the total emission reductions if there is no restriction on trading. The GDP gain of the Former Soviet Union is the largest in 2010 in the trading cases. The GDP change in Middle East Asia is negative, and reaches the highest level in the no trading case. Carbon leakage is particularly observed in the no trading case.

1. Introduction

The AIM model (Asian-Pacific Integrated Model) estimates the emission and absorption of greenhouse gases in the Asia-Pacific region and judges their impact on the natural environment and socio-economy. It aims to contribute to policy-making with respect to global warming and its evaluation.

The AIM model consists of a greenhouse gas emissions model (AIM/emission) that forecasts the amount of anthropogenic greenhouse gas emissions, a warming phenomenon model (AIM/climate) that forecasts the concentration of greenhouse gases in the atmosphere and estimates the temperature increase, and a warming impact model (AIM/impact) that estimates the influence that climate change has on the natural environment and socio-economy of the Asia-Pacific region (Matsuoka et al., 1995).

The AIM/emission model is made up of models of social and economic activities that become the origin of greenhouse gas emissions through energy consumption, changing land use, and agricultural and industrial production. At its heart lies the energy model, comprising a world model as well as country-specific models for the Asia-Pacific region. The world model is a top-down model that uses economic indices based on prices and elasticity to express the connection between energy consumption and production. The country-specific model is a bottom-up end-use model that focuses on the activities of the people who deal with industrial production and the consumption of energy as well as changes in the technologies used in these countries, and forecasts from these detailed descriptions the total energy consumption and production. These two models are linked to each other. Future energy efficiencies are calculated based on the end-use model and international trade effects are estimated based on the top-down model.

The AIM/top-down model was used to analyze the economic impacts of post-Kyoto scenarios presented by EMF16. It was found that Japan's marginal cost of CO2 reduction is the highest among the USA, the EU, and Japan in 2010 in the no trading case. The highest GDP loss is observed in the USA. The marginal cost becomes much less in the global trading case. The countries of the Former Soviet Union sell emission rights and the USA buys the largest amount of them. Emission reductions by trading will account for a large part of the total emission reductions if there is no restriction on trading. The GDP gain of the Former Soviet Union is the largest in 2010 in the trading cases. The GDP change in China is negative while that in India is positive, although the values are small. The GDP change in Middle East Asia is negative, and reaches the highest level in the no trading case. Carbon leakage is particularly observed in the no trading case.

2. The AIM Model Structure

The AIM model is a recursive dynamic equilibrium model of the world economy used to analyze the effects of post-Kyoto scenarios. The model divides the world into 21 geopolitical regions. To analyze the impacts of post-Kyoto scenarios, Annex I is divided into the following regions: Japan, Australia, New Zealand (NZL), the United States of America (USA), Canada, the European Union (EU), and Eastern Europe and the Former Soviet Union (EEFSU). The AIM model focuses on the Asia-Pacific region, which is divided into 10 regions: Taiwan, the Republic of Korea, Hong Kong, Singapore, China, India, Indonesia, Malaysia, the Philippines, and Thailand. Other regions are Latin America (L-America), Middle East Asia and North Africa (ME-Asia), Sub-Saharan Africa (SS-Africa), and Rest of World (ROW).

Goods are aggregated into seven energy goods and four non-energy goods. Energy goods are coal, crude oil, petroleum and coal products, natural gas, nuclear energy, renewable energy, and electricity. Non-energy goods are aggregated into four categories. The first is energy-intensive products; the second is agriculture, other manufactures and services; the third is transport industries; and the last is savings.

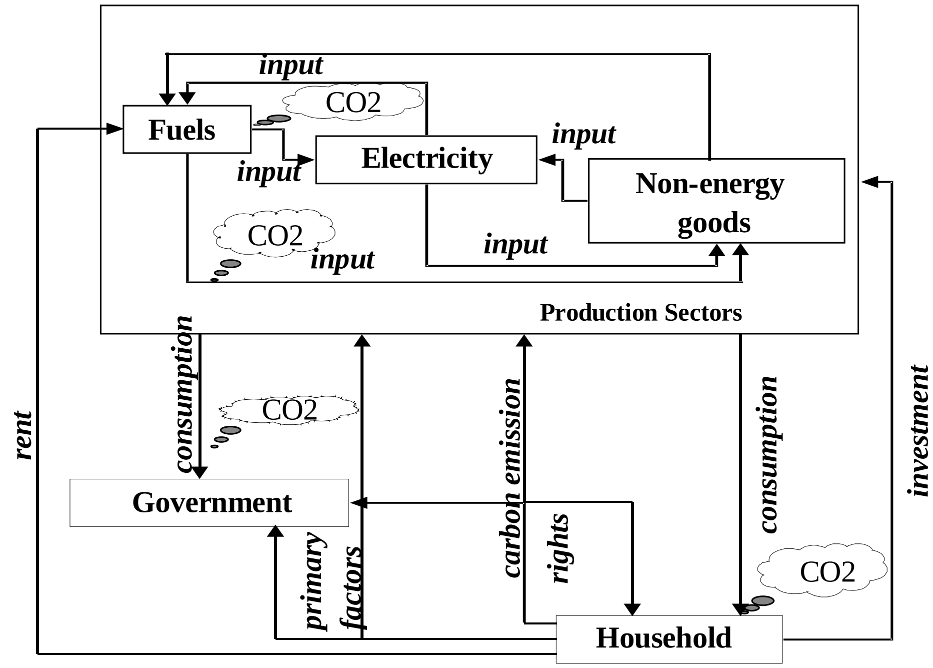
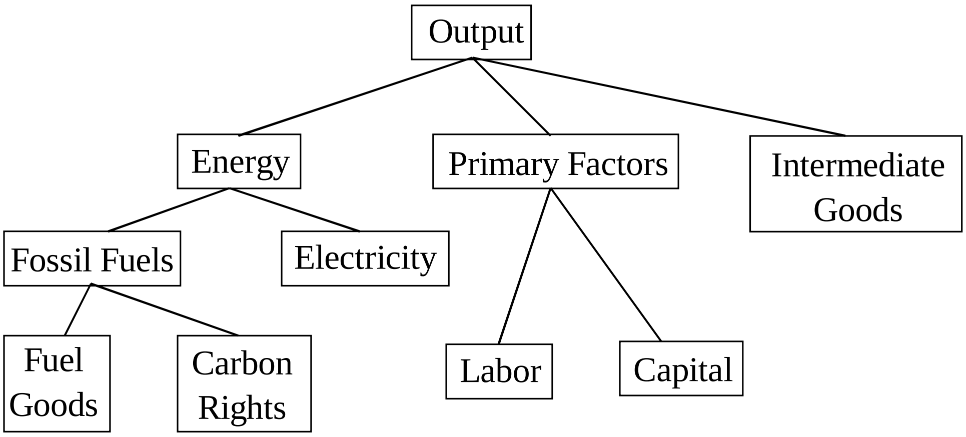


Figure 1 **AIM/top-down model structure**

Figure 1 shows the structure of the AIM/top-down model. The model has three sectors—the production, household, and government sectors—in each region. CO2 and other greenhouse gases are emitted by each of these sectors. The production of electricity and of non-energy goods uses fossil fuels in the production sector, and the use of automobiles and other direct uses of fossil fuels emit CO2 in the household and government sectors. It is assumed that the household sector has carbon emission rights and distributes them to the other sectors and within the household sector itself. Fossil fuels cannot be used without carbon rights. The price of carbon rights depends on several factors such as emission targets and the method of emission trading. The household sector also supplies primary factors to the production and government sectors. An agent in the household sector determines consumption and saving. The marginal propensity to save is a calibrated function of a weighted aggregate of regional and global rates of return on fixed capitals. A regional investment is calculated with the GDP growth rate, regional and global rates of return. Investment is balanced with saving on a global scale. The model allows for trade in intermediate goods. AIM assumes identical preferences in all countries for foreign versus domestic goods; i.e., the elasticity of substitution is the same for all regions. Domestic and export goods are not perfect substitutes.

Figure 2 shows the nesting of the production structure in AIM. All industries have a similar production structure. Output is calculated by primary factors, intermediate goods, and energy. Energy is nested into fossil fuels and electricity, and fossil fuels are in turn nested into fuel goods and carbon emission rights. We assume elasticity between fuel goods and carbon rights equals zero. Therefore, carbon rights become a constraint on production functions.



Elasticity of Substitution:
Energy/Primary/Intermediates=0.3 (EIS), 0.2 -0.5 (Others)
Electricity/Fossil Fuels =0.3, Fuel/Fuel=1
Labor/Capital=1, Fuels/Carbon=0

Figure 2 **Nesting of production structure in AIM**

3. Post-Kyoto Simulation

AIM was run under five scenarios: no trading, Annex I trading, full global trading, double bubble, Annex I + China and India, and no trading with 5% offset. These were analyzed for implementation of the Kyoto agreements. Each region must achieve the following reductions by 2010: Australia, +8%; New Zealand 0%; Japan +6%; USA, -7%; EEFSU, 0%; and EU, -8%. It is assumed that carbon emissions can be traded without quantitative limitations on trading cases within the allowable emissions. For non-Annex I countries, the emissions are bounded by their BaU emissions when they are involved in trading.

3.1 Reference case

Figure 3 shows CO2 emissions in the reference case. It was 5.8 GtC in 1992 and will rise to about 20 GtC in 2010. The increases in Latin America and Middle East Asia are large. Those in Korea, Singapore, and Malaysia are also large (these countries are included in ROW in Figure 3). Some of the figures are ten times greater than the 1990 levels. The emissions of the USA, Canada, EU, Japan, and Australia are between 2.2 and 2.4 times greater than the 1990 levels.

Data were calibrated based on 1992 data. Energy data were calibrated by IEA data (IEA, 1995), and other goods were calibrated by GTAP database (Hertel, 1995; McDougall, 1997). GDP growth data from world economic outlook (IMF, 1998) were used to calibrate productivity growth rate from 1990 to 2000, and the median values of GDP growth rates of the International Energy Outlook were used for the years 2000 to 2020. The ratio of GDP growth in 2100 was estimated based on the IPCC Morita database, using the median values in that database. CO2 emissions in 2010 were calibrated using the numbers in the national reports.

3.2 Changes of CO2 emissions under the Kyoto agreement

How much will the marginal cost be in order to permanently achieve the Kyoto targets in each case? Figure 4 shows the CO2 emissions and marginal costs in the no trading case in 2010. The bar graph shows CO2 emissions. The left-hand bar for each region shows the 1990 emission level, the bar that is second from the left shows the target emission level, the bar that is third from the left shows the BaU emission level, and the right-hand bar shows the emission level in the no trading case. The BaU emission of EEFSU is less than the target, reflecting the economic deterioration of that region. The emission of EEFSU in the no trading case is higher than the BaU emission by about 1%; that is, CO2 leakage is observed.

The line graph shows the marginal costs to achieve the emission targets. The emission of EEFSU is below the 1990 level until 2030 in the BaU case, so no policy intervention is necessary in 2010. On the other hand, CO2 emission in NZL in the reference case is 11 MtC in 2010, and its emissions must be reduced to 7 MtC. As NZL has to reduce about 50% of its emissions, the marginal cost becomes exceptionally high. Apart from NZL, the marginal cost of Japan is the highest at 234 US$ (1992) /tC. The ranking of other regions is EU, Canada, USA, and Australia, in that order. Although the target for Australia is +8%, the emission in the BaU case is larger than the target and an intervention policy is required to reduce emissions. However, the cost is the lowest except for EEFSU.

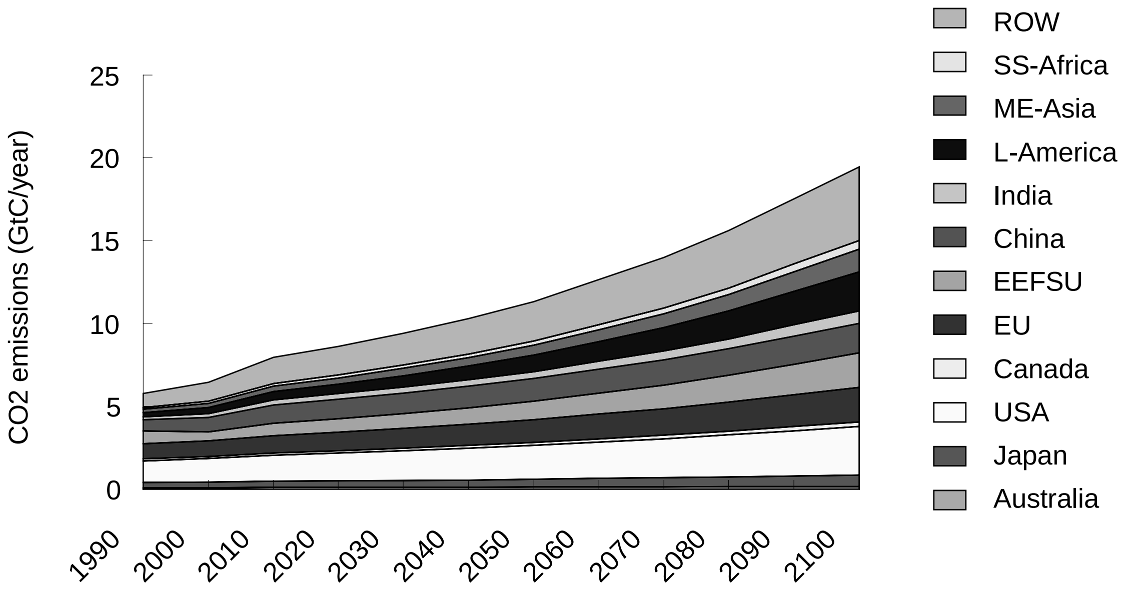


Figure 3 **World CO_2 emissions (reference case)**

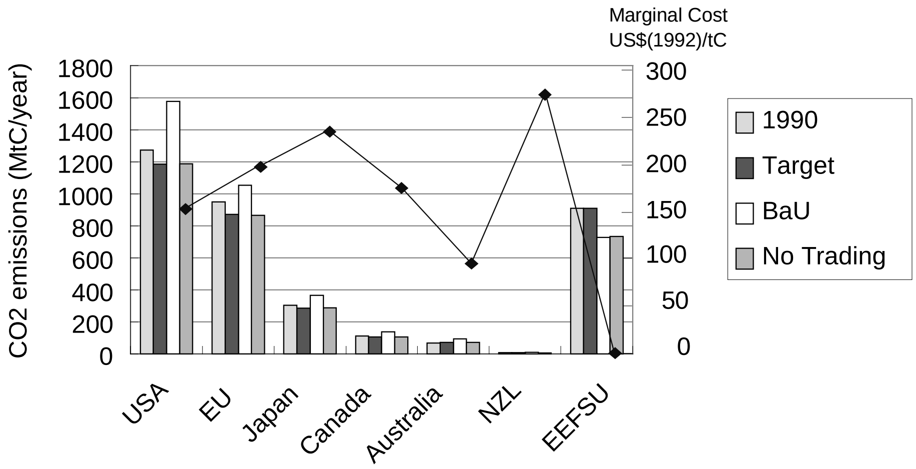


Figure 4 **CO_2 emissions and marginal costs in 2010 (no trading case)**

Figure 5 plots changes in emission right prices in Annex I countries in the no trading case from 1990 to 2050. Except for EEFSU, emission right prices rise sharply in 2010 compared to 2000, while that of EEFSU rises slowly from 2030. When a heavy reduction policy is adopted, Annex I countries must struggle to achieve it. They will try to invest in energy-related industries for the development of new energy sources and/or to decrease energy demand. The first step is usually difficult when the burden is severe.

How much will the emission right prices be in the trading cases? Figure 6 compares emission right prices in the trading scenario. The emission right in the global trading case is priced lower than those in other cases. It is about 38 US$ in 2010, compared to the emission right price in the Annex I case of 65 US$ in 2010. It is much less than that in the no trading case. The emission right price in the EU in the double bubble case is almost the same as that in the no trading case, and the emission right price curve also follows the same pattern.

Figure 7 shows the amounts of emission right trading in the Annex I trading case. EEFSU will export emissions and the USA, EU, Japan, and Canada will import them. The amounts imported by the USA decrease as time goes on, and the amounts exported by EEFSU also decrease.

Figure 8 shows the amounts of emission right trading in the global trading case. EEFSU, Latin America, and ROW export emission rights, while the USA, EU, and Japan continue to import them. The amount imported by the USA will increase in the global trading case, although it decreases in the Annex I trading case. One reason is that as the economic impact in the Annex I trading case is much larger than that in the global trading case and emission rights can only be imported from EEFSU, investments are shifted to energy industries and more renewable energy will become available in the future. On the contrary, as Annex I countries can import emissions much more cheaply in the global trading case than in the Annex I trading case, they rely on emission trading and reductions in their own countries are not promoted.

Figure 9 compares CO2 emission changes in Annex I countries in 2010. In the no trading case, the USA has to reduce emissions by about 25% and Japan has to reduce them by about 22%. Carbon leakage is observed in EEFSU. The emission level of EEFSU is 1% larger compared to the BaU emission. In the Annex I and global trading cases, EEFSU will reduce emissions by 32% and 23%, respectively, and will sell emission rights. In the global trading case, the USA will reduce emissions by 7% compared to the BaU case, which is significantly less compared to the no trading case.

Figure 10 shows CO2 emission changes in non-Annex I countries in 2010 under the same three scenarios. Carbon leakage is observed in many countries in the no trading case. For example, in 2010 the emission level of Singapore is 4.5% higher compared to the BaU case and that in Korea is 2.6% higher. Carbon leakage in China is less than that in other countries.

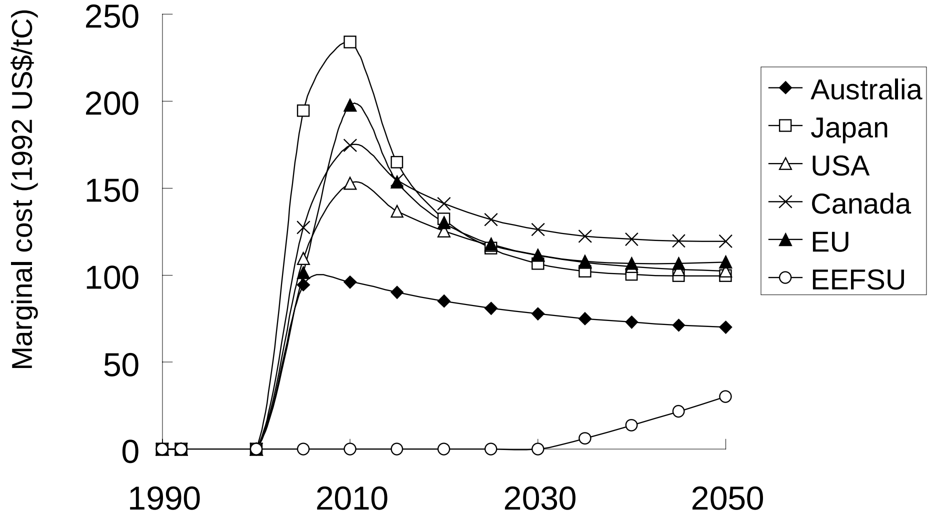


Figure 5 **Emission right prices (no trading case)**

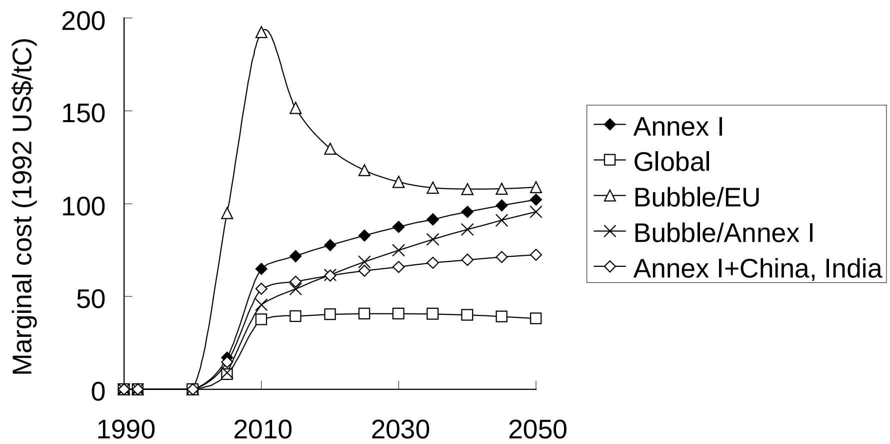


Figure **6 Emission right prices (trading case)**

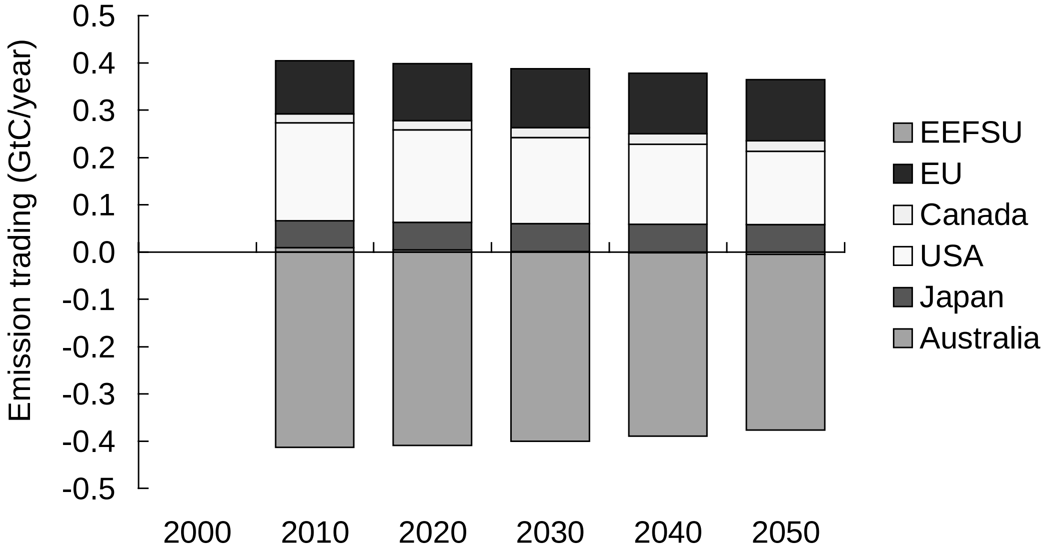


Figure 7 **Emission right trading (Annex I trading case)**

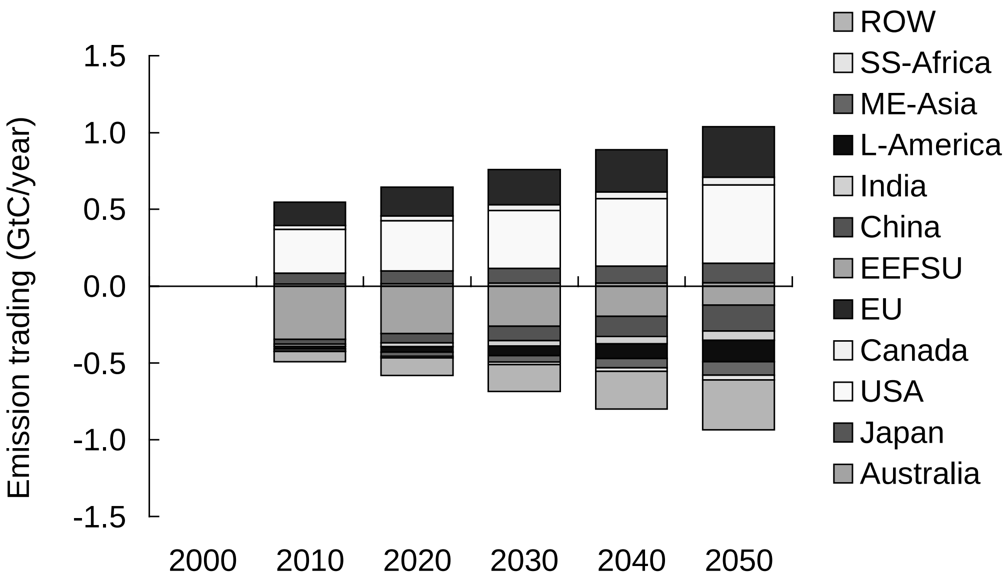


Figure 8 **Emission right trading (global trading case)**

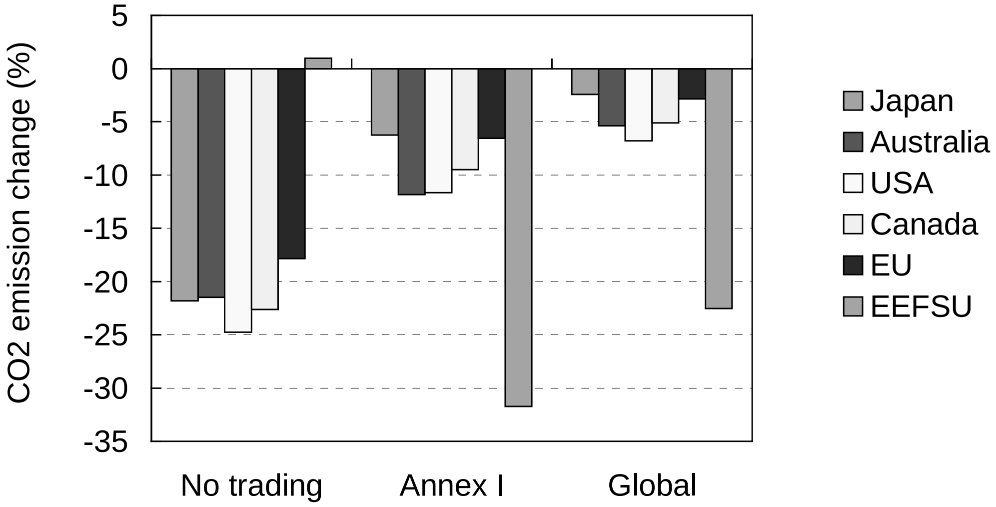


Figure 9 **CO_2 emission changes in Annex I countries in 2010**

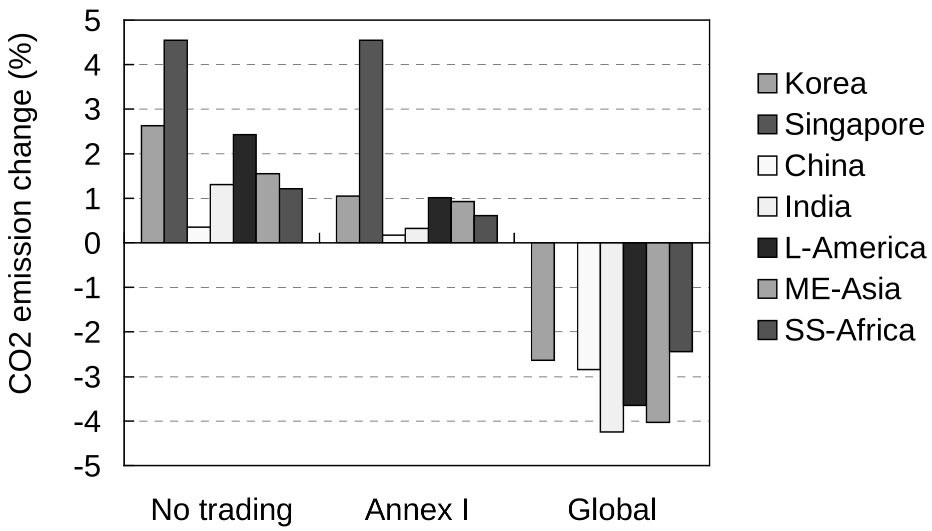


Figure 10 **CO_2 emissions changes in non-Annex I countries in 2010**

3.3 Impacts on GDP

How much will the GDP losses be? Figure 11 shows a comparison of GDP losses in Annex I countries under different scenarios in 2010. The GDP loss is 0.45% in the no trading case, higher than for the other cases, in the USA. The GDP loss in the double bubble case is highest in the EU, at about 0.35%. The impacts on GDP in the global trading case are the lowest in 2010 except for

EEFSU. The GDP loss in EEFSU in the no trading case is 0.21%. EEFSU gains GDP in trading cases, because the countries of that region sell emission rights. The GDP gain in the Annex I trading case is the largest for EEFSU, at about 3.5%. The GDP gain for EEFSU in the global trading case is about 1.6%, which is less than in other trading cases. The GDP losses in the no trading with 5% offset case are between those in Annex I trading and in no trading. Annex I trading has a much greater effect on GDP than in the no trading with 5% offset case.

Figure 12 shows GDP losses in non-Annex I countries. The GDP losses vary according to the country. The GDP changes in China and Middle East Asia are negative, while those in Korea and India are positive. The loss of Middle East Asia is the highest among these regions, and reaches its maximum level in the no trading case.

4. Major Findings

Several interesting findings are obtained from this simulation.

(1) The marginal cost ranking is NZL, Japan, EU, and USA, in that order. The marginal costs of the USA, EU, Japan, and NZL in the no trading case in 2010 are 153$, 198$, 234$, and 274$, respectively. CO2 emission in NZL in the reference case is 11 MtC in 2010, and emissions must be reduced to 7 MtC. As NZL has to reduce about 50% of its emissions, the marginal cost becomes exceptionally high. Except for NZL, the marginal cost of Japan is the highest, followed by that of the EU. The highest GDP loss is observed in the USA. The percent GDP losses of the USA, EU, and Japan in 2010 in the no trading case are 0.45%, 0.31%, and 0.25%, respectively, while their percent energy reductions in 2010 are 22.5%, 14.8%, and 14.7%. The percent energy reduction of the USA in 2010 is larger than those of the EU and Japan.

(2) Who earns by emission trading? Global trading has a great impact on GDP, with a much lower marginal cost compared to other trading cases. The marginal cost in the global trading case is less than 40 US$ (1992) /tC, which is significantly less than that in the no trading case. EEFSU sells emission rights, while the USA buys the largest amount of emission rights (207 MtC/year). This is 17% of the target and 53% of the total emission reduction in 2010. Japan will buy 57 MtC in 2010, representing 20% of the target emission and 71% of the emission reduction. Emission reductions by trading will account for a large part of emission reductions if there is no limitation on trading. The GDP gain of EEFSU in 2010 is the largest among the regions in trading cases.

(3) The GDP loss of the EU in the double bubble case is larger than that in the no trading case. Double bubble has no merit for the EU.

(4) The GDP changes in China are negative in all cases while those in India and Korea are positive, although the numbers are small at less than 0.4%. Non-Annex I countries are directly or indirectly affected by the reduction strategies of Annex I countries. The GDP loss in Middle East Asia is 1.5% in the no trading case. The GDP changes in Middle East Asia are negative in all cases.

Emission trading is effective in reducing CO2 emissions in the sense that it has less GDP impact. Emission reductions by trading will account for a large part of the total emission reductions if there is no restriction on trading. The Kyoto protocol states that the acquisition of emission reduction units shall be supplemental to domestic actions which expresses anxiety that emission trading reduces incentive of Annex I countries to introduce a substantial policy of greenhouse gas emission reduction. It is essential to improve energy efficiency, to develop renewable energy, and to change the socio-economic structure, so that fossil fuels will be less used.

References

Hertel,T.W. (1995). *Global Trade Analysis?Modeling and applications*,Cambridge University Press,1995.

IEA/OECD (1995). *Energy statistics and balances of non-OECD countries 1992-1993,* OECD.

IEA/OECD (1995). *Energy statistics of OECD countries 1992-1993*, OECD.

IMF (1997, 1998). *World Energy Outlook*, IMF.

Matuoka, Y., M. Kainuma and T. Morita (1995). Scenario analysis of global warming using the Asian Pacific Integrated Model (AIM), *Energy Policy*, 23(4/5), 357-371.

McDougall, R. A. (1997). *Global Trade Assistance, and Protection : The GTAP 3 Data Base,* Center for Global Trade Analysis Purdue University,1997.

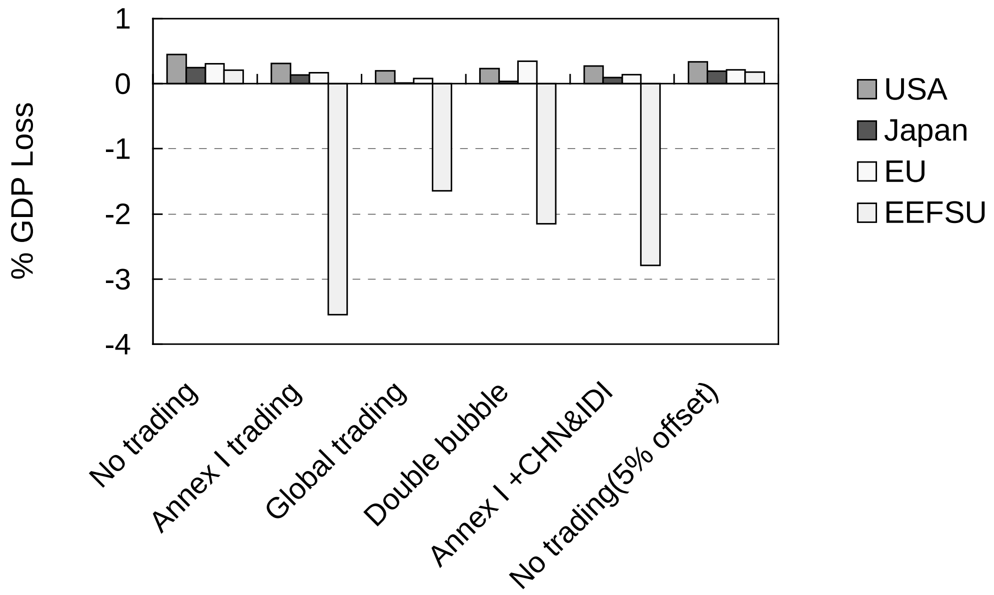


Figure 11 **Comparison of GDP losses in Annex I countries in 2010 under different scenarios**

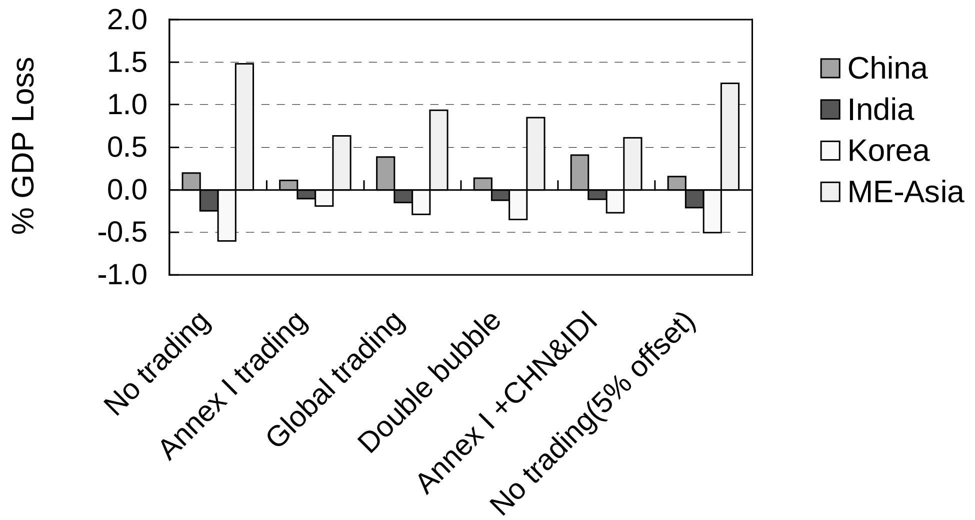


Figure 12 **Comparison of GDP losses in non-Annex I countries in 2010 under different scenarios.**