

4. Cost Analysis of Mitigation Policies

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Summary. This analysis evaluates the economic and environmental impacts of climate change policies. Firstly, the economic impacts of the Kyoto Protocol are analyzed to assess the short-term effects of climate change policies. It is found that the GDP loss to Japan, the USA, the EU, and Russia will be 0.42%, 0.56%, 0.44%, and 0.25%, respectively, if the Annex B countries ratify the Kyoto Protocol and reduce their emissions without emissions trading and without taking carbon sinks into account. On the other hand, the GDP loss to Japan and the EU will grow if the USA does not ratify the Kyoto Protocol, and these losses will be recovered if the Kyoto mechanisms are adopted. Atmospheric stabilization scenarios are then examined to estimate long-term economic and environmental impacts. It is found that the global mean temperature will increase 1.8-2.8°C by the year 2100 under 550 ppmv scenarios. Impacts on crop productivity in India and the incidence of malaria in China are estimated to become very serious.

4.1 Introduction

The Kyoto Protocol was adopted in 1997 as a first step toward stabilizing the atmospheric concentrations of greenhouse gases. The most important feature of the Protocol is the quantified emissions reduction targets. These would result in a reduction in emissions of greenhouse gases from Annex B countries in the 2008-2012 period to about 5 percent below their 1990 levels. For the purpose of meeting these commitments, the Protocol established the principles of emissions trading, joint implementation and the Clean Development Mechanism (CDM). The Protocol also approved the principle that removal of atmospheric carbon using carbon sinks formed by direct human-induced land use changes and forestry activities could be counted as a means of managing emissions.

In March 2001, President Bush announced that the United States would not ratify the Kyoto Protocol. Since the United States emits the largest amount of CO₂ of any country in the world, the influence of this decision on other industrialized nations could be quite significant.

This paper analyzes the effect of the decision of the USA as well as other important factors related to the reduction of greenhouse gas emissions. Several cases are studied. One case assumes ratification of the Protocol by Annex B countries, including the United States. Another case assumes that it becomes international law without ratification by the United States. Other factors such as

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price-induced technological change and a movement to boycott the products of non-ratifying countries are also considered.

Even though there are many hurdles to effectively reducing greenhouse gas emissions under the Kyoto target, it is necessary to go further to meet the ultimate goal of the United Nations Framework Convention on Climate Change (UNFCCC); “stabilization of greenhouse gas concentrations in the atmosphere at a level that will prevent dangerous anthropogenic interference with the climate system.”

As an example of a stabilization scenario, the target of stabilizing the atmospheric concentration of CO₂ to less than 550 ppmv is considered. The global temperature changes and the rise in sea levels are estimated. Estimated climate changes are used to analyze the climatic impacts on crop production and infectious diseases in the Asia-Pacific region.

4.2 Structure of AIM/CGE (Energy) for Mitigation Analysis

The AIM/CGE (Energy) model is a recursive dynamic equilibrium model of the world economy used to analyze the effects of climate stabilization policies (Kainuma *et al.* 1999). The model divides the world into 21 geopolitical regions. To analyze the impacts of the Kyoto Protocol, Annex B countries are categorized into the following regions: Japan, Australia, New Zealand, the United States of America (USA), Canada, the European Union (EU), and Eastern Europe and the Former Soviet Union (EEFSU). The AIM model focuses in detail on the Asia-Pacific region, which is divided into 10 regions: China, Taiwan, the Republic of Korea, Hong Kong, Singapore, India, Indonesia, Malaysia, the Philippines, and Thailand. Other regions are Latin America, Middle East Asia and North Africa, Sub-Saharan Africa, and the Rest of World (ROW).

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

Figure 1 shows the structure of the AIM/CGE (Energy) model used for the cost analysis. 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 non-energy goods involves the use of fossil fuels and the emission of CO₂ in the production sector. In addition, 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 having carbon emission rights. The price of these carbon rights depends on several factors such as emissions targets and the

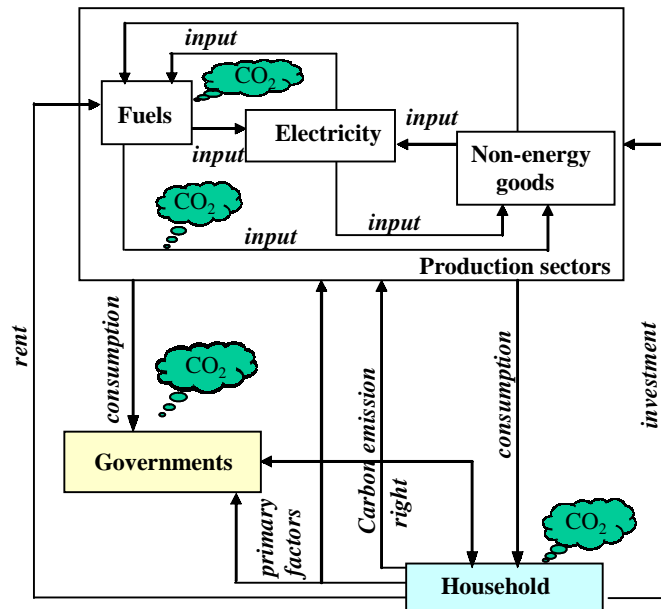


Fig. 1. The structure of AIM/CGE (Energy) for mitigation analysis

method of emissions trading. The household sector also supplies primary factors to the production and government sectors. An agent in the household sector determines consumption and savings. The marginal propensity to save is a calibrated function of a weighted aggregate of regional and global rates of return on fixed capital. Regional investment is calculated using the GDP growth rate and regional and global rates of return. Investment is balanced with savings 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 imported 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 including 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. It is assumed that the elasticity between fuel goods and carbon rights equals zero. Therefore, carbon rights become a constraint on production functions.

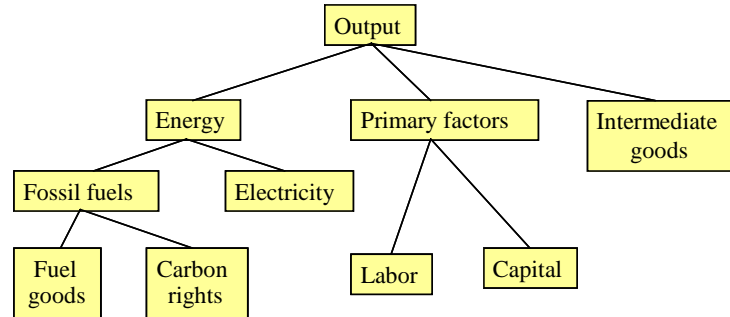


Fig. 2. Nesting of the production structure (elasticity of substitution: energy/primary/intermediates =0.3 for energy intensive products and 0.2-0.5 for other products; electricity/fossil fuel=0.3; fuel/fuel =1; labor/capital=1; fuel/carbon=0)

4.3 Cost of the Kyoto Protocol

4.3.1 Scenario assumptions

The emissions reduction target adopted at COP3, held in Kyoto, is analyzed using the AIM model. The reduction target for each country compared to the 1990 emissions level is as follows: Australia: 0.8%, New Zealand: 0%, FSU: 0%, Japan: -6%, Canada: -6%, USA: -7%, EU: -8%. It is assumed that several policy measures such as a carbon tax and the Kyoto mechanisms are used to meet these targets.

Besides the reference scenario, three sets of scenarios are examined. In the first set, it is assumed that each country should reduce emissions without adopting a flexibility mechanism. In the second set, emissions trading is assumed without any restrictions on the amount of carbon traded. In the third set, CDM is also counted besides emissions trading without restriction of tradable amounts. In each set, the impacts of participation or non-participation of the USA in the Kyoto Protocol are examined. Also examined are price-induced technological change and a movement to boycott goods exported by non-ratifying countries. In the price-induced technological change scenario, it is assumed that technologies shift to energy-saving types as the price of energy rises. In the boycott movement scenario, it is assumed that the price of goods exported by non-ratifying countries is 10% higher than the price in the reference scenario.

In addition to above scenarios, restriction case with one-third of the reduction commitment and the effects of carbon sinks are analyzed. The quantities absorbed by the sinks are assumed to be as follows: EU: 9.84 Mt-C/year, FSU: 19.46 Mt-C/year, Australia: 0 Mt-C/year, Canada: 12.0 Mt-C/year, Japan: 13.0 Mt-C/year, New Zealand: 0.2 Mt-C/year, USA: 28.0 Mt-C/year.

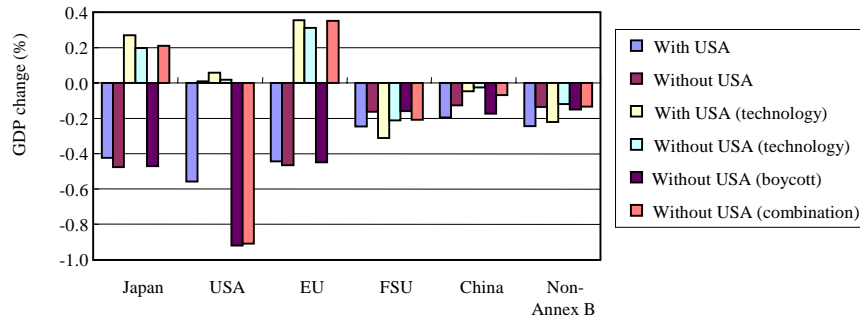


Fig. 3. Percentage change in the GDP in 2010 without emissions trading

4.3.2 GDP changes in 2010

Figure 3 shows the percentage reduction in the GDP compared to the reference scenario without emissions trading. Six scenarios are compared. They are classified according to three factors: ratification and non-ratification by the USA, price-induced technological development and a boycott movement. The combination scenario is one that includes both price-induced technological development and a boycott movement.

The GDP loss for the USA is the highest in the “with USA” scenario, even though the carbon price is the lowest among Japan, the USA, and the EU. The GDP change is negative in every region in the “with USA” scenario, while that for the USA becomes positive in the “without USA” scenario. The GDP changes become positive for Japan, the USA and the EU, while remaining negative for Russia in the “priced-induced technological change with USA” scenario. The absolute value of the impacts decreases in the “priced-induced technological change without USA” compared to the “with USA” scenario. This is because it is assumed that there is a very high potential for technological change if the price of energy increases substantially. The GDP change for the USA is negative and the amount of the loss in the “boycott movement” scenario is larger than the “with USA (ratifying the Kyoto Protocol)” scenario. This means that the economic loss to the USA is greater than if the USA ratifies the Protocol as long as other countries boycott US goods. However, the impacts are also negative for Japan, the EU and Russia. The effect of a boycott movement on the world economy is not good. In the “technological change+boycott movement” scenario, the GDP changes are positive for Japan and the EU, and the negative impact on China is lessened.

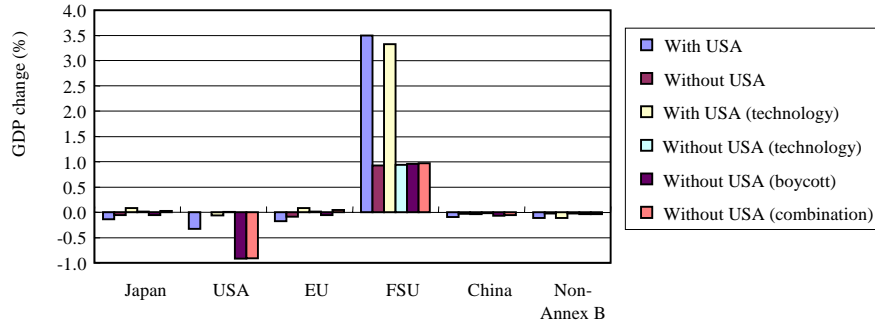


Fig. 4. Percentage change in the GDP in 2010 with emissions trading

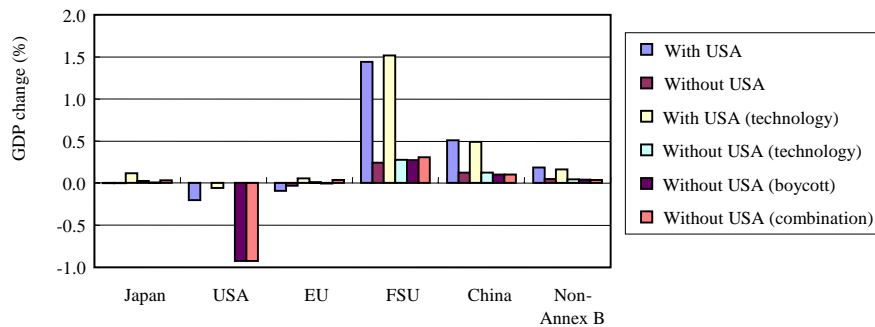


Fig. 5. Percentage change in the GDP in 2010 with emissions trading and CDM

Figure 4 shows the percentage change in the GDP in 2010 in the "emissions trading with no restrictions" scenarios. Again six scenarios are analyzed. In these scenarios, positive impacts for Russia are observed, especially in the "with USA" scenarios and the "price-induced technological change" scenario. Although a negative impact for the USA with the "boycott" scenario is observed, the impact is not large for other regions.

Figure 5 shows the percentage change in the GDP in the "emissions trading and CDM with no restrictions" scenarios. Positive impacts for Russia and non-Annex B countries are observed, especially in the "with USA" and "price-induced technological change" scenarios. Impacts are minimal for Japan, the USA and the EU.

When the assumption is that the amount of tradable carbon is restricted, for example, to one-third of the emissions reduction, the impacts on Annex B countries become greater compared to the "no-restrictions" scenarios. The impacts for Russia are negative in the "without USA" scenarios. The gains for Russia from emissions trading are much less than those corresponding to the "no-restrictions" scenarios.

When carbon sinks are taken into account, the GDP impacts are substantially reduced. The GDP impacts on Japan, the USA, the EU, and Russia in 2010 are -

0.28, -0.47, -0.41, and -0.23, respectively, in the "with USA" scenario. These would be -0.33, 0.01, -0.43, and -0.15, respectively, in the "without USA" scenario. Impacts decrease in the emissions trading scenario. These would be -0.04, 0.01, -0.06, and 0.6 for Japan, the USA, the EU and Russia, respectively, in "the emissions trading without USA" scenario.

Table 1 shows the GDP changes in three sets of scenarios. The GDP gain for China is the highest in the "CDM case with USA" scenario. This gain is lowered in the "without USA" scenario.

Table 2 shows the corresponding carbon price. The carbon price for Japan is the highest in all the scenarios. If the CDM is assumed in addition to emissions trading, the carbon price becomes very low. This is especially true in the case of the "without USA" scenarios. If price-induced technological change occurs, the price becomes much lower.

Table 1. Percentage change in the GDP in 2010

	Japan	USA	EU	FSU	China	Non-Annex B
<u>without emissions trading</u>						
With USA	-0.42	-0.56	-0.44	-0.25	-0.20	-0.24
Without USA	-0.48	0.01	-0.47	-0.16	-0.13	-0.14
With USA (technology)	0.27	0.06	0.35	-0.31	-0.05	-0.22
Without USA (technology)	0.20	0.02	0.31	-0.21	-0.03	-0.12
Without USA (boycott)	-0.47	-0.92	-0.45	-0.16	-0.17	-0.15
Without USA (combination)	0.21	-0.91	0.35	-0.21	-0.07	-0.13
<u>with emissions trading</u>						
With USA	-0.14	-0.33	-0.19	3.50	-0.09	-0.11
Without USA	-0.06	0.00	-0.08	0.92	-0.03	-0.02
With USA (technology)	0.08	-0.07	0.08	3.32	-0.04	-0.11
Without USA (technology)	0.01	0.00	0.01	0.94	-0.01	-0.03
Without USA (boycott)	-0.06	-0.92	-0.06	0.96	-0.07	-0.04
Without USA (combination)	0.02	-0.92	0.04	0.97	-0.06	-0.04
<u>with emissions trading and CDM</u>						
With USA	0.00	-0.20	-0.09	1.44	0.51	0.19
Without USA	0.00	0.00	-0.03	0.24	0.12	0.05
With USA (technology)	0.11	-0.06	0.06	1.51	0.49	0.16
Without USA (technology)	0.03	0.00	0.01	0.27	0.12	0.05
Without USA (boycott)	0.00	-0.92	-0.01	0.27	0.10	0.04
Without USA (combination)	0.04	-0.92	0.04	0.31	0.10	0.04

Table 2. Price of carbon in 2010

	Japan	USA	EU	FSU
<u>without emissions trading</u>				
With USA	343	177	256	0
Without USA	337	0	250	0
With USA (technology)	252	145	195	0
Without USA (technology)	247	0	191	0
Without USA (boycott)	355	0	264	0
Without USA (combination)	260	0	200	0
<u>with emissions trading</u>				
With USA	69	69	69	69
Without USA	25	0	25	25
With USA (technology)	61	61	61	61
Without USA (technology)	23	0	23	23
Without USA (boycott)	27	0	27	27
Without USA (combination)	25	0	25	25
<u>with emissions trading and CDM</u>				
With USA	38	38	38	38
Without USA	10	0	10	10
With USA (technology)	35	35	35	35
Without USA (technology)	9	0	9	9
Without USA (boycott)	11	0	11	11
Without USA (combination)	11	0	11	11

Unit: US\$/t-C

4.3.3 Carbon leakage

Figure 6 shows CO₂ emissions changes in 2010 under the "no-trading," "emissions trading" and "emissions trading and CDM" scenarios without the USA compared to the emissions of the reference scenario. Carbon leakage in non-Annex B countries is observed in the no-trading scenario. Leakage in non-Annex B countries decreases as the GDP recovers in the Annex B countries in the trading scenario. In the "emissions trading and CDM" scenario, as the amount of allowable emissions of the non-Annex B countries is restricted to the reference scenario, theoretically there is no leakage. The emissions of Russia in the "trading" scenario are higher than those in the "no-trading" scenario by 0.16 Gt-C.

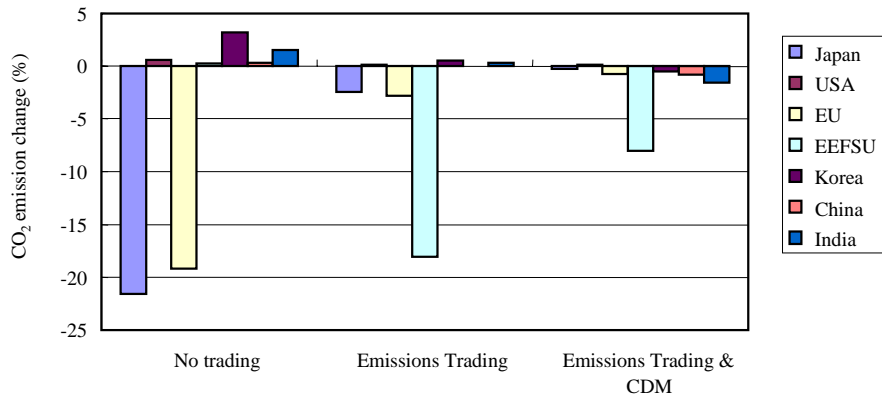


Fig. 6. CO₂ emissions changes in 2010 compared to the reference scenario

4.3.4 Major findings

The change in the GDP in 2010 to achieve the target of the Kyoto Protocol is less than 0.3% in any region if emissions trading is assumed. It can be said that achievement of the target will not have a major influence on any single economy. If it is assumed that there is a movement to boycott the goods of the non-ratifying countries, the GDP loss will grow further. On the other hand, there is a possibility of reducing the economic loss or even expanding the economy by promoting the introduction of energy conservation technologies.

No ratification by the United States lowers the carbon price and decreases the CDM incentive. In this case, total greenhouse gases will increase compared to the reference scenario.

4.4 Long-term Emissions Reduction Scenarios

4.4.1 Long-term mitigation scenarios

The economic impacts of the Kyoto Protocol have been evaluated using the AIM model. Although the Kyoto Protocol is very important as a milestone in climate policy, it is necessary to reduce emissions by more than the reduction target specified by the Protocol in order to achieve the long-term goals of the UNFCCC. Considerable efforts have been devoted to estimating the different stabilization pathways in the post-SRES experiments (IPCC 2001a). Based on these experiments, stabilization of emissions pathways and economic as well as climatic impacts were studied using the AIM model. The emissions model examines

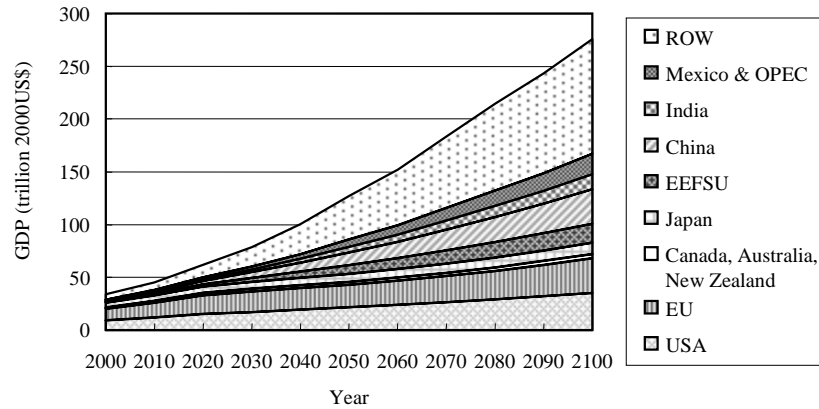


Fig.7. Projection of the world GDP under the reference scenario

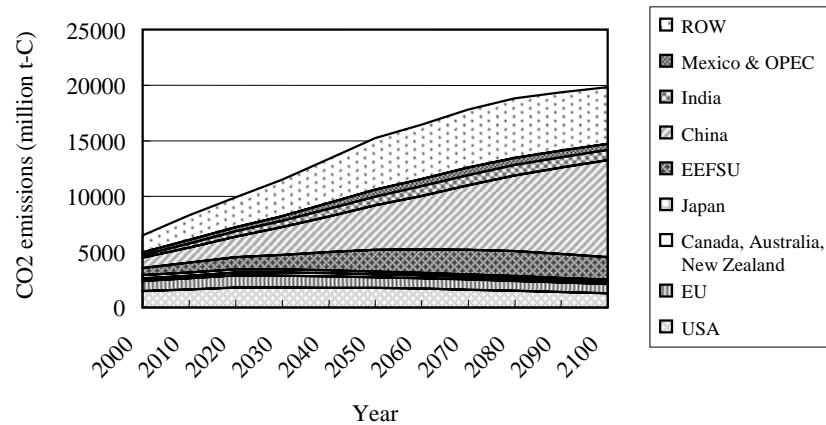


Fig. 8. Projection of CO₂ emissions under the reference scenario

several important variables such as GDP changes, energy consumption, carbon emissions, and marginal costs. Outputs of the emissions model are fed as inputs into the climate model. Estimated climate changes under different scenarios are used to estimate the climatic impacts on food production and infectious diseases focusing on the Asia-Pacific region.

Atmospheric stabilization scenarios were used that limit the atmospheric concentration of CO₂ at 550 ppmv. As a reference scenario the driving forces used by the SRES B2 scenario (IPCC 2000) were taken. It is assumed that carbon emissions can be traded without quantitative limitations on trading cases within the allowable emissions. The global allowable emissions are specified in the 550 ppmv scenarios and they are allocated according to the population.

Figure 7 shows a projection of the world GDP from 2000 through 2100. World growth rates during this period vary from 1.25% to 3.16%, with an average of 2.1%. The highest is that of China, which varies from 1.5% to 6.4%. Figure 8

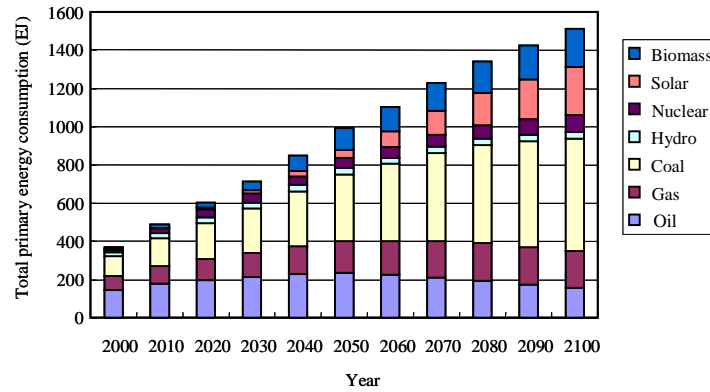


Fig. 9. World energy demand in enduse sectors under the reference scenario

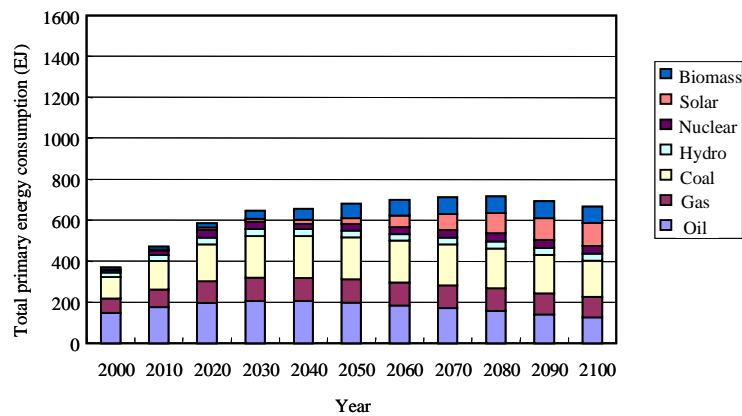


Fig. 10. World energy demand in enduse sectors under the WRE 550 scenario

shows a projection of world CO₂ emissions. It is projected that China will become the top CO₂-emitting country after 2020. The growth rate in world CO₂ emissions will follow a downward curve, whereas that of China will increase. The growth rate in CO₂ is much higher than the growth rate of the GDP in China under this reference scenario. This is because energy efficiency in China is estimated to be lower than that of the developed countries in this case.

The results of the reference scenario are compared with three 550 ppmv scenarios. The three 550 ppmv scenarios examined are WRE 550, WGI 550, and MID 550. The WRE scenario was proposed by Wigley *et al.* (1995) to find the optimal path to 550 ppmv from the economic point of view. WGI 550 is a scenario proposed by IPCC Working Group I (IPCC 1995). It is a path aimed at avoiding an abrupt change in emissions in achieving the 550 ppmv target. The MID 550 scenario is proposed, representing the mean of these two scenarios.

Figure 9 shows world energy demand in enduse sectors in the reference scenario and Fig. 10 shows the results of the WRE 550 scenario. In the reference scenario, the use of solid energy increases from 18% in 2000 to 48% in 2100, and

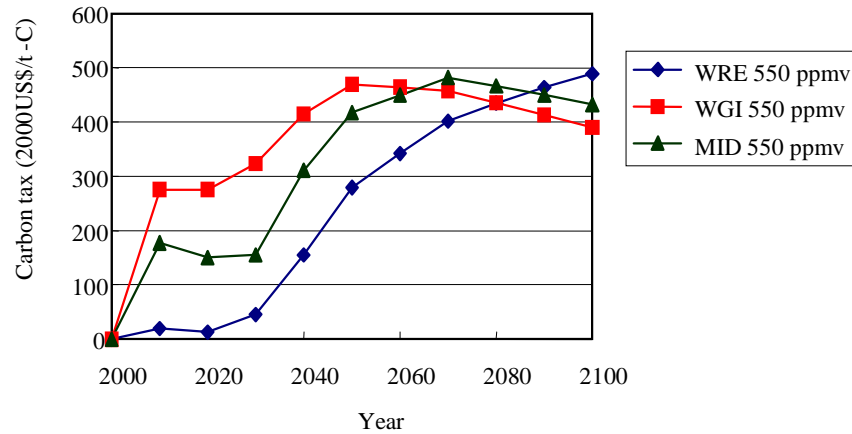


Fig. 11. Projection of marginal costs to reduce emissions

more than half is used in China in 2100. The world final energy demand in the WRE 550 scenario decreases to nearly half that in the reference scenario in 2100. This reduction comes about mainly from cutting coal use. The share of coal in the WRE 550 scenario becomes 29% in 2100. Electricity demand will increase in the policy scenarios. The share of electricity will increase from 17% in 2000 to 29% in 2100 in WRE 550.

4.4.2 GDP changes until 2100

Figure 11 shows the projections of the marginal costs for reducing emissions. The marginal costs for the WGI 550 scenario are the highest through the year 2060, those of MID 550 become the highest from 2060 through 2080, and then those of WRE 550 become the highest from 2090 onwards. Although the constraint of the WGI 550 scenario is the severest until 2070, the marginal costs become the second highest in 2060. The restructuring of the energy system at an early stage will decrease the marginal costs after 2050.

Figure 12 shows the projections for GDP changes compared to the reference scenario. The GDP loss in the WGI 550 scenario increases until 2050 and then recovers, while that of WRE 550 increases until 2070. The GDP loss in WRE 550 is the highest among the three 550 scenarios in 2100. This means that even if the impact of WRE 550 is minimal for the first three decades, it will become large later. The environmental impacts that will be discussed in Section 4.4.4 show that if the timing of reductions is early, this will reduce the impacts compared to scenarios in which action is taken later.

Figure 13 shows the consumption changes relative to the reference scenario. The values shown are the present discounted values for macroeconomic consumption change with respect to the reference scenario in trillions of 2000 US dollars through 2050. The discount rate is 5%. Consumption in India will grow at

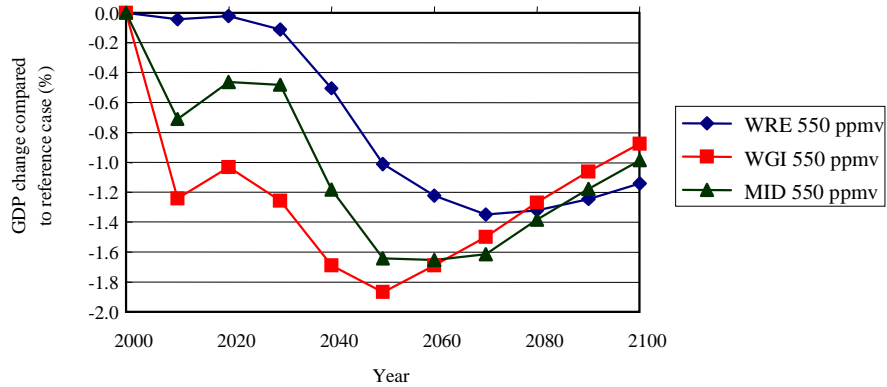


Fig. 12. Projection of GDP changes compared to the reference scenario

the highest level, especially in the WGI 550 scenario. Consumption will decline in Annex B countries and China. The greatest decline is in the US, followed by China, under the assumptions of the policy scenarios.

4.4.3 Global climate change

The impact on the global mean temperature is shown in Figure 14. By 2100, the temperature rises by 2.77°C compared with the 1990 value in the reference scenario. The results of the IPCC SRES range from 1.4°C to 5.8°C (IPCC 2001b). As the economic assumptions of the reference scenario are taken from the SRES B2 scenario, it is lower than the average of the SRES range. While the SRES B2

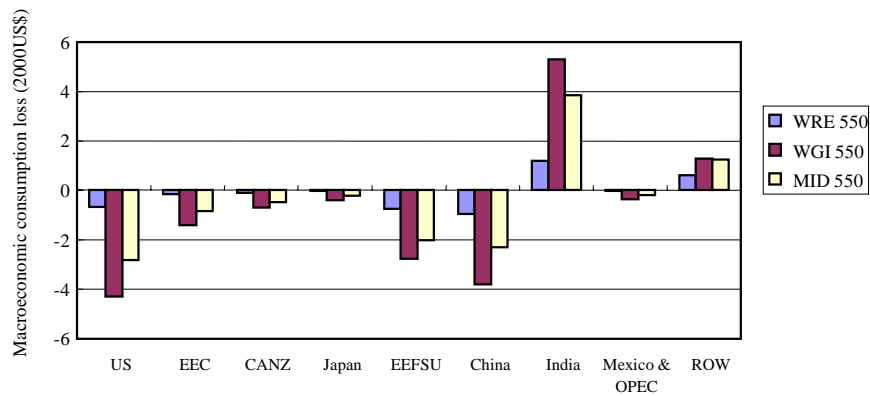


Fig. 13. Present discounted value of macroeconomic consumption loss with respect to the reference scenario (in trillion 2000 US\$)

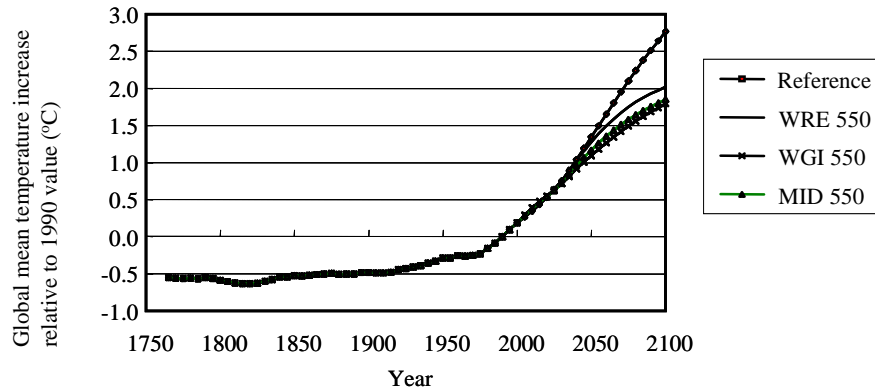


Fig. 14. Temperature increases relative to the 1990 value

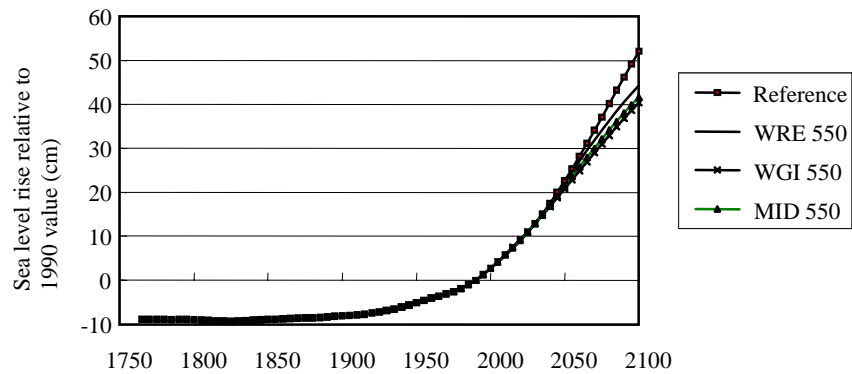


Fig. 15. Rise in the sea level relative to the 1990 value

emissions range from 10.8 Gt-C to 21.8 Gt-C in 2100, the result of the reference scenario is 21.9 Gt-C. This is because the reference scenario uses the assumptions of population and GDP from SRES B2, but does not focus so much on environmental sustainability.

The temperature increase in the WGI 550 scenario is the lowest, at 1.79°C in 2100. The increase in the WRE 550 scenario is 2.02°C. Although the targets of these two scenarios are the same, there is a 0.23°C difference in the temperature increase in 2100. These 550 ppmv scenarios can decrease the temperature by 0.75°C to 0.98°C in 2100 compared to the reference scenario. Although the macroeconomic consumption loss of the WRE 550 scenario is lower than that of the WGI 550 scenario, its impact on climate change is greater.

The globally averaged sea level rise relative to that of 1990 is shown in Figure 15. It ranges from 40 cm to 52 cm. The global sea level in 2100 is projected to rise by 9 cm to 88 cm for the full range of SRES scenarios. The sea level in the WRE 550 scenario rises higher by 3.9 cm than that in the WGI 550 scenario.

4.4.4 Potential impacts in the Asian region

Climate change has direct or potential impacts on water resources, agricultural production, natural ecosystems, and human health, even if socioeconomic interactions are ignored. In the real world, global trade, immigration, and measures for adaptation modify the direct impacts. Hence, there are two stages of the impact study: the direct and indirect stages. In this study, the direct impacts under the reference and 550 ppmv scenarios were considered.

Figure 16 shows the changes in winter wheat productivity in 2100 compared to 1990. The productivity of wheat will decline significantly in Sri Lanka, Malaysia, Korea-PDR, Burma, and other tropical countries.

Figure 17 shows changes in rice productivity in 2100 compared to 1990 under the reference and 550 ppmv scenarios. A slight decrease in rice production is expected in most countries, while a slight increase is expected in Bhutan and Taiwan. The productivity decline in India is projected to be the highest.

Air and water pollution, as well as solid and hazardous wastes, affect human health directly. Global climate change will also affect human health in the future in many ways. For example, global warming will result in increasing temperatures and changing vegetation close to the ground. This will allow expansion of the habitat of the anopheles mosquito, which is the malaria vector. In addition, the development period of the malaria protozoa will shorten and their reproductive potential will increase. As a result, it is expected that the global risk of a higher incidence of malaria will increase.

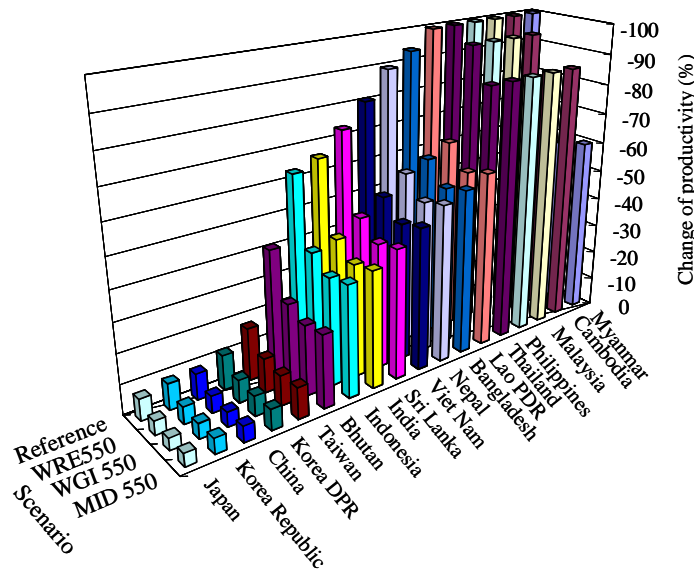


Fig. 16. Change in winter wheat productivity from 1990 to 2100 (see color plates)

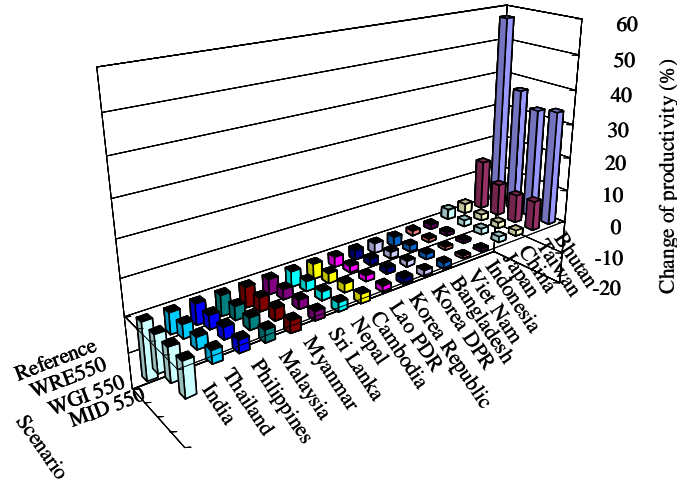


Fig. 17. Change in rice productivity from 1990 to 2100

Figure 18 shows the changes in the populations living where there is endemic malaria. The risk of a higher incidence of malaria in China, Nepal, Taiwan, Indonesia, and Sri Lanka will increase due to the environmental changes. Although China may be little affected by climate change in terms of food productivity, the impact it will experience in terms of malaria risk will be the greatest in the Asian region. Even under the 550 scenarios, the population living in areas at risk will double in 2100 compared to 1990.

4.4.5 Major findings

Several climate change stabilization pathways are examined by the AIM model. An urgent task is to take action to combat global warming as it is an irreversible process and, once it occurs, the probability is very high that it will have multiplier effects that will further expand its impact. It is necessary to consider the many uncertainties involved in human activities such as population growth, economic development, and technological innovation, as well as uncertainties in natural processes to estimate future CO₂ emissions and to make plans for climate stabilization. The scenario approach is a practical means of analyzing the policy options under such uncertainties.

Although the emissions of developing countries were lower than those of developed countries in 2000, it is expected that they will grow much faster than those of developed countries in the future. The estimated impacts on developing countries in the Asian region are serious. The model projects that the early implementation of emissions reductions can minimize the scale of such impacts in the future.

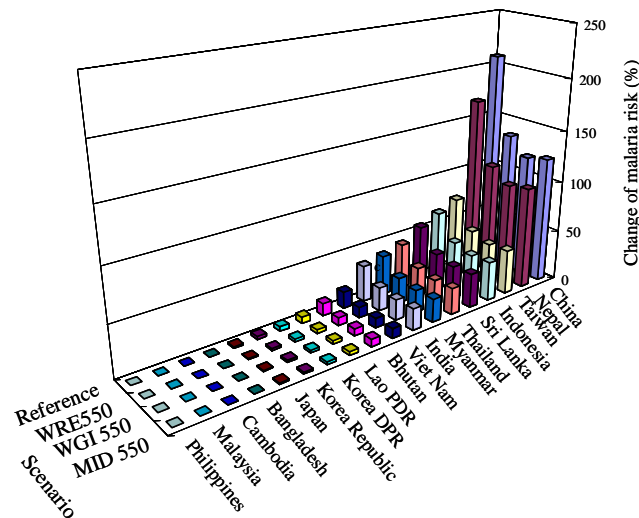


Fig. 18. Change in population living in areas at high malaria risk from 1990 to 2100 (see color plates)

4.5 Concluding Remarks

Without the Kyoto target, the global temperature will increase by more than 2°C in 2100. In such a case, severe impacts of climate change can be predicted on agricultural productions and human health.

It is predicted that ratification of the Kyoto Protocol may have negative economic impacts. However, there are several ways to mitigate these economic impacts as well as possibilities for promoting the growth of economies. For example, if investments are shifted to energy-saving technologies, there is a high likelihood of improving the economy. It is found that the GDP will increase if the price-inducing mechanism is enhanced and the CDM is introduced.

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