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Article

The Costs of Implementing the Kyoto Protocol and Its Implications to China

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The MERGE model is used to analyze the costs of the Kyoto commitment under different scenarios. The results show that costs can be reduced sharply if "hot air" rights are traded. Costs can be further reduced through the clean development mechanism (CDM) and through the global trading mechanism in 2010. However, emissions trading is not so effective in reducing costs in the long run. If China controls its emissions, it will be a very important market for the international trading of carbon emissions rights. The importance of China will increase along with the decrease of "hot air" in former Soviet Union. The CDM can be an opportunity for China to increase its international trade and encourage the inflow of foreign investment.

Keywords: Kyoto Protocol, Costs, Clean development mechanism, Emissions rights trading, China.

1. Introduction

The Third Session of the Conference of Parties (COP3) of the United Nations Framework Convention on Climate Change (UNFCCC) was held in Kyoto, Japan in December 1997. The most important fruit of the Conference was the Kyoto Protocol. Some countries made commitments to reduce their carbon emissions in the 2008 to 2012 period under their 1990 levels by different percentages. The Kyoto Protocol is a milestone for the reduction of carbon emissions. It is the first time that human beings have taken active steps to mitigate global warming. However, these commitments are still far from the ultimate objective of the UNFCCC: namely, the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

One year after the Kyoto Protocol was officially opened for signature, 84 parties (including the European Community) have signed the legally binding agreement. This rapid progress shows that many countries are taking climate change seriously and that implementation of the Kyoto Protocol is becoming pressing. There is no doubt that a price is involved in the implementation of the Kyoto Protocol to

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achieve global environmental benefits. Therefore, performing a cost assessment is the first step towards implementing the Kyoto Protocol.

To reduce the carbon emissions of the committed countries in a cost-effective way, the Kyoto Protocol lays out so-called flexibility mechanisms, including joint implementation (JI) (Article 6), clean development mechanism (CDM) (Article 12) and emissions trading (ET) (Article 17). Many studies show that the costs of carbon reduction can be dramatically reduced by a combination of domestic measures and flexibility mechanisms.

JI refers to joint implementation between two Annex I countries of the UNFCCC. It consists of a bilateral agreement between two entities to complete a greenhouse gas (GHG) project. JI can potentially provide credit for emissions reduction to investors at a lower cost than domestic measures. In other words, JI is a form of emissions trading.

The CDM is a successor to JI. However, it takes place between Annex I countries and non-Annex I countries and can be bilateral or multilateral. Three specific goals of the CDM are identified in Article 12 of the Kyoto Protocol. These are: (1) to assist non-Annex I Parties in achieving sustainable development; (2) to contribute to the ultimate objective of the Convention and (3) to assist Annex I Parties in achieving compliance with their quantified emission limitations and reduction commitments. Because the CDM takes the concerns of both the Annex I Parties and non-Annex I Parties into account, it can be a win-win mechanism. Both Annex I Parties and non-Annex I parties have shown interest in the CDM.

In this article, the MERGE model is used to analyze the costs of carbon reduction by region under different scenarios and to analyze the potential for China to participate in carbon reduction by different mechanisms, such as ET and the CDM.

2. The MERGE model

MERGE is a model for evaluating the regional and global effects of GHG reduction policies. Because it is an open model, users can change the parameters according to their own judgement. Because of its features and the availability of data, the MERGE model was chosen as the tool for this study. Full explanations of MERGE are published in print (Manne and Richels 1999) and on the internet (Manne 2000). Version 3.1 is used in this study and is an integrated model with one module each for energy technology assessment, macroeconomics, climate, and impact.

The energy technology assessment module is a bottom-up linear program. Energy is divided into electric and non-electric energy. Energy supplies include both exhaustible hydrocarbon resources and also backstop technologies. There are 11 technologies for producing electric energy and 13 technologies for producing non-electric energy in MERGE 3.1. Associated with each of the supply technologies are coefficients describing costs and carbon emissions per unit of activity level. There are upper bounds on the speed of introduction of new technologies and lower bounds on the rates of decline of obsolete technologies. Usually, energy consumption need not grow at the same rate as GDP. Over the long run, they may be decoupled. Energy conservation possibilities are summarized through two macroeconomic parameters: the elasticity of price induced substitution (ESUB) and autonomous energy-efficiency improvements (AEEI).

The macroeconomic module is a top-down module. It describes the balance of the economy using a macroeconomic production function. Along with capital and labor, energy is viewed as a basic input into the production function.

The climate module is used to calculate global mean temperature change. MERGE 3.1 takes the three most important GHGs into account: carbon dioxide, methane, and nitrous oxide. The impact module is used to assess damage from global warming.

In MERGE 3.1, the world is disaggregated into nine geopolitical regions: (1) the United States (USA); (2) the Europe OECD (OECDE); (3) Japan; (4) Canada, Australia and New Zealand (CANZ); (5) Eastern Europe and the Former Soviet Union (EEFSU); (6) China; (7) India; (8) Mexico and OPEC (MOPEC) and (9) the rest of the world (ROW). The former five regions together comprise the Annex I countries of the Convention and the latter four regions together make up the non-Annex I countries.

The trade of energy, carbon emissions rights, and energy intensive products also can take place between the nine regions. This leads to the possibility of "leakage" when there are no limits on carbon emissions for major producers of energy intensive products.

The base year is set as the year 2000. MERGE 3.1 adopts 10-year time intervals through 2050 and 25-year intervals through 2100. This analysis focuses on the years 2010 and 2020.

3. Scenarios

3.1. Reference scenario

The reference scenario does not take the Kyoto Protocol into account; namely, there is no carbon emissions limitation imposed on any region. However, this is not a fixed scenario. Energy efficiency will increase along with the development of economy and society. The AEEI is set as 40% of the GDP growth rate for most regions during the projection period.

Most of the input parameters in MERGE 3.1 are compatible with the cases reported by the Energy Modeling Forum Study 16 in the October 1998 and 1998 International Energy Outlook (U.S. Department of Energy 1998). This paper uses most of the same inputs, except for some data concerning China. Here, certain parameters were adjusted according to the new situations of China and some latest studies: the GDP growth rate (Lo and Xing 1999, 165-66), population (Lo and Xing 1999, 164-65) and energy consumption of China (Lo and Xing 1999, 187-90) in the base year 2000. Previous work by the author presents an overview and explanation of this adjustment (Li and Nishioka 1999). Figure 1 shows carbon emissions by region under the reference scenario.

For other scenarios, the Kyoto Protocol is taken into account. Under the Kyoto Protocol, most developed countries must cut their carbon emissions under their 1990 levels by at least 5% in the commitment period 2008 to 2012. For the sake of simplicity, the year 2010 was used as the commitment year. Moreover, the emissions of commitment countries are assumed to remain at the same level as 2000 after 2000. Table 1 shows the Kyoto commitments of Annex I countries by region. As for the emissions of non-Annex I countries, they are limited by the emissions of the reference case provided by MERGE 3.1. For

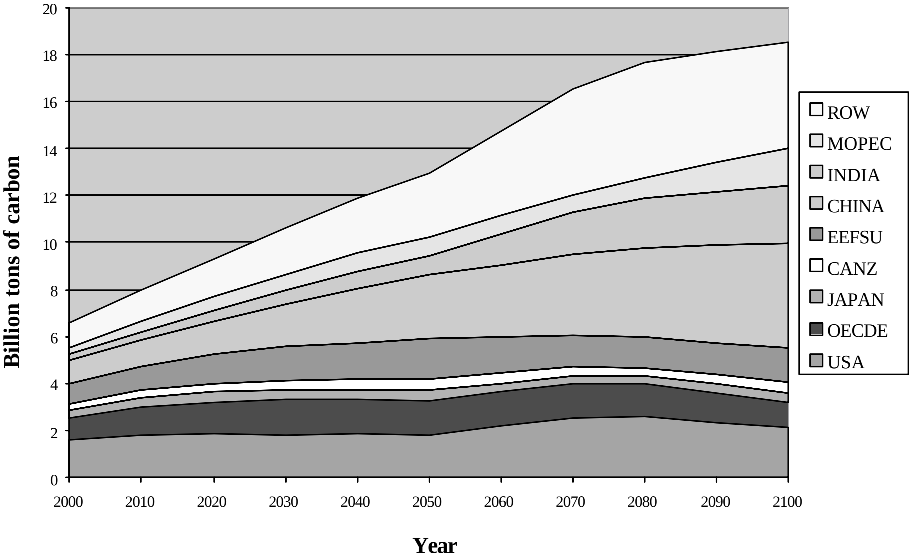


Figure 1. Carbon emissions under reference scenario by region.

China, the limitation is 1247 million tons of carbon in 2010 and 1557 million tons in 2020. These are the inputs used to calculate the incremental values of carbon.

In comparison to the reference scenario, five scenarios are designed to show the possibilities of different ways to implement the Kyoto Protocol. Under the no-trading scenario, every committed country may cut its carbon emissions only through domestic measures. The Annex I trading scenario allows Annex I countries to trade carbon emissions rights among themselves. This scenario stands for the mechanism of JI. “Hot air” is allowed to enter the market for carbon emissions rights, although whether this is permitted under the Kyoto Protocol is unclear. “Hot air” means the amount by which any Party’s emissions are expected to be below that required by the Kyoto Protocol. This is widely expected to be the case for EEFSU. Under the global-trading scenario, the trade of carbon emissions rights can take place on a global scale without constraints.

Table 1. Emissions levels under the Kyoto commitments.

		USA	OECDE	JAPAN	CANZ	EEFSU	AN.1
Emissions 1990 (billion tons)		1.346	0.971	0.274	0.216	1.290	4.097
Reference emissions 2010		1.826	1.191	0.392	0.312	1.024	4.745
Reference emissions 2020		1.869	1.349	0.439	0.368	1.229	5.254
Kyoto commitments/1990		93%	92%	94%	100%*	98%**	
Emissions target 2010, 2020		1.252	0.893	0.258	0.216	1.264	3.883
Reduction/ref 2010	Billion tons	0.574	0.298	0.134	0.096	0	1.102
	%	31	25	34	31	0	23
Reduction/ref 2020	Billion tons	0.616	0.456	0.181	0.152	0	1.405
	%	33	34	41	41	0	27
“Hot air” in 2010 (/ref)		0	0	0	0	0.24 (23%)	
“Hot air” in 2020 (/ref)		0	0	0	0	0.035 (3%)	

* Commitments of Australia, Canada and New Zealand are 108%, 94% and 100% respectively.
** Commitment of Russia is 100%, but some economic transition countries have different reduction commitments.

Two scenarios were designed to represent the CDM: the CDM buyers market scenario (CDM BM) and the CDM sellers market scenario (CDM SM). Under these two scenarios, trading of carbon emissions rights can take place freely among Annex I countries. However, Annex I countries can only buy one-third of their commitments from non-Annex I countries in the former scenario, and non-Annex I countries can only sell one-third of Annex I countries' commitment to Annex I countries in the latter scenario. The limit of one-third of the commitments on the carbon trade between Annex I countries and non-Annex I countries was set because the Kyoto Protocol indicates that emissions trading shall be supplemental to domestic actions (Article 17), and different Parties have a different understanding of the CDM. This limit may be an optimistic estimate.

4. The costs of implementing the Kyoto Protocol by region

Because energy prices and energy structures are different in different regions, the costs of carbon reduction will be different for each region. Figure 2 shows the incremental values for carbon by region under the no-trading scenario. The results indicate that the committed countries will be subject to relatively high costs for reducing their carbon emissions to the Kyoto targets. The incremental value of carbon of OECDE is likely to be the highest, around U.S.$ 350 per ton of carbon. In comparison, the incremental value of carbon of the United States is considerably lower than other regions. This is because of the lower energy prices in the United States.

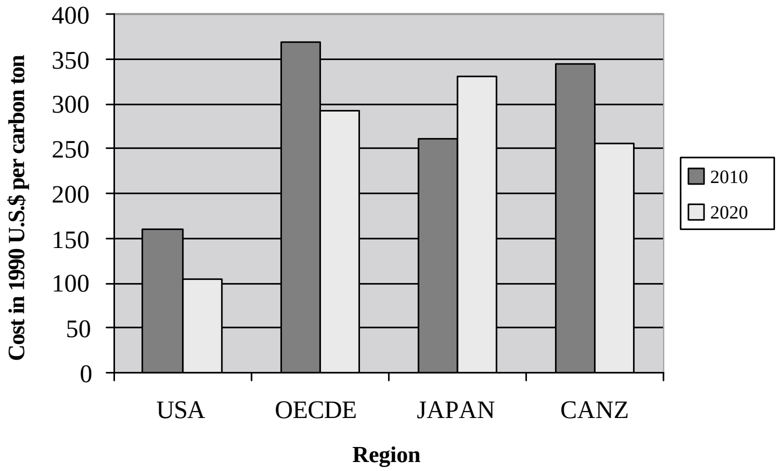


Figure 2. Incremental values of carbon by region under the no-trading scenario.

Additionally, Figure 2 illustrates that the incremental value of carbon will decrease from 2010 to 2020 in the USA, OECDE and CANZ. However, the situation of Japan is reversed. As a result of the relatively high cost of carbon reduction, energy demand and energy structure will be adjusted by means of the energy price according to the elasticity of energy, capital and labor. The cost of carbon reductions will therefore probably decrease in the future. However, because the energy structure of Japan is relatively efficient at present, it is unlikely to improve further. Moreover, because of the scarcity of Japan's energy

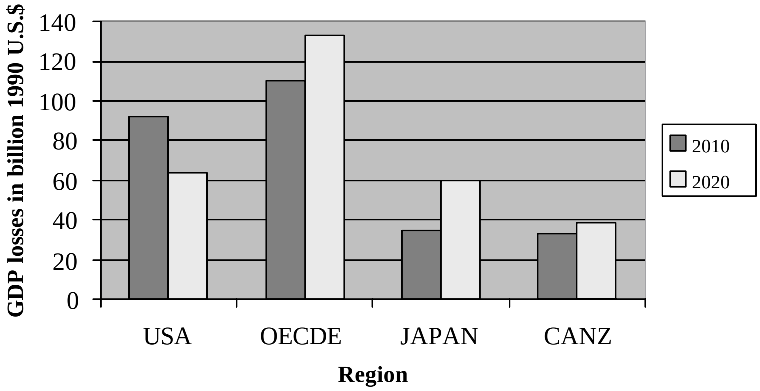


Figure 3. GDP losses by region under no-trading scenario.

resources, carbon reduction costs will likely increase. Therefore, Japan's incremental value of carbon will be the highest among the regions in 2020.

Figure 3 shows the GDP losses in 2010 and 2020 by region. OECDE will be subject to the largest loss, which will be around U.S.$ 110 billion in 2010 and U.S.$ 130 billion in 2020. The GDP loss of CANZ will be small in absolute terms. However, because CANZ has the smallest GDP, the ratio of the GDP loss to the GDP will be the highest, around 2.2% in 2010 and 2.1% in 2020. The ratio for USA will be 1.1% in 2010 and 0.6% in 2020, and the ratio for OECDE will be 1.0% both in 2010 and in 2020. The ratio will be constant or decrease in these three regions, even though the GDP loss will increase in OECDE and in CANZ. However, the GDP loss in Japan will increase from U.S.$ 35 billion in 2010 to U.S.$ 60 billion in 2020, and the ratio will increase from 0.8% to 1.1%. If the committed regions are viewed as a whole, the GDP loss will be 1.1% in 2010 and 1.0% in 2020.

Figure 4 shows the incremental value of carbon emissions rights of different scenarios in 2010 and 2020. The values were produced from the result of integrating the impacts of different factors such as

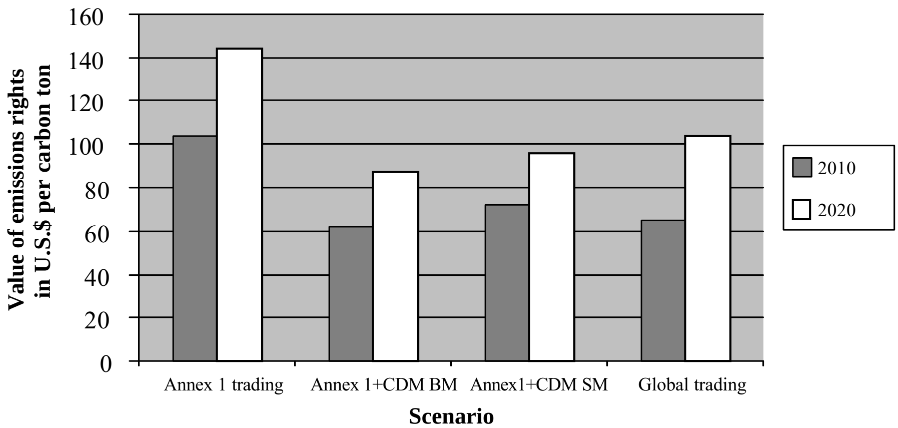


Figure 4. Incremental value of carbon emissions rights under different scenarios.

supply and demand and the expansion of technology. Under the Annex I trading scenario, the incremental value of carbon emissions rights decreases sharply to around U.S.$ 100/carbon tons in 2010 as compared to the no-trading scenario (see Figure 2). This is because under the Annex I trading scenario, a large quantity of hot air enters the market, and hot air is widely considered zero-cost. However, good times will not last long because the incremental value will increase to more than U.S.$ 140/carbon tons in 2020. On one hand, hot air decreases from 240 million tons in 2010 to 35 million tons along with the development of the economy and the increase of carbon emissions in EEFSU. On the other hand, the amount of carbon to be reduced (compared to the reference scenario) in the committed countries increases. The gap between the demand and supply of cheap carbon emissions rights becomes larger and larger. The simulation results indicate that the export of carbon emissions rights of EEFSU will decrease from 440 million tons in 2010 to 370 million tons in 2020 under the Annex I trading scenario.

Under the global-trading scenario, the incremental value of carbon emissions rights further decreases to U.S.$ 65/carbon tons in 2010 and U.S.$ 104/carbon tons in 2020. The participation of non-Annex I countries in the carbon emissions rights market further decreases the cost of carbon reduction.

Under the CDM buyers market scenario, the incremental value of carbon emissions rights goes down to its lowest figure, U.S.$ 62/carbon tons and U.S.$ 87/carbon tons in 2010 and 2020 respectively. In the buyers market, sellers of carbon emissions rights are price takers. Buyers attempt to hold the carbon price to the marginal cost of reduction in the selling countries through market mechanisms. However, the committed countries are only able to satisfy one-third of their commitments through buying emission rights from the non-Annex I countries. This means that in regard to carbon emissions rights supply exceeds demand as compared to the situation in the global-trading scenario where there is no limit on purchase. The price of carbon emissions rights is therefore lower in the buyers market than that under the global-trading scenario.

Under the CDM sellers market, buyers are price takers. The incremental value of carbon emissions rights increases to U.S.$ 72 and U.S.$ 96/carbon tons in 2010 and in 2020 respectively. The incremental value in 2010 is larger than that in both the buyers market scenario and the global-trading scenario. However, the incremental value of carbon emissions rights in 2020 under the global-trading scenario is larger than that under the CDM scenarios.

Figure 5 shows the potential for the committed countries to satisfy their obligations through the purchase of carbon emissions rights. Because international trade will reduce the costs of carbon reduction dramatically, most countries would prefer to import carbon emissions rights rather than take domestic actions to satisfy their commitments, especially in 2010. Japan will buy all of its commitment if the CDM or global trading is permitted, and will buy more than 90% of its commitment even if trade is permitted only in Annex I countries. The USA and the OECDE will buy more than 50% of their obligations under the global trading and CDM scenarios. However, if trade is permitted only in Annex I countries, the willingness of the USA and the OECDE to purchase will decrease to 35% and 31% respectively.

Because the amount of carbon to be reduced will increase in 2020 (compared to that under the reference scenario), the share in 2020 of carbon reduced by importing carbon emissions rights will decrease

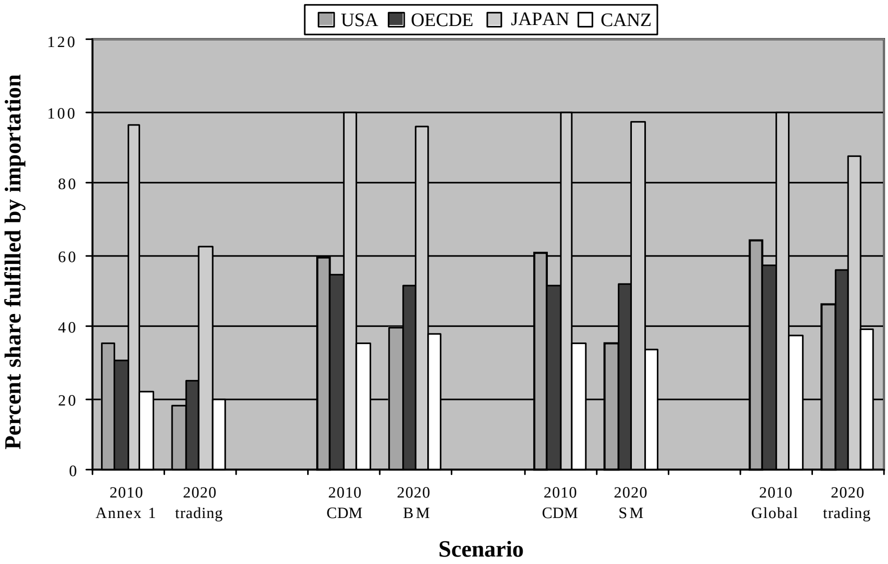


Figure 5. Share of total carbon to be reduced that will be fulfilled by importing carbon emissions rights under different scenarios.

in 2020 for most regions, even though their import volumes will increase slightly. If all the committed countries are taken as a whole, 51% of the total commitment can be satisfied under the Annex I trading scenario in 2010, 78% under the CDM buyers market, 78% under the CDM sellers market and 82% under global trading. In 2020, this will decrease to 27%, 52%, 50% and 55% respectively. This decrease indicates that the costs of carbon reduction in non-Annex I countries will increase at a more rapid rate than that of Annex I countries, and that the costs of carbon abatement are inclined to be close in the long run. Therefore, the importance of domestic actions will increase along with the economic development of non-committed countries.

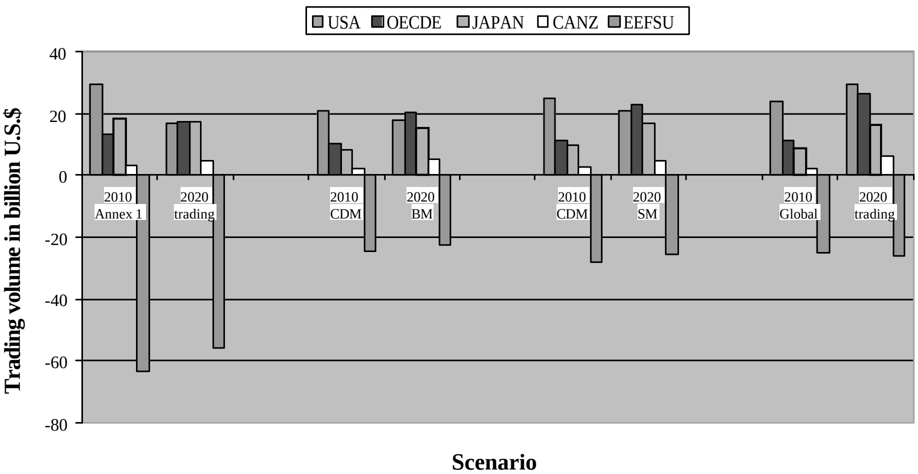


Figure 6. Volume of carbon emissions rights trading by region under different scenarios.

Figure 6 shows the trading volumes of carbon emissions rights under different scenarios by region. The positive figures represent import volumes, and the negative figures represent export volumes. The USA shows a difference from other committed regions. The import volume of carbon emissions rights will decrease from 2010 to 2020 except under the global-trading scenario. However, the trading volumes of all other committed regions will increase from 2010 to 2020 under all scenarios except for Japan under the Annex I trading scenario.

If all the committed regions are taken into account, the total trading volume will increase from 2010 to 2020 under all scenarios except for the Annex I trading scenario. On the one hand, the total trading volume will increase; on the other hand, the share of total carbon emissions reduction fulfilled by importing carbon emissions rights will decrease. This indicates that the total costs of carbon reduction will increase considerably.

The total carbon trading volume of the Annex I trading scenario is U.S.$ 64 billion in 2010, which is the highest figure. However, emissions trading can only satisfy 51% of the total commitment. The total trading volume will decrease to U.S.$ 41 and U.S.$ 48 billion under the CDM buyers market scenario and the CDM sellers market scenario respectively, and can satisfy 78% of the total commitment. The total trading volume under the global-trading scenario is U.S.$ 46 billion, and can satisfy 82% of the total commitment. It is clear that the greatest cost savings can be made under the global-trading scenario, rather than under the CDM buyers market scenario or the CDM sellers market scenario. The least cost savings is achieved under the Annex I trading scenario. However, when compared to the no-trading scenario, considerable costs still can be saved under the Annex I trading scenario.

The role of EEFSU is evident in Figure 6. It illustrates that EEFSU will be a beneficiary in the market of carbon emissions rights if hot air is permitted to enter the market. EEFSU will show a converse inclination under different scenarios. Annex I trading will be its optimal scenario.

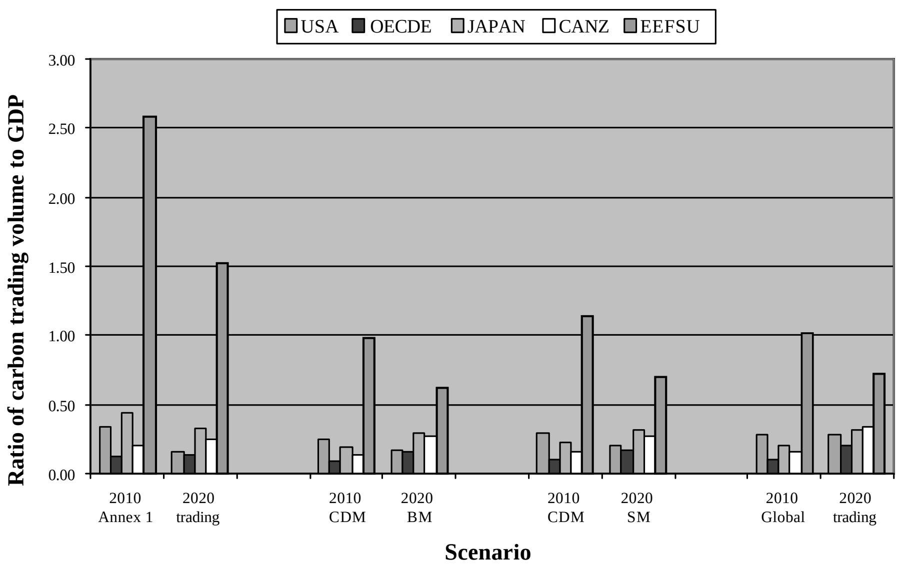


Figure 7. Ratio of carbon trading volume to GDP under different scenarios.

Another way to see the costs of carbon reduction is by examining the ratio of carbon trading volume to GDP, shown in Figure 7. Although the cost seems considerable, it is quite small when compared to GDP. For example in Japan, the ratio of carbon trading volume to GDP is only 0.4%, 0.2%, 0.2% and 0.2% in 2010 under the Annex I trading, CDM buyers market, CDM sellers market and global-trading scenarios, respectively. Because Japan can satisfy its commitment only through the purchase of carbon emissions rights under most scenarios (except for the Annex I trading scenario), the trading volume is its total costs for carbon reduction. For other regions, limited domestic actions must be adopted. However, because the largest part of their commitments still can be satisfied through purchase of carbon emissions rights, the trading volumes are still close to their total costs. If all committed regions are taken as a whole, the trading volume in 2010 is only around 0.3% and 0.2% under the Annex I trading scenario and the other scenarios respectively. The ratio increases slightly in 2020 under all of the scenarios except for the Annex I trading scenario. This indicates that not only the absolute costs, but also the ratio of the costs to the GDP, will increase from 2010 to 2020.

Table 2. Summary of the costs of the Kyoto commitment.

		Total costs (billion U.S.$)	Share of GDP (%)
No-trading	2010	270	1.1
	2020	296	1.0
Annex I trading	2010	159	0.6
	2020	215	0.7
CDM buyers market	2010	68	0.3
	2020	122	0.4
CDM sellers market	2010	79	0.3
	2020	135	0.4
Global trading	2010	72	0.3
	2020	146	0.5

Table 2 lists the total costs of all committed countries for carbon reduction. The results show the costs of the Kyoto commitment are around 1% of GDP if international trade is prohibited. This can be reduced sharply if hot air enters the market, and can be further reduced under the CDM and global-trading scenarios. Because the committed countries can buy one-third of their obligations from non-Annex I countries without any limitation on the purchase from EEFSU in the CDM scenarios, the results of the CDM scenarios and global-trading scenario are similar. In other words, committed countries can buy enough carbon emissions rights through Annex I trading and the CDM to minimize their costs.

The results also demonstrate that if international trading of carbon emissions rights is permitted, the cost of unit carbon reduction is inclined to increase in the future. However, if commitments must be realized through only domestic measures, the cost of unit carbon reduction is inclined to decrease in the future. Therefore, the costs of carbon reduction for committed countries can be reduced through the importation of emissions rights during the first commitment period. However, emissions trading is not as efficient at reducing the costs in the long run. It does not further technological advancement in the committed countries, because considerable carbon reduction can be achieved through the replacement of outdated technologies in developing countries by the current technologies of committed countries, rather than through the development of more advanced technologies in the committed countries themselves. If carbon reductions rely only on domestic measures, more advanced technologies are needed.

5. The potential of the emissions trading and clean development mechanisms in China

China is the world's largest developing country. Its energy consumption reached 1097 Mtoe in 1996. Carbon emissions from fuel combustion amounted to 856 Mt. Both its energy consumption and carbon emissions were second in the world only to those of the United States (see Table 3). China has made great achievements in economic development since the 1980s. During the period from 1978 to 1997, its average annual economic growth rate exceeded 9%. However, the economy of China is still behind those of developed countries. China's per capita GDP was only U.S.$ 860 in 1997. This is only one sixth of the world average and 3% of Japan's per capita GDP. To improve the living of citizens, China will further develop its economy. Because energy is the material basis of its economy, its demand for energy and carbon emissions will increase as its economy develops further. However, China must take the path of sustainable development because of the pressures of scarce energy resources and the environment. Because the sustainable development of host countries is one of the most important purposes of the CDM, it is consistent with the development strategies of China. Therefore, the CDM can, in theory, be practiced in China.

Table 3. Indexes of selected countries in 1996.

Items	China	USA	Japan	Russia	India	World *
GDP per capita in 1997 (1997 U.S.$)	860	28740	37850	2740	390	5130
Total energy consumption (Mtoe)	1097	2135	510	616	450	9448
Energy consumption per capita (toe)	0.90	8.03	4.05	4.16	0.48	1.68
Carbon emissions (Mt-carbon)**	856	1451	321	413	235	6163
Carbon emissions per capita (t)	0.70	5.45	2.55	2.79	0.25	1.10
Energy consumption of unit GDP (toe/1000 U.S.$, 1990)	1.57	0.34	0.15	1.80	1.09	0.39
Carbon emissions of unit GDP (t/1000 U.S.$, 1990) **	1.22	0.23	0.10	1.21	0.57	0.25

* Excludes North Korea, Vietnam, and Albania.
** Carbon emissions are only from fuel combustion.
Calculated based on the data of IEA, OECD/World Bank.

At the same time, China's current energy efficiency is still very low, although significant achievements have been made in improving its energy efficiency since 1978. Energy consumption per U.S.$ 1000 GDP of China was 1.57 toe in 1996, which is 4 times the world average and 10 times that of Japan, and 40% more than that of India, another large developing country (see Table 3). This has led not only to serious environmental pollution but also to very high carbon emissions per unit of GDP. Therefore, there is major potential for energy efficiency improvements in China.

Moreover, China's energy structure is dominated by coal, the most carbon-intensive form of energy. Coal accounted for 62% of its total primary energy consumption in 1996. However, coal only constituted 24% of the world's total primary energy consumption. China's shares of hydropower and nuclear power are much lower than the world average, though China has rich hydropower and uranium resources. Therefore, the difference in carbon emissions per unit of GDP between China and other countries is larger than the difference in energy consumption per unit GDP. In 1996, China's carbon emissions were 1.22 tons/U.S.$ 1000 GDP. This is 5 times the world average and 12 times that of Japan (see Table 3 and

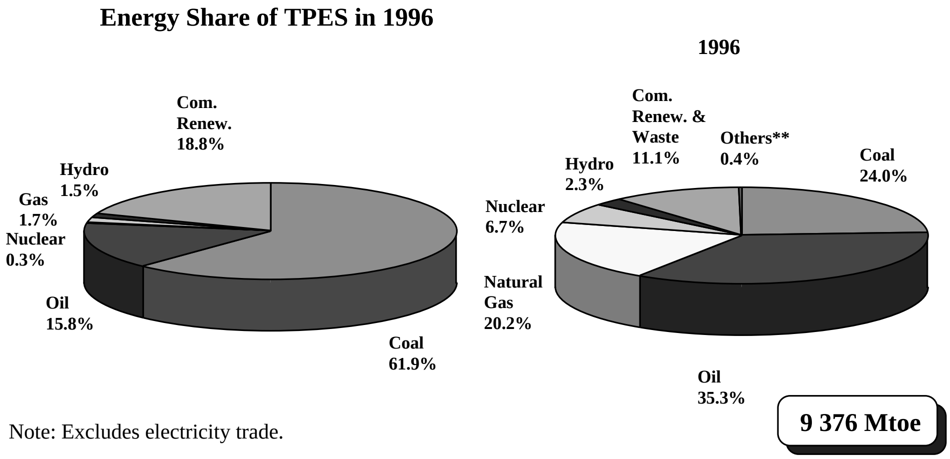


Figure 8. Total primary energy structure (TPES) of China (left) and the world (right) (data from IEA).

Figure 8). Thus, the improvement of China's energy structure can lead to considerable reductions in environmental pollution and abatement of carbon emissions in China.

The economic development of China requires more energy. However, because China's energy efficiency is still quite low, and its energy structure is still very poor, there is great potential to improve its energy efficiency and energy structure. Consequently, the CDM, which aims at sustainable development in host countries and satisfying the obligations of committed countries through carbon reduction from the projects, holds great promise for China. Table 4 lists the potential of the CDM in China under different scenarios based on the MERGE model.

Table 4. Carbon emissions rights market in China.

	Global trading		CDM buyers market		CDM sellers market	
Year	2010	2020	2010	2020	2010	2020
Net carbon exports (million tons)	222	296	208	283	202	266
Net carbon exports of China/total carbon reduction in commitment countries (%)	20	21	19	20	18	19
Net carbon exports of China/total carbon import of commitment countries (%)	31	39	31	40	30	39
Carbon price (U.S.$ /ton)	65	104	62	87	72	96
Carbon trading volume (billion U.S. $)	14	31	13	25	15	26
Ratio of carbon trading volume to GDP (%)	0.7	0.9	0.7	0.7	0.8	0.8

Table 4 shows that China will be a very important market for the international trading of carbon emissions rights under different scenarios. China will export extensive carbon emissions rights, which can satisfy around 20% of the world's Kyoto commitment in 2010 and 2020, and which will account for around 30% and 40% of the total import of carbon emissions rights of the committed countries in 2010 and 2020 respectively. Although the share of carbon emissions reduction obtained through domestic action will increase from 2010 to 2020 in the committed countries, these countries nevertheless will increase their trade of carbon emissions rights with China. EEFSU will have much hot air in 2010, and will be the biggest supplier of carbon emissions rights. Along with the economic development and carbon emissions increase, hot air will decrease. This is why China is likely to take the place of EEFSU and become the largest supplier of carbon emissions rights in 2020.

China's export volume of carbon emissions rights will be between U.S.$ 13 and 15 billion in 2010, accounting for 0.7% of its GDP. The volume will increase to between U.S.$ 25 and 31 billion in 2020, accounting for 0.8% of its GDP. At present, China's foreign trading volume is about 30% of its total GDP. If this share remains constant in future, China's carbon trading volume will account for 2.3% and 2.7% of its total foreign trade in 2010 and 2020 respectively. If China's international trade can be balanced, then the export of carbon emissions rights will account for 4.7% and 5.4% of its total export in 2010 and 2020 respectively.

Domestic carbon emissions of China are slightly different for each of the scenarios listed in Table 4. However, the sum of its domestic emissions and net carbon exports is limited by the emissions in the reference case provided by MERGE 3.1. Nevertheless, this limitation is much greater than the emissions of the reference scenario in this article, and so it will not have a significant negative impact on the economic development of China in the future (Table 5). Under the limitation, the sum of domestic emissions and exports can be different for each scenario, such as the CDM sellers market scenario, because the carbon emissions can be delayed to the next period if the sum of carbon emissions and exports is less than the limitation in the current period.

Table 5. Domestic carbon emissions and exports in China (in million tons of carbon).

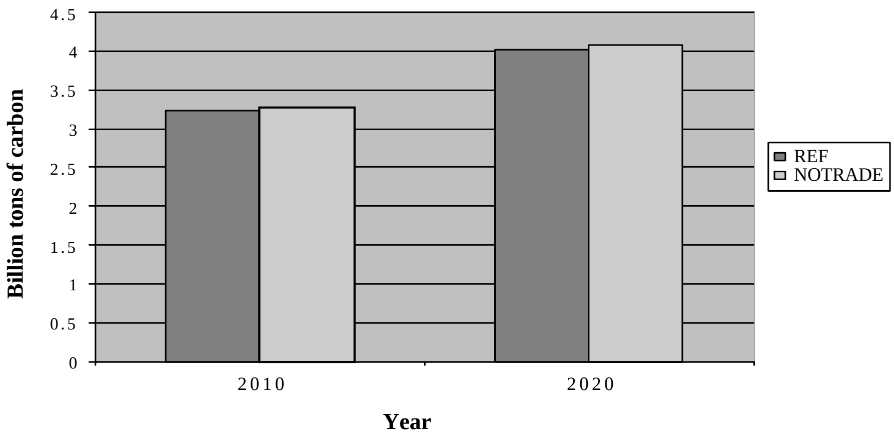
Scenarios		Year 2010	Year 2020
Reference scenario		1095	1378
Limitation (provided by MERGE 3.1)		1247	1557
CDM buyers market	Domestic emissions	1039	1274
	Net exports	208	283
	Total	1247	1557
CDM sellers market	Domestic emissions	1040	1295
	Net exports	202	266
	Total	1242	1561
Global trading	Domestic emissions	1024	1261
	Net exports	222	296
	Total	1246	1557

6. Carbon leakage

Carbon leakage is the increase in the GHG emissions of non-Annex 1 countries resulting from the reduction of GHGs in the Annex 1 countries. Theoretically, Annex 1 countries will consume less energy because of their commitments to GHG reduction under the Kyoto Protocol. Because the demand for carbon-intensive energy will decrease in Annex 1 countries, international prices of carbon-intensive energy will also decrease. In turn, this may increase the consumption of carbon-intensive energy and GHG emissions in non-Annex 1 countries. Some fear that increased emissions from non-Annex 1 countries will partially offset reductions in Annex 1 countries. Bjart Holtsmark (1998) estimated that carbon leakage would be around 14% of the total abatement within the Annex B region and approximately the same size as the total abatement within the European Union.

However, MERGE 3.1 results show that carbon leakage is not as serious as feared. Comparing the reference scenario and the no-trade scenario, carbon emissions of non-Annex 1 countries will increase from 3.227 to 3.268 billion tons in 2010 and from 4.030 to 4.092 billion tons in 2020. This amounts to only 41 million tons in 2010 and 62 million tons in 2020. Carbon leakage will be around 4.8% in 2010 and 4.5% in 2020 of the total reduction in Annex 1 countries, and around 1.3% in 2010 and 1.5% in 2020 of the emissions of non-Annex 1 countries.

Nevertheless, the extent of carbon leakage is a controversial issue. Carbon leakage under the latest version of MERGE, MERGE 3.5, is more serious than under MERGE 3.1 (Manne 1999). This is associated with lowered oil and gas prices and with changes in the geographical location of energy-intensive production.



(REF: reference scenario, NOTRADE: no-trading scenario).

Figure 9. Carbon emissions of non-Annex 1 countries (in billion tons of carbon).

7. Conclusions

To analyze the costs of the Kyoto commitment, the MERGE model is used to simulate possible approaches to satisfying the Kyoto commitment. The results of this article are based upon this model, especially upon the reference scenario. Compared with the results of other models, the incremental value of carbon under the emission trading scenario and the CDM scenarios is higher in this model. One of the important reasons for these results is that energy consumption and carbon emissions of China in this study are lower. A comparison between the results of this article with those of another model, a second generation model (SGM), is presented in Table 6 (SGM, Sands 1999).

During the recent years, the Chinese government implemented a series of policy measures to improve the national economic structure and environment, and these policies have achieved pronounced effects. Total energy consumption in China decreased from 1389 Mtce in 1996 to 1360 Mtce in 1998. More

Table 6. Comparison between the results of SGM and this study.

		SGM	This study
Energy consumption of China in 2010, exajoules		64.8	57.5
Carbon emissions of China in 2010		1388	1247
Carbon incremental value, U.S.$ 1990/t	Annex I trading	84.5	104
	Annex I + CDM	96.9 (Annex I)	72
		2.7 (China)	
	Global trading	22.4	65
Carbon export of China, Mt	Annex I + CDM	43	30
	Global trading	290	31

importantly, the energy consumption structure has improved, with the share of coal reduced from 74.6% to 71.6%. Energy consumption will not increase before 2000 because the Chinese government will continuously control coal production and energy intensive products. Although energy consumption will increase again after 2000, the energy consumption structure is expected to improve and China's high rate of carbon emissions is expected to slow. Therefore, the energy consumption and carbon emissions values for China used in this study are lower than in some other studies.

Although this study leaves many uncertainties, some general insights can be drawn:

The costs of the Kyoto commitment are relatively high if international trade of carbon emissions rights is forbidden. Costs can be reduced sharply if the hot air enters the market, and can be further reduced through the CDM and the global trading mechanism.

If the trade of carbon emissions rights can take place freely in Annex I countries and the committed countries can buy up to one-third of their obligations from non-Annex I countries, they can buy enough carbon emissions rights in 2010 as they expect under the global trading mechanism. In other words, the limitation of one-third on the CDM is not a real constraint on the committed countries' purchases from non-Annex I countries as long as there is a large amount of hot air that is permitted to enter the market. However, the limitation of one-third can become a real constraint if hot air cannot be traded or if hot air is eliminated in the future.

If international trading of carbon emissions rights is permitted, the cost per unit of carbon reduction is likely to increase in the future. However, if the commitments must be realized by only domestic measures, the cost per unit of carbon reduction is likely to decrease in the future. Therefore, the costs of carbon reduction for committed countries can be reduced through imports in the first commitment period. However, emissions trading will not be as efficient a means for reducing costs in the long run.

China will be a very important market for international trading of carbon emissions rights, and its importance will increase along with the decrease of hot air in EEFSU. At the same time, the CDM can be an opportunity for China to increase its international trade and introduce foreign investment.

The above results are based only on an economic cost-benefit analysis. Economic efficiency is taken fully into account, but some important factors, such as equity, are omitted. Moreover, this analysis does not consider the legitimacy of the trading of hot air. Some countries consider the trading of hot air to be inconsistent with the target of the UNFCCC. Only after resolving such issues can the CDM or emissions trading be put into practice.

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