5. Application of AIM/Enduse Model to China

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Summary. Along with rapid economic growth, as a nation, China has become the second highest consumer of energy in the world and the greatest emitter of CO_2. The amount of future CO_2 emissions in China and the means of reducing these emissions are currently important issues to resolve. Base on sectoral and technological information, this study analyzed future CO_2 emissions scenarios with respect to several cases and assessed the effects of different policy options using the AIM/Country model. It also analyzed CO_2 reduction costs for various sectors. From the results, it was found that CO_2 emissions will increase along with the rapid economic development in China, but it is possible to gradually minimize the growth rate of CO_2 emissions through technological progress directed towards efficient markets and the adoption of policies for CO_2 reduction. Technological progress plays a key role in CO_2 emissions mitigation and local air pollution abatement.

5.1 Introduction

In China, the annual average GDP growth rate was 8.9% in the 1980s following the country's economic reforms and the opening up of its economy. From 1991 to 2001 the average growth rate increased to 9.86%, giving China one of the highest economic growth rates in the world. Rapid economic development has stimulated major social changes in China. The reform of economic mechanisms, changes to government functions, nurturing of the market economy, raising the quality of life, etc., comprise the major social changes in China. The industrial structure is also changing. For example, secondary industries have increased their share of overall economic activity, expressed as a common characteristic of countries in the early phase of industrial development. During the same period, personal income rapidly increased and residential consumption patterns also changed greatly. The period over which these changes will take place will be much shorter in China than was the experience of the developed countries.

Along with rapid economic development, energy production and consumption has increased very quickly. In 2000 the figures were 901 Mtoe (million ton oil equivalent) and 903 Mtoe respectively, with annual growth rates of 5.2% and 4.8% from 1980 to 2000. China is now one of the world's major countries with respect to energy production and consumption. One significant characteristic of energy production and consumption in China is that coal plays a larger role than in most other countries. In 1994, coal accounted for 78% of total energy production

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and 48% of final energy consumption. This level of energy production and consumption creates serious environment problems and is indicative of low energy efficiency. Since there are limitations on energy resources and little capacity to import energy into China from the international market, it is difficult to change this situation in the near future. Following the increase in energy consumption together with the invariable energy structure, CO_2 emissions in China increased from 0.41 billion tons of carbon in 1980 to 0.65 billion tons of carbon in 1990. The share of CO_2 emissions in China in relation to total world CO_2 emissions has been growing, and this trend can be expected continue in future. Rapid economic growth, with fossil fuels meeting a large part of energy consumption, and the demand for a better life style will drive China into becoming a conspicuous consumer of energy and emitter of CO_2 compared to the rest of the world.

Considering this development trend, a better understanding of future trends in relation to energy demand and CO_2 emissions is critical, and it is also important to assess the effects of various means of reducing CO_2 emissions in China. Many research activities on CO_2 emissions scenarios in China have already been conducted. Some significant scenarios were provided by the IPCC (IS92 and SRES scenarios) (Nakicenovic 2001), IEW, WEC, GREEN, SGM and several other groups (Houghton *et al.* 1995). It is noticeable that the range of variability in the results of these scenarios is very large (Zhou *et al*. 1997). Up to now, most of these research activities have been based on a macroeconomic approach and did not consider the far-reaching technological progress and structural social changes that have been observed in recent years in China. The study described in this report tries to assess the effects of such technological progress and structural social changes as well as possible policies on future energy consumption and CO_2 emissions based on more detailed data, including energy services and processes, energy technologies, and various social changes.

Since 1994, the Energy Research Institute has worked together with the AIM team at NIES to develop an AIM/Country model for China. After several years work, the AIM-China model was developed with the inclusion of 26 sectors involving more than 500 technologies. Energy demand and CO_2 emissions by 2030 were simulated, while some policies that focus on technological progress and collaboration were assessed as to their contribution to controlling CO_2 emissions.

5.2 Input Assumptions and Simulations

Growth in economic development is a key assumption for this research. It is commonly viewed that China can continue to develop very quickly as long as no major social upheaval occurs. Many studies had been conducted to forecast future economic development in China. By synthesizing several forecasts on economic development in China, annual average GDP growth rates of 9% from 1990 to 2000, and 7.5%, 6.5%, and 5.5% from 2000 to 2010, 2010 to 2020, and 2020 to 2030, respectively, were used for the economic development scenario in this research.

Population is another key factor for making forecasts in this research. Major aspects of population growth that needed to be considered include: planned population policy; the decline in fertility accompanying the expected increase in income; the shift in the age of marriage to later in life; the prospect of fewer children due to family working patterns involving both the husband and wife typically having jobs; the desire for fewer children among well-educated people; the increase in the average life span; the decline in the death rate, and so on. It is believed that the growth in the population will follow the pattern of developed countries in the Asian region. Based on these factors, and with reference to the results of some other forecasts on population, the population scenario used in this research was that the population will be 1.28 billion in 2000 and 1.39 billion, 1.47 billion and 1.54 billion in 2010, 2020 and 2030, respectively, with an average natural growth rate of 1.14% from 1990 to 2000 and 0.88%, 0.55% and 0.45% from 2000 to 2010, 2010 to 2020, and 2020 to 2030. The rate of urbanization was taken as 32%, 38%, 43%, and 49% in 2000, 2010, 2020 and 2030, respectively.

According to the current statistics on China's national economy as well as the available data, energy end users in this study are divided into five sectors; the industrial, agricultural, services, residential and transport sectors. Table 1 gives the classification of these sectors and their sub-divisions. Every sector is split into several sub-sectors, or a products or services mode. The industry sector is classified into sub-sectors, and then every sub-sector includes one or more products. For example, the non-ferrous metals sub-sector includes a number of products such as copper, aluminum, zinc and lead. For the transport sector, under every sub-sector, transport modes for passenger transport and freight transport are given. The residential sector is split into urban and rural to match the different development patterns in each. Different technologies related to the demand for services are collected for every sub-sector and product. Energy services and technology selection for each sector or product is determined so that energy

Table 1. Classification of energy end user sectors

Sectors	Industrial sector	Agricultural sector	Residential sector	Services sector	Transport
Sub-sectors or products	Iron and steel Non-ferrous metals Building materials Chemical industry Petrochemical industry Paper-making Textile Machinery Power generation Oil refinery	Irrigation Farming work Agricultural products processing Fishery Animal husbandry	Urban energy use Rural energy use Space heating Cooling Lighting Cooking and hot water Household electric appliances	Space heating Cooling Lighting Cooking and hot water Electric appliances	Railway transport Road transport Waterways transport Air transport

consumption and CO_2 emissions can be estimated.

Energy services scenarios for major sectors and products are listed in Table 2. These scenarios reflect the situation of economic development and structural social change in China. The scenarios determine the increase in the level of demand for energy services that will be met by the selected technologies.

Table 3 lists the major technologies used in this model. In AIM-China, these energy use technologies are mainly broken down into three categories:

1. Technologies for services production: they are technologies to satisfy services

Table 2. Energy services forecast by industrial sector (index, 1990=1)

Energy Services	1990	2000	2010	2020	2030
Steel	1	1.8	2.1	2.3	2.6
Cement	1	3.3	5.2	6.0	6.6
Glass	1	2.0	3.5	4.3	4.9
Paper	1	2.1	2.6	3.2	3.7
Bricks	1	1.3	1.8	2.1	2.4
Soda ash	1	2.4	0.5	6.1	7.0
Caustic soda	1	1.9	3.0	3.6	4.1
Fertilizer	1	1.5	1.8	2.1	2.3
Services area	1	1.3	2.0	2.5	3.1
Traffic volume for private cars	1	21.0	118.7	523.3	916.6
Car traffic volume in cities	1	19.8	120.5	534.0	924.7
Car traffic volume in rural areas	1	55.6	68.3	209.7	682.5
Railway passenger transport	1	1.3	1.8	3.5	6.1
Steam locomotives	1	0.0	0.0	0.0	0.0
Diesel locomotives	1	2.0	2.8	4.5	6.2
Electric locomotives	1	2.5	3.6	7.9	16.4
Railway freight transport volume	1	1.5	2.0	2.4	2.6
Road transport	1	2.2	4.0	5.7	7.4
Waterways transport	1	1.3	1.6	1.6	1.6
Air transport	1	4.9	12.9	80.0	182.0
Rural population	1	1.0	1.0	1.0	0.9
Rural households	1	1.2	1.2	1.2	1.2
Rural household land area	1	1.0	0.9	0.9	0.9
Urban population	1	1.4	1.8	2.1	2.5
Urban households	1	1.5	2.0	2.5	3.1
Urban household area	1	1.3	1.6	1.8	2.1
Cooking in urban households	1	0.0	2.0	2.5	3.1
Electric cooking in urban areas	1	0.0	4.7	6.5	8.6
Hot water in urban areas	1	17.5	54.7	111.3	175.2
Space heating in urban areas	1	1.9	2.9	4.1	5.4
Air conditioners in urban areas	1	46.7	141.7	296.7	689.3
Fans in urban areas	1	1.9	2.8	3.7	4.7
Lighting: C in urban areas	1	1.3	1.3	1.6	1.9
Lighting: F in urban areas	1	10.0	25.1	34.3	46.9
Refrigerators in urban areas	1	2.3	4.6	7.8	10.9
Color TVs in urban	1	2.3	4.4	7.0	10.6
Black/white TVs in urban areas	1	1.3	1.7	0.5	0.0
Washing machines in urban areas	1	2.5	4.6	8.4	14.2

supply. These technologies include the renewal of various old technologies and newly installed technologies.

2. Technologies for energy recovery utilization: including various technologies for residual heat, combustible gases and black liquor recovery and their utilization.
3. Technologies for energy conversion: in-plant electric power generators, technologies for thermal energy conversion (e.g. industrial boilers) as well as electric power generation using residual heat and combustible gases, etc.

More than 500 technologies have been collected for the analysis, which covers the major technologies used in every sector defined in Table 1. Some advanced technologies have been taken into account even though they are not currently used in China. Basic data for the technologies include the purchase price, annual rate of

Table 3. Energy services technologies used in this simulation

Classification	Technologies (equipment)
Iron and steel	Coke oven; Sintering machine; Blast furnace; Open hearth furnace (OH); Basic oxygen furnace (BOF); AC-electric arc furnace; DC-electric arc furnace; Ingot casting machine; Continuous casting machine; Continuous casting machine with rolling machine; steel rolling machine; Continuous steel rolling machine; Equipment for coke dry quenching; Equipment for coke wet quenching; Electric power generated with residue pressure on top of the blast furnace (TRT); Equipment for coke oven gas; OH gas and BOF gas recovery; Equipment for co-generation
Non-ferrous metals	Aluminum production using the sintering process; Aluminum production using the combination process; Aluminum production using the Bayer process; Electrolytic aluminum using the upper-insert cell; Electrolytic aluminum using the side-insert cell; Crude copper production with flash furnace; Crude copper production using an electric furnace; Blast furnace; Reverberator furnace; Lead smelting-sintering in a blast furnace; Lead smelting using a closed blast furnace; Zinc smelting using the wet method; Zinc smelting using the vertical pot method
Building materials	Cement: Mechanized shaft kiln; Ordinary shaft kiln; Wet process kiln; Lepol kiln; Ling dry kiln; Rotary kiln with pro-heater; Dry process rotary kiln with pre-calciner; Self-owned electric power generator; Electric power generator with residue heat
	Bricks and tiles: Hoffman kiln; Tunnel kiln
	Lime: Ordinary shaft kiln; Mechanized shaft kiln
	Glass: Floating process; Vertical process; Colburn process; Smelter
Chemical industry	Equipment for synthetic ammonia production: Converter; Gasification furnace; Gas-making furnace; Synthetic column; Shifting equipment for sulphur removal
	Equipment for caustic soda production: Electronic cells using the graphite process; Two-stage effects evaporator; Multi-stage effects evaporator; Equipment for rectification; Ion membrane method
	Calcium Carbine production: Limestone calciner; Closed carbine furnace; Open carbine furnace; Equipment for residual heat recovery
	Soda ash production: Ammonia and salt water preparation; Limestone calcining; Distillation column; Filter
	Fertilizer production: Equipment for organic products production; Equipment for residual heat utilization
Petrochemical industry	Facilities for atmospheric and vacuum distillation; Facilities for rectification; Facilities for catalyzing and cracking; Facilities for cracking with hydrogen adding; Facilities for delayed coking; Facilities for light carbon cracking; Sequential separator; Naphtha cracker; De-ethane separator; Diesel cracker; De-propane cracker; Facilities for residual heat utilization from ethylene
Paper-making	Cooker; Facilities for distillation; Facilities for washing; Facilities for bleaching; Evaporator; Crusher; Facilities for de-water; Facilities for finishing; Facilities for residue heat utilization; Facilities for black liquor recovery; Co-generator; Back pressure electric power generator; Condensing electric power generator

diffusion rate, unit energy consumption, life span, year of entering the market and year of obsolescence, production capacity, etc. Table 4 gives a sample list of technological data for the coke making process in the steel industry.

Prices and emissions factors for energy and other materials inputs are listed in Table 5.

In the analysis of the AIM-China model, particular attention was paid to natural gas supply and traditional biomass supply. According to the possible future for natural gas production and imports, no limitation was placed on natural gas use except in the residential sector. Natural gas use in the residential sector is strongly limited by government policy and investment in infrastructure. Traditional biomass use was limited to maintaining it at the most at the 1994 level among

Table 3. Energy services technologies used in this simulation (continued)

Classification	Technologies (equipment)
Textiles	Cotton weaving process; Chemical fiber process; Wool weaving and textile process; Silk production process; Printing and dyeing process; Garment making; Air conditioners; Lighting; Facilities for space heating
Machinery	Ingot process: Cupola; Electric arc furnace; Fan
	Forging process: Coal-fired pre-heater; Gas-fired pre-heater; Oil-fired pre-heater; Steam hammer; Electric-hydraulic hammer; Pressing machine
	Facilities of heat processing: Coal-fired heat processing furnace; Oil-fired heat processing furnace; Gas-fired heat processing furnace; Electric processing furnace
	Cutting process: Ordinary cutting; High speed cutting
Irrigation	Diesel engine; Electric induct motor
Farming work	Tractor; Other agricultural machines
Agricultural products processing	Diesel engine; Electric induction motor; Processing machines; Coal-fired facilities
Fishery	Diesel engine; Electric induction motor
Animal husbandry	Diesel engine; Electric induction motor; Other machines
Space heating for dwellings	Heat supplying boiler in a thermal power plant; Boiler for district heating; Dispersed boiler; Small coal-fired stove; Electric heater; Brick bed linked to a stove (Chinese KANG)
Cooling in dwellings	Air conditioner; Electric fan
Lighting in dwellings	Incandescent lamp; Fluorescent lamp; Kerosene lamp
Cooking and hot water in dwellings	Gas burner; Bulk coal-fired stove; Briquette-fired stove; Kerosene stove; Electric cooker; Cow dung-fired stove; Firewood-fired stove; Methane-fired stove
Electric Appliances	Television; Cloth washing machine; Refrigerator; Others
Space heating in the services sector	Heat supplying boiler in the thermal power plant; Boiler of district heating; Dispersed boiler; Electric heater
Cooling	System of central air conditioner; Air conditioner; Electric fan
Lighting	Incandescent lamp; Fluorescent lamp
Cooking and hot water	Gas burner; Electric cooker; Hot water pipeline; Coal-fired stove
Electric appliances	Copying machine; Computer; Elevator; Others
Passenger and freight transport	Railways (passenger and freight): Steam locomotive; Internal combustion engine locomotive; Electric locomotive
	Highway (passenger & freight): Public diesel vehicle; Public gasoline vehicle; Private vehicle; Large diesel freight truck; Large gasoline vehicle; Small freight truck
	Waterways (passenger & freight): Ocean-going ship; Coastal ship; Inland ship
	Aviation (passenger & freight): Freight airplane; passenger airplane

rural residents.

To assess the effect of technological progress and the alternative policy options for energy consumption and CO_2 emissions in China, several cases were defined to run the model. The cases defined in Table 6 include the "frozen technology case," the "market case" and the "policy case." They are described in the following.

The frozen technology case, only used for comparison with other cases, can also be called the no technological progress case. It is presumed that the present services production technologies and energy efficiency will remain at the same level as in 1990 without any technological progress. However, this does not mean that energy consumption for this case will increase at the same rate of growth as that for economic development.

In the market case, in a properly functioning market it is assumed that technologies can be selected based on market mechanisms. It will consider technological options after rational assessment of the economic benefits provided by the energy services technologies. This case is designed to emphasize the contribution of market mechanisms to energy use conservation and CO_2 emissions reduction. China is at the stage of economic reform shifting from a planned economy to a market economy and this is expected to be completed in the next 10 years (Zheng *et al.* 1995). The results of the analysis for this case could be used to explain the benefits of market mechanisms, and it is also used as a base line emissions scenario for the medium term.

Table 4. Technological parameters in the coke making process of the steel industry

Name of technologies	Output mass	Input materials	Fixed price (yuan/t*)	Life span (yr.)	Year of introduction	Year of obsolescence	Output	Input
							(100Mcal/t*)	
Small coking oven	Coke	Coal	185	20	1930	2030	36.46	76.00
	Coke	Utility*	185	20	1930	2030	36.46	4.80
	Coke	Electricity	185	20	1930	2030	36.46	0.40
	Coke oven gas	Coal	185	20	1930	2030	5.20	76.00
Large coking oven	Coke	Coal	210	20	1970	2050	36.46	68.00
	Coke	Utility**	210	20	1970	2050	36.46	4.80
	Coke	Electricity	210	20	1970	2050	36.46	0.44
	Coke oven gas	Coal	210	20	1970	2050	5.80	68.00
International	Coke	Coal	330	30	1985	2100	36.46	59.89
Advanced coking oven	Coke	Utility*	330	30	1985	2100	36.46	4.05
	Coke	Electricity	330	30	1985	2100	36.46	0.23
	Coke oven gas	Coal	330	30	1985	2100	7.20	59.89
New advanced coking oven	Coke	Coal	380	30	1995	2100	36.46	54.20
	Coke	Utility*	380	30	1995	2100	36.46	4.26
	Coke	Electricity	380	30	1995	2100	36.46	0.23
	Coke oven gas	Coal	380	30	1995	2100	7.60	54.20

* ton steel output

** "Utility" used in this table is defined in Appendix A of Part IV.

The policy case is defined in order to analyze the effects of climate policies in reducing CO_2 emissions. As a commonly used method, the policy case was defined here as the levying of a carbon tax of 100 yuan per ton of carbon and returning all the revenues from this carbon tax as subsidies for the diffusion of advanced technologies. The introduction of a carbon tax is assumed to begin from 2000. The introduction of advanced technologies would be promoted by policies that contribute to CO_2 emissions reductions. Analysis of the carbon tax does not mean a pure tax; it can be considered here to be a mixture of comprehensive policies such as an energy tax, government regulations, etc. It is only used here as a means of introducing the carbon tax as a modeling parameter.

The four other cases are selected in order to estimate CO_2 reduction costs. As discussed above, subsidies can be invested in advanced technologies to reduce fixed costs (the price of the technology), thus expanding the introduction of

Table 5. Price and CO_2 emission factors

	Emission factor	Price				
		1990	1994	2000	2010	2030
Coal	10062	2.86	2.90	3.00	3.20	3.50
Coke	12300	8.82	8.89	9.00	9.40	9.80
Crude oil	7811	8.00	9.00	10.00	11.00	12.00
Gasoline	7658	25.00	26.00	26.50	29.00	31.00
Kerosene	7748	25.00	26.00	26.50	29.00	31.00
Diesel	7839	25.00	26.00	26.50	29.00	31.00
LPG	6833	4.29	10.00	14.00	16.00	18.00
NGS	5639	4.29	10.00	12.00	13.00	16.00
Town gas	5835	4.00	6.00	8.00	8.60	9.60
Black liquid	10751	0.00	0.00	0.00	0.00	0.00
Electricity	26449	34.90	35.00	37.00	40.00	43.00
Biomass	0	0.03	0.03	0.04	0.05	0.08
Utility*	14374	4.00	4.16	4.40	4.50	4.80
Steam	14374	4.00	4.16	4.40	4.50	4.80
Water	0	0.30	0.42	0.60	0.80	1.00
Recycled steel	0	1100.00	1120.00	1150.00	1200.00	1300.00

Unit: emission factor: g-C/100Mcal
price: 1990 yuan/100Mcal for energy and 1990 yuan/ton for materials (water and recycled steel)
* "Utility" used in this table is defined in Appendix A of Part IV.

Table 6. Definition of the cases

	Technology selection	Tax rate (Yuan/t carbon)	Subsidy
Frozen technology			
Market	√		
Policy	√	100	All tax revenues

efficient technologies to save energy and reduce CO_2 emissions. By using the linear program sub-module for optimal subsidy assignment, an estimate can be made of the lowest additional cost that would be required at the national level to reduce CO_2 emissions. In the model calculation, four subsidy cases were defined to analyze the reduction of costs. The four cost estimation cases are: a subsidy used as equivalent to the revenue from a 50 yuan per ton carbon tax, a 100 yuan per ton carbon tax, a 500 yuan per ton carbon tax and a 1000 yuan per ton carbon tax.

5.3 Simulation Results

Based on the technologies and services assumption, by using AIM-China, the forecast results for energy demand and CO_2 emissions according to the different cases for China are presented in Fig. 1.

It can be clearly seen from Fig. 1 that CO_2 emissions will increase quickly with economic development in China. Compared with the base year of 1990, CO_2 emissions will be 1.7, 2.5 and 3.8 times the 1990 level in 2000, 2010 and 2030 for the market case, which can be regarded as a possible development case, 1.6, 2.1 and 3.3 times for the policy case, which represents the lowest growth rate of CO_2 emissions. There is little possibility for China to adopt some intervention policies within the near future, so the CO_2 emissions for the market case are very important. All the results show that China will play an important role in world's energy production and consumption, as well as in its CO_2 emissions.

From the CO_2 emissions in the market case, it is noticeable that it is possible for China to maintain a low CO_2 emissions growth rate compared with its rate of economic growth. The basic assumption for the analysis is that the annual economic growth rates are 9% from 1990 to 2000, 7.5% from 2000 to 2010, and 6% from 2010 to 2030, so the elasticity values for CO_2 emissions are 0.58, 0.53 and 0.37 for the market case. This represents a relatively low elasticity relative to the experience of developed countries.

A properly functioning market could contribute to the diffusion of technologies

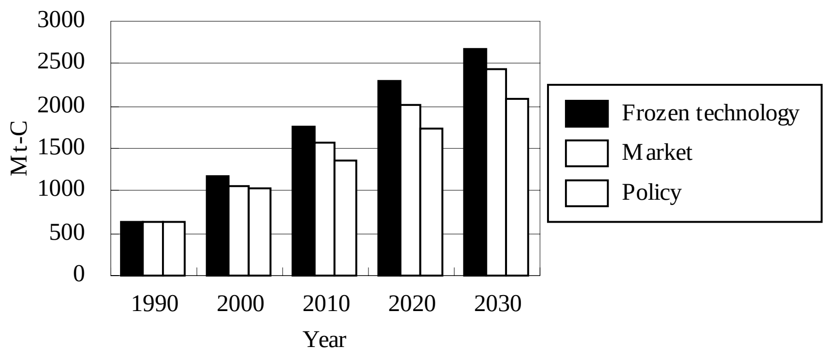

Fig. 1. CO_2 emissions in China

to reduce CO_2 emissions. Compared with the frozen technology case, there would be a 10.37% CO_2 emissions reduction for the market case in 2010 and 9.32% in 2030. This shows that establishing a better market mechanism is an efficient way to achieve advanced technology diffusion in China.

Industry is the major sector that emits CO_2 (Fig. 2). In 1990, the results show that CO_2 emissions from industry account for 75% of the total in the market case, and will generally decline to 70% in 2030, giving it the dominant role in future.

There is no significant reduction in CO_2 emissions in the transport sector (Fig. 3). Vehicle prices are very high compared to other countries, and the prices of gasoline and diesel for vehicle use are comparatively low. So the benefit of lower energy consumption from the use of efficient vehicles cannot compensate for the expenditure for the vehicles. Thus, efficient vehicles cannot be expected to be widely adopted. CO_2 emissions will increase in the rural residential sector for the market case compared to the no technological progress case. The major reason is that a substantial amount of biomass energy will be replaced by commercial energy based on the market along with the rise in income. However, there is

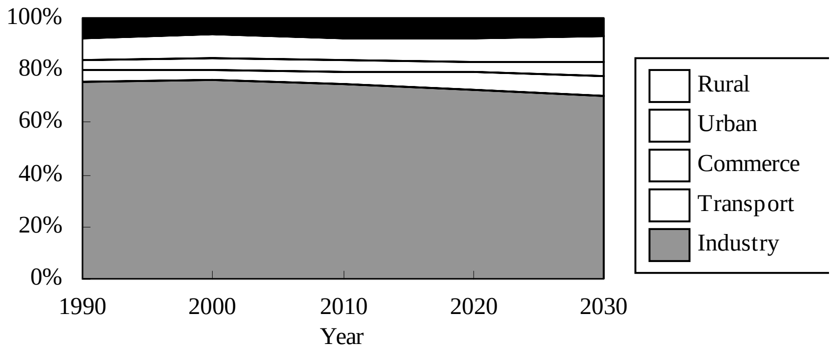

Fig. 2. Share of CO_2 emissions in China by sector for the market case

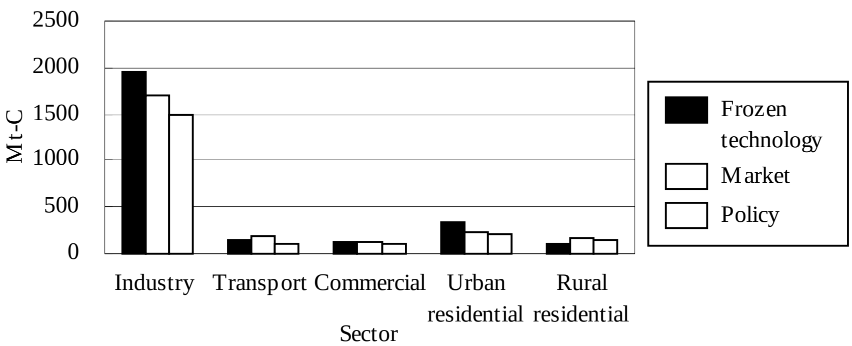

Fig. 3. CO_2 emissions in 2030 by sector

considerable potential for CO_2 emissions reductions in the residential sector, including both urban and rural areas, if policy options are adopted.

CO_2 reduction policies are effective in reducing the rate of growth of CO_2 emissions. From Fig. 3, it can be demonstrated that adoption of intervention policies for CO_2 reductions using taxes and subsidies can provide greater reductions in CO_2 emissions compared with the market case. However, the reduction results differ according to the policy options. A combination of policies for taxes and subsidies are comparatively better than a taxes only policy.

The introduction of energy conservation technologies in the industrial, residential and services sectors will benefit from a carbon tax, but it is not such a substantial benefit for the transport and agriculture sectors. Due to the low energy prices and high vehicle prices, carbon taxes and subsidies have a very minimal effect in the transport sector. The reason for the lower impact of a tax in the agriculture sector is that some advanced technologies are already being selected in the market case.

Figure 4 gives an example of CO_2 emissions in the steel making sector in China. Significant emissions reduction was observed in this sector. Technological progress really plays a very important role in reducing unit energy use and, therefore, in CO_2 emissions reduction.

In the study, SO_2 emissions were simulated for these three scenarios. Since desulphurization technologies are not considered here, a reduction in SO_2 emissions is calculated from technological change among the scenarios. In order to provide better information on future CO_2 emissions and SO_2 emissions, a detailed inventory based on more than 2,300 counties in China was established. Figure 5 and Fig. 6 present the CO_2 emission intensity in 2010 and SO_2 emission intensity in 2010, respectively. The emission intensity is given in a rather simple way based on the future whole emissions in China and the extrapolation of the present intensity in each county.

Figure 7 presents the costs of emissions reductions by sector. In this figure, the vertical axis is the average cost for CO_2 emission reduction. Subsidies in four cost cases are described here. The horizontal axis is the rate of cumulative CO_2 reductions due to the subsidies beginning in the year 2000 to 2010 compared with

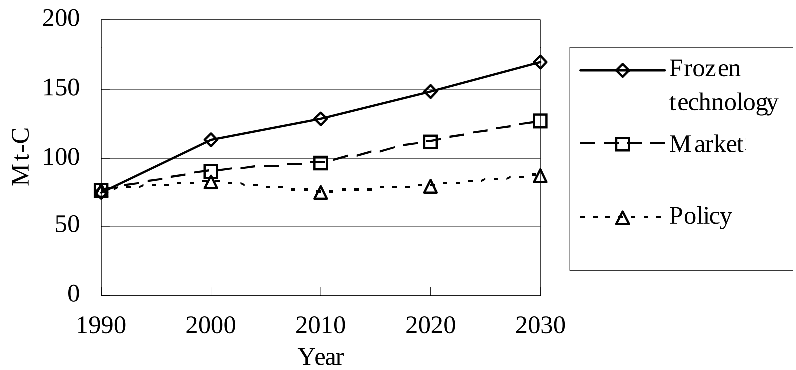

Fig. 4. CO_2 emissions in the steel making sector in China

the market case.

From Fig. 7 it can be seen that the average CO_2 emissions reduction costs for the transport sector are very high. This is for the same reason that the amount of CO_2 emissions reduction according to the policy option is small. A rational way for the transport sector to reduce its CO_2 emissions is to encourage vehicle producers to introduce new technologies and decrease new vehicle prices to a

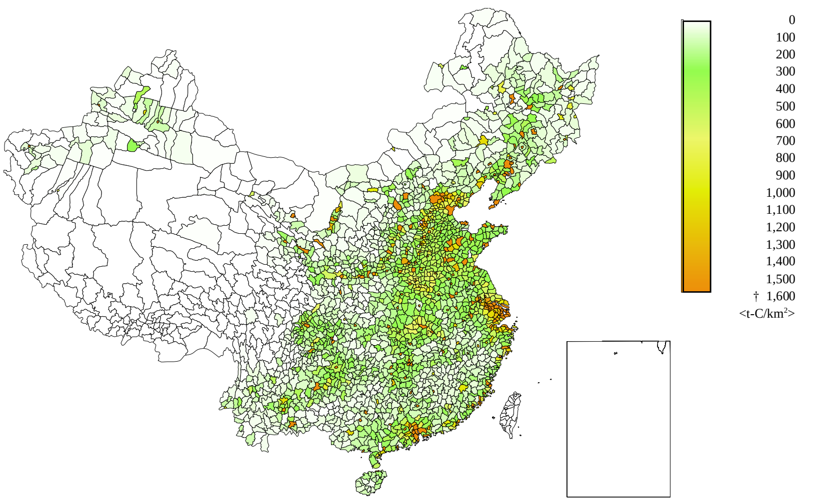

Fig. 5. CO_2 emission intensity in China for 2010 (see color plates)

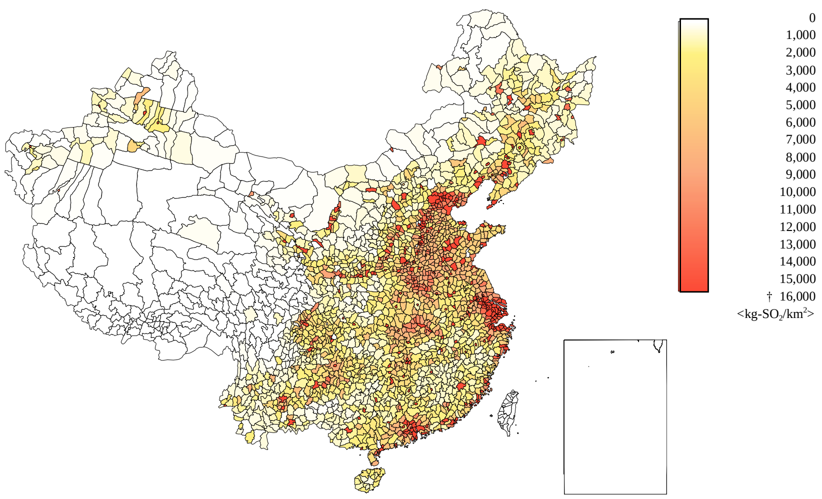

Fig. 6. SO_2 emission intensity in China for 2010 (see color plates)

suitable level. In contrast, in the residential sector, CO_2 reduction costs are relatively low since the major energy utilization technologies such as refrigerators, washing machines, TVs and lighting devices, etc., are already in a competitive market. The prices for these are rational and they can provide a better service and conserve more energy, so it is easier to introduce energy saving technologies in the residential sector. Another factor is an increase in the standard of living that requires clean energy in the residential sector. The consumption of electricity, natural gas and other types of gas will increase while coal consumption declines. The costs for the industry sector stand at the mid point. Since there are many technologies in this sector, it is reasonable for the combined average costs for CO_2 reductions to maintain this level.

This analysis of average costs for CO_2 reductions presents a brief ranking in the CO_2 emissions reduction costs for each sector. The residential sector has the lowest costs, followed by the commercial sector, industry sector, etc.

Table 7 gives an example of technology selection for typical cases. These technologies are listed in Table 4. From this result, the technological process and the contribution of technological progress to CO_2 emissions reduction can be readily understood. It shows the effects of different cases (policies) on technology selection or progress. For these technologies, the effects of a policy of taxes and subsidies is better than that of a tax only policy, but this may not be true for technologies in other sectors or processes.

Table 8 shows the cost-effective technologies identified through this study.

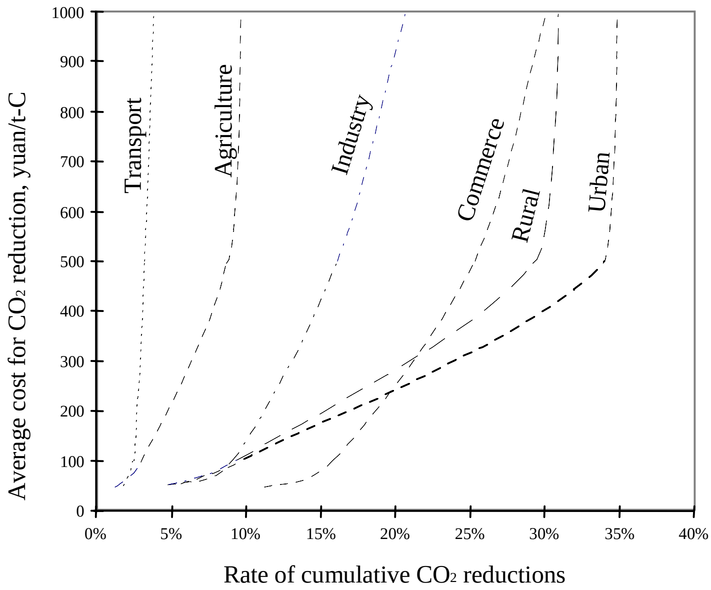

Fig. 7. Average cost for CO_2 reductions by sector

5.4 Findings and Conclusion

Based on this analysis, the conclusions were as followings:

1. China will continue a path of rapid economic development, and energy consumption and CO_2 emissions also will increase quickly to satisfy the demand for economic development. CO_2 emissions will rise 1.7, 2.5 and 3.8 times 1990 levels in 2000, 2010 and 2030 for the market case if no intervention

Table 7. Technology selection for several cases in the coke making process in the steel industry

Technology	1990	2000		2010		2020		2030	
		Market	Policy	Market	Policy	Market	Policy	Market	Policy
Small size coke oven	59.9	18.0	-	1.1	-	0.0	-	0.0	-
Large size coking furnace	40.1	70.6	62.9	85.5	-	87.5	-	100.0	-
Large size coking furnace from Japan	0.0	11.5	37.1	13.4	35.3	12.5	30.0	0.0	-
New coking oven + coke wetting	0.0	0.0	-	0.0	64.7	0.0	70.0	0.0	100.0

Unit: %

Table 8. Cost-effective technologies

Sector	Technologies
Steel	Large-scale equipment (Coke oven, blast furnace, basic oxygen furnace etc.); Equipment for coke dry quenching; Continuous casting machine; TRT; Continuous rolling machine; Equipment for coke oven gas, OH gas and BOF gas recovery; DC electric arc furnace
Chemicals	Large-size equipment for chemical production; Waste heat recovery system; Ion membrane technology; Existing technology improvements
Papermaking	Co-generation system; Facilities for residual heat utilization; Black liquor recovery system; Continuous distillation system
Textiles	Co-generation system; Shuttleless loom; High-speed printing and dyeing
Nonferrous metals	Reverberator furnace; Waste heat recovery system; QSL for lead and zinc production
Building materials	Dry process rotary kiln with pre-calciner; Electric power generator using residual heat; Colburn process; Hoffman kiln; Tunnel kiln
Machinery	High-speed cutting; Electric-hydraulic hammer; Heat preservation furnace
Residential	Cooking using gas; Centralized space heating system; Energy-saving electric appliances; High-efficiency lighting
Services	Centralized space heating system; Centralized cooling and heating system; Co-generation system; Energy-saving electric appliances; High-efficiency lighting
Transportation	Diesel trucks; Low energy consumption cars; Electric cars; Natural gas cars; Electric railway locomotives
Technology used in common	High-efficiency boiler; FCB technology; High-efficiency electric motor; Variable-speed motors; Centrifugal electric fan; Energy-saving lighting

policies are adopted.

2. Massive CO_2 emissions could be reduced by market mechanisms. The 182 million tons of carbon and 249 million tons of carbon will be reduced in 2010 and 2030 by comparing the market case and the frozen technology case. In order to reduce China's CO_2 emissions, market mechanisms should be improved to promote the distribution of efficient technology in order to have a better effect on energy conservation and CO_2 emissions reduction.
3. China can reduce CO_2 emissions further if some policy options are adopted. From the analysis it was noticed that there is a large potential for China to reduce CO_2 emissions by adopting different intervention policies. Levying a carbon tax and returning it as a subsidy is the most efficient way for CO_2 emissions reductions to be achieved among the policies assessed in this research.
4. The residential sector and services sector have comparatively low costs for CO_2 emissions reduction. China will be benefit from making efforts to reduce CO_2 emissions in the residential and services sectors, since it is not only a low cost strategy for CO_2 emissions reduction, but can also reduce SO_2 emissions and TSP (Total Suspended Particles) emissions, which will improve local air quality. The industry sector has a medium level of costs from the analysis, but this is an aggregated result. Some products in the industrial sector benefit from energy conservation, which should be considered for CO_2 emissions reduction at low cost.
5. There has been a rapid growth in energy consumption in the transport sector, and effective energy consumption measures are not significant. Thus this sector will be the most important for reducing CO_2 emissions. More countermeasures should be introduced, such as fuel taxes and the encouragement of competition to reduce vehicle prices and raise the efficiency of vehicles.
6. International technological collaboration is essential for energy conservation and CO_2 emissions reduction in China. Some advanced technologies from developed countries have very high efficiencies and can save substantial amounts of energy, and they are widely used in the developed countries. But there are still few of such technologies in China due to the cost and other factors. It is important for China to further collaborate in the introduction of energy saving technologies with the developed counties.
7. Further research activities on climate change should be promoted in China to achieve a better understanding of greenhouse gas (GHG) emissions and other aspects of climate change. In order to support China in developing its policy response to climate change, these types of research activities can help to establish a common knowledge base among researchers in China and other countries. This is an essential premise for future collaboration between developed countries and developing countries.

Base on these findings, the conclusions from this study are summarized as follows:

1. Technological progress plays a very important role in GHG emissions reduction and energy use in China, which will contribute significantly to global and local environmental conservation
2. The market mechanism is an efficient way to achieve the diffusion of advanced technologies in China
3. International collaboration on knowledge transfer is a key factor for the enhancement of technological progress in China
4. Sophisticated policies should be designed at the sectoral level, especially in transport, commerce and the chemical industry.
5. New environmental policies are required that are designed for the early stages of development in China in order to integrate strategies for both the local environment and global environment
6. International collaboration on technology should be promoted at the earliest opportunity to help developing countries to enhance their ability to ensure a clean environment.

From the analysis, it was also found that the analysis itself could be improved in future. For example, in order to ensure that the policy assessment is more accessible to policy makers, some macroeconomic analysis is necessary to feedback to the bottom-up end use model. By linking this with a top down model, some indirect costs could be analyzed when adopting policy options, with consideration for interrelationships among the sectors. The effect of insufficient investment should be analyzed to reflect the most likely energy consumption and CO_2 emissions patterns in China. In addition, more policy options should be assessed, especially for the non-intervention case, for example, renewable energy orientated policies, green lighting practices, shifting the energy supply pattern, etc. International collaboration also should be considered as an important approach to reducing CO_2 emissions in China.

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