# Comparison of $CO_2$ emission scenarios and mitigation opportunities in China's five sectors in 2020

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## Abstract

This study has been created in order to better inform climate policy recommendations for China through the study of emissions reduction potential and mitigation opportunities in the major emission sectors in the country. The LEAP model along with three scenarios has been employed in this study. The study has projected that under all scenarios, China's emissions in major sectors will increase. However, through the current sustainable development strategy and even more aggressive emission reduction policies, an annual average of 201–486 million metric tons (MMT) of emissions could be reduced. The cost analysis shows that opportunities are available to achieve significant additional emission reductions at reasonable rates. Besides the results on mitigation opportunities in each sector, this research also explores sectoral preference when determining policies from different perspectives. This study concludes that China's "unilateral actions" since 2000 should be recognized and encouraged. If further emission reduction were required, sector-based mitigation policies would be a very good option and selecting proper policy-making perspective(s) and identifying the most cost-effective mitigation measures within sector and across sectors would be the key information needed to devise these policies.
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## 1. Introduction

Although the recently completed COP12 made little measurable progress towards new emission reduction agreements for international action beyond 2012 (PEW Center, 2006), it is quite notable that almost every country has begun to study future greenhouse gas emission and mitigation options with greater zeal in preparation for approaching international negotiations. This has especially been the case in China, the largest developing country and the second largest GHG emitter in the world—predicted to soon surpass the US to become the first (IEA, 2006). As a result, China is facing greater international pressures than ever before.

The main objectives of this study are to identify key emission sectors, assess important technologies in target sectors, and analyze the corresponding cost. These results will give insight to policy makers in creating feasible and practical climate polices.

This study employs a sector-based perspective, which is characterized by the flexibility to reduce emissions where most cost effective; the feasibility to carry out policies in the sectors; and its important role in future international climate change agreements (Wang et al., 2007b; WRI, 2005). Various climate change consultants have also suggested using this perspective in studying mitigation problems previously (Clinton et al., 2005; Schmidt and Helme, 2005).

With this purpose and perspective in mind, the paper begins in Section 2 with an overview of China's emissions and identification of target sectors. The section concludes with a summary of the current situation as well as policy trends in these sectors. Section 3 presents the methodology and scenario settings in the study and is then followed in Section 4 with results of the scenario analysis with information about future emission and mitigation

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opportunities, as well as policy implications from the results. The paper concludes in Section 5 with the three emission scenarios; the mitigation opportunities in each scenario; and the different policy perspectives; the final part of this section outlines recommendations for achieving additional emission reductions.

## 2. Background

### 2.1. Main sector identification

In 2000, $CO_2$ emissions in China were estimated at 3090 million metric tons ($MMTCO_2$). To identify the target sectors in this research, we first studied the electricity, cement, iron and steel, pulp and paper, transportation, residential, commercial, and forestry and agriculture sectors, and used a judgment matrix from the following aspects to select them: (1) share in national emission, (2) energy consumption intensity, (3) data availability, (4) knowledge accumulation in mitigation technology, and (5) sectoral influence to the country, etc. The final target sectors turned out to be electricity, cement, iron and steel, pulp and paper, and transportation. The target sectors are distinguished from other sectors by being energy-intensive in nature; influential to country's development; and comparatively greater data and technology availability. Moreover, their total emissions in 2000 reached 80% of national $CO_2$ emissions, which means mitigation in these sectors would, to a greater extent, influence overall emissions reduction in China.

### 2.2. Sectoral background

#### 2.2.1. Electricity sector

China's electric power industry has developed very rapidly over the past two decades as a result of industrial and social demands. Total national installed capacity increased from 137.89 GW in 1990 to 305.14 GW in 2000, at an average annual growth rate of 8.3%. In sum, power generation in China doubled from 1990 to 2000 (China Electricity Statistic Yearbook, 2005).

#### 2.2.2. Iron and steel sector

China's iron and steel industry has also gone through rapid development since 1990. Take crude steel for example. Production of crude steel in China broke 100 million tons in 1996 to become the largest steel-producing country in the world. From 1990 and 2000, the production of crude steel doubled from 66.35 to 128.50 MMT (China Iron and Steel Statistics, 2001). The case is similar for China's other iron and steel industry productions, such as pig iron, coke, and ferroalloy (Wang et al., 2007b).

#### 2.2.3. Cement sector

China's cement industry has grown remarkably since economic reforms in the late 1970s. At the beginning of reforms in 1978, China ranked fourth in world cement output and produced about 65 million tons of cement a year. By 1985, China had become the world's leading producer, and, in 2000, the annual production reached 718.3 Mt, which covered over one-third of the total global output (CCAP, 2006a).

#### 2.2.4. Pulp and paper sector

Annual production and consumption of paper in China has been increasing since 1990. Paper production in China grew at an annual rate of 15.4% during the 10-year period from 1991 to 2000. In 2001, total paper production in China was 30.50 million tons. In 2000, China was the world's third largest paper producer, after the United States and Japan (China is now the second largest paper producer after the United States) (CCAP, 2006a).

#### 2.2.5. Transport sector

China's transport sector also experienced rapid development along with the booming economy and improving living standards. From 1990 to 2000, the volume of passenger traffic doubled from 562.9 billion persons-km to 1226 billion persons-km, while freight traffic volume in 2000 was 1.4 times that of the 1990 levels. From a road transport perspective, from 1990 to 2003, the average annual growth rate of vehicle ownership was 12%, while the average annual growth rate of private vehicle ownership reached 31% in the same period (Shen, 2005). Owing to data limitations, the transport sector in this study refers only to road transport.

### 2.3. Emission background

Electricity generation and consumption accounts not only for major national $CO_2$ emissions but also for 15% of global and 40% of non-Annex I electricity sector emissions. The cement sector (including electricity use) accounted for the second largest segment of domestic $CO_2$ emissions (20%) and contributed to 36% of global and 56% of non-Annex I cement sector emissions. China's iron and steel sector accounted for 10% of national and 30% of global $CO_2$ emissions, accounting for almost two-thirds of non-Annex I emissions in that sector (CCAP, 2006b). Finally, the transport sector (referring to road transport sector in this study) contributed 5% to global road transport emissions (estimated from WRI, 2005) (Fig. 1).
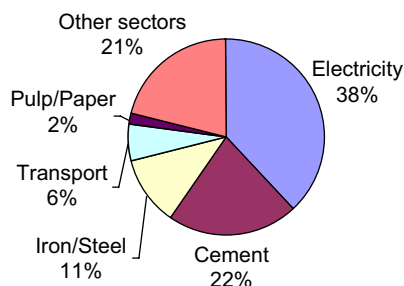


Fig. 1. The sectoral emission situation in China in 2000.

## 2.4. Policy background in China

Both national and sectoral policies would greatly impact the future trends of emission in these target sectors. Although China, as a developing country, is not duty bound to limit its emissions output under the Kyoto Protocol, the Chinese government is very aware of the potential effects of global warming and climate change, while also recognizing the urgency for all nations to shoulder the responsibility of reducing greenhouse gas emissions. As a result, even before having made any international commitments to the climate change regime, China has already begun implementing various measures that benefit overall national emissions reduction.

From a national perspective, the current basic principle of China's energy strategy is to focus on sustainable development, which means working on energy conservation and economic development concurrently, but with an emphasis on increasing energy efficiency. Reducing pollution from energy production has become the goal to reach in order to realize sustainable energy use in China. China has also been pursuing other policies in realizing sustainable development, which includes using market tools, promoting new and renewable energy, replacing low-efficiency and out-dated equipments, adjusting sectoral structure, and improving development and utilization of advanced technologies (Counsellors' Office of the State Council, 2006). The establishment of the 1996 Renewable Energy Law, the 1997 Energy Conservation Law, Tenth and Eleventh Five-Year Plans, and the ambitious objective of achieving a 20% decrease in energy intensity by 2010 (compared with 2005) (State Council of the People's Republic of China, 2006) has showcased the efforts of the Chinese government in developing a sustainable energy future.

Table 1
Energy-related policies and measures implemented in sectors before and after 2000

| | |
|---|---|
| *Electricity* | |
| Before 2000 | Increasing capacity to deliver power to the consumer |
| | Improving the energy efficiency of end-users from the Energy Conservation Law in 1997 |
| | Ownership and management reformation since 1997 |
| | Market system renovation to give investors incentives to promote generation since 1985 |
| | Nuclear power development since 1992 |
| | $SO_2$ and $NO_x$ control |
| After 2000 | Industry structure and ownership reformation to enhance competition in electricity sector from the National Power Industry Framework Reform Plan in 2002 |
| | Improving the energy efficiency |
| | Tenth Five-Year Plan to restructure the electricity sector from plant size, equipment, etc. since 2000 |
| | Promoting nuclear power in the Tenth Five-Year Plan since 2000 |

Table 1 (continued)

| | |
|---|---|
| | Implementation of the Renewable Energy Law in 2006 |
| | Construction of big hydro-electric power in China |
| | Political preference in wind power projects |
| *Iron and steel* | |
| Before 2000 | Concrete energy conservation plan in the iron and steel industry from Sixth to Tenth-Five-Year Plan |
| | Establish and apply standards, labeling and certification of energy efficiency since the 1980s |
| | Eliminate out-dated technologies and equipments and promote new energy conservation technologies and equipments since the 1980s |
| | Implement incentive policies in terms of finance, credit and taxation towards energy conservation projects since the 1980s |
| After 2000 | Iron and steel as a key sector in China's Medium and Long-Term, Energy Conservation Plan in 2004 |
| | China's Iron and Steel Industry Development Policy to restructure the production and technology in steel industry in 2005 |
| *Cement* | |
| Before 2000 | Elimination of small illegal cement plants since 1999 |
| | Implementation of technical retrofit since "Policy Outlines of Energy Conservation Technologies" in 1984 |
| After 2000 | Improvement of both production capacity and product quality in the Tenth Five-Year Plan since 2000 |
| | Management reformation and more provincial control over the industry since 2000 |
| | Energy efficiency enhancement including extra investment and technology upgrades |
| | Market system renovation to attract foreign investment |
| | More environmental protection supervision from government |
| *Pulp and paper* | |
| Before 2000 | Technology and equipment update |
| After 2000 | Rearrange industry structure |
| *Transport* | |
| Before 2000 | Law on Fuel Saving Management in Transport Sector to improve management structure and enhance management efficiency in 1986 |
| | Seventh Five-Year Plan in 1986 to develop auto-manufacturing industry into key industry |
| | Policies on Auto Industry in 1994 to encourage individuals auto buyers and to enhance reformation and investment centralization |
| | Standards for the Scrapping of Motor Vehicles in 1997 to regulate the scrapping time |
| After 2000 | Detailed rules on the implementation of the Energy Conservation Law in the Transport Industries in 2000 |
| | Summary of the Tenth Five-Year Plan of National Economy and Social Development in 2001 to encourage families to buy autos |
| | New policies on auto industry in 2004 to make more market-oriented management system, and to encourage energy-saving and environmental-friendly automobiles |
| | Maximum limits of fuel consumption (L/100 km) for passenger cars in 2004 |
| | The China Medium and Long Term Energy Conservation Plan in 2004 to encourage developing diesel vehicles and public transport and set a goal for passenger cars to reach in 2010 |

From the sectoral level, numerous energy-related policies have been implemented in specific sectors, as shown in Table 1. Policies have been separated into two parts by the year 2000. All these policies will lay the foundation for future projections.

## 3. Methodologies and scenarios

### 3.1. LEAP model

This study has used an accounting and scenario-based modeling platform called LEAP, "Long-range Energy Alternative Planning System", developed by Stockholm Environment Institute (SEI, 2005a, b). LEAP is a software tool to generate different energy consumption and $CO_2$ emission in different scenarios. Its scenarios are based on comprehensive accounting of how energy is consumed, converted, and produced in a given region or economy under a range of alternative assumptions on population, economic development, technology, price, etc. Unlike the optimization model, LEAP does not intend to point out the optimum scenarios, although it can be used to identify least-cost scenarios; similarly, LEAP, unlike macroeconomic models, does not attempt to estimate the impact of energy policies on the economy and the environment, although such models can be run in conjunction with LEAP.

The analytical procedure in LEAP model is described in Fig. 2. It can be summarized as five steps: sectoral production projections, corresponding energy demand, $CO_2$ emissions, total cost calculation, energy savings, and $CO_2$ abatement potential calculation (Wang et al., 2007b).

(1) *Sectoral production*: Sectoral production is described in terms of the sum of each production. Take the electricity sector for example; it referred to the aggregate generation of coal-fired plants (small, mid-

dle, big-size plants, sub-critical plants, circulating fluidized bed combustion, integrated gasification combined-cycle, pressurized fluidized bed combustion plants), natural gas plants, oil-power, hydro-power, wind power plants, and other new-energy plants. The methods in other sectors are similar to the electricity sector. In particular, in the iron and steel sector, the production is divided into several processes, including coke-making, sintering ore, pig iron, crude steel and steel products, and the sum of production output from each process is the sectoral production:

$$P_i = \sum p_{j,i}, \tag{1}$$

where $P_i$ is the production output (of process $i$, for iron and steel specifically) and $P_{j,i}$ is the production output (in process $i$) through equipment $j$.

(2) *Energy demand*:

$$E = \sum_i \sum_j \sum_n e_{n,j,i} p_{j,i}, \tag{2}$$

where $E$ is the aggregate energy consumption of sector and $e_{n,j,i}$ is the energy consumption of fuel type $n$ used in equipment $j$ (within process $i$).

(3) *$CO_2$ emission*:

$$CE = \sum_i \sum_j \sum_n cef_{n,j,i} e_{n,j,i} p_{j,i}, \tag{3}$$

where $CE$ is the total $CO_2$ emission of sector and $cef_{n,j,i}$ is the $CO_2$ emission factor from fuel type $n$ through equipment $j$ (within production process $i$).

(4) *Costs*:

$$C = \sum_i \sum_j \left\{ \left[ \sum_n (e_{n,j,k} ep_n) + \sum_k (m_{k,j,i} mp_k) + fc_{j,i} \right] p_{j,i} \right\}, \tag{4}$$
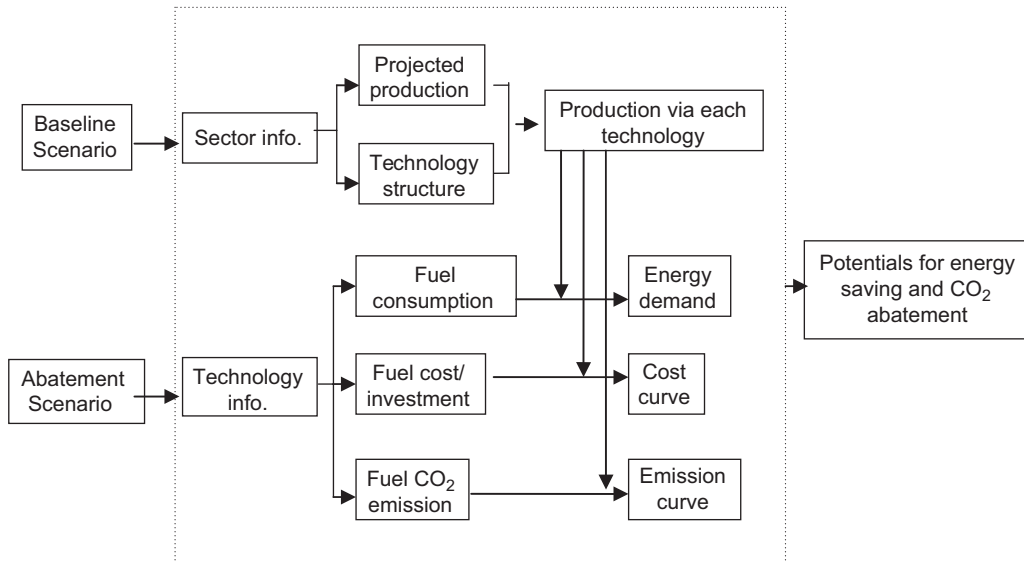


Fig. 2. Structure and analytical procedure of the LEAP model.

where $C$ is the total cost of sector including equipment fixed costs and variable costs for raw materials and fuels, $ep_n$ is the unit price of fuel type $n$, $m_{k,j,i}$ is the demand for raw material $k$ per unit of production used in equipment $j$ within production process $i$, $mp_k$ is the unit price of raw material $k$, and $fc_{j,i}$ is the fixed cost per unit production through equipment $j$ (within production process $i$).

(5) *Energy savings and $CO_2$ abatement potentials*: Through comparing the results driven by different scenarios, the energy saving potential and the $CO_2$ abatement potential under different scenarios in any target year or during the whole target period can be acquired.

### 3.2. Scenario definitions

#### 3.2.1. Scenario description

This scenario analysis is based on the LEAP model where abundant bottom-up technologies have been included. Policies that are implemented in different scenarios are assumed to affect the adoption of specific technologies.

The scenario analysis timespan covers the years 2000–2020 with 2000 as the baseline year.

There are three scenarios generated in each sector in this study. Scenarios in different sectors share the same assumptions for gross domestic product to avoid uncertainty when forecasting production and also help researchers focus on analyzing the differences between scenarios, which, largely, is due to industrial restructuring and technological advancement (Wang et al., 2007b). The first scenario assumes implementation of only those policies and projects announced prior to 2000—the "Pre-2000 Policy" scenario. The second scenario assumes implementation of all policies announced before 2006—or the "Recent Policy" scenario. The third scenario assumes implementation of select packages of GHG mitigation options—herein referred to as the "Advanced Options" scenario. Take the electricity sector for example. In the "Pre-2000 Policy" scenario, we assume the super-critical and ultra-super-critical units will develop from 0% of total generation in 2000 to 12.3% in 2020; in the "Recent Policy scenario", due to the Tenth and Eleventh Five-Year Plans to restructure the electricity sector from plant size and equipment since 2000, the generation share of SC/USC units in total will rise to 13.4% in 2020; in the "Advanced Options" scenario, in terms of the mitigation measure through replacing small coal-fired units with SC/USC units, the share will rise to 14.5% in 2020.

When comparing emissions in the first two scenarios ("Pre-2000 Policy" scenario and "Recent Policy" scenario), the study reflects the efforts China has been undertaking, voluntarily, since 2000. These efforts have been highlighted through policies with strong relations to emissions control and policies with indirect effects towards emission reduction. The comparison in emissions between the "Pre-2000 Policy" and the "Advanced Options" scenarios displays the total emissions reduction potential in any given sector.

This is because under the "Advanced Options" scenario all feasible mitigation options are considered, giving China the lowest possible emissions reduction limit. However, if we compare the "Recent Policy" scenario and the "Advanced Options" scenario, we would obtain a different emissions reduction potential in the sectors, but it would be a smaller potential than the previous comparison. Expert reviews (given in a Project Workshop in March 2006 in Beijing) pointed out that it would be very pessimistic to project China under the "Pre-2000 Policy" scenario, while it would also be too optimistic to project China under the "Recent Policy" scenario. As a result, in this study, we will treat the two values as the scope of possible emissions reduction potential. The analysis in the "Advanced Options" scenario will give results that point to the cost effectiveness of mitigation options measured, which would help identify priorities in technology research, development, and utilization.

#### 3.2.2. Main assumptions and sources in scenario definitions

The core work for scenario definitions is to identify technology development trends and to confirm the proportion of specific technologies at the 1-year mark. The above policies, specifically the measures and objectives in these policies, are the main sources for our assumptions. Some other related studies have given us abundant inspiration and information (Martin et al., 1999; Research Team of China Climate Change Country Study, 1999; Ke and Shang, 2000; Sinton and Ku, 2000; DRC et al., 2001; Hu and Jiang, 2001; CICRCCU, 2002; Huo, 2002; Mason et al., 2002; Zhou et al., 2003; He et al., 2005; Huang, 2006; Zhang, 2006; Wang et al., 2007a).

Important assumptions in this study, including energy consumption factors and emission factors, are based on the literature from WRI (2005), Mason et al. (2002), Hu and Jiang (2001), and Sinton and Ku (2000). Cost information includes fixed costs and variable costs. Fixed costs mainly refer to the cost of facilities (including purchase, installation and maintenance, etc. and amortizing to per unit products during their lifetime). Variable costs mainly refer to energy costs. Energy cost information is based on prices in 2000. It is worthy to note that in order to describe future changes in technology we add a factor, "whole energy efficiency improvement ratio annual". This means that even if there were no equipment substitutions, the equipment would still show energy efficiency improvements. Table 2 lists the general assumptions in scenario definitions, including whole energy efficiency improvement ratio per annum, fuel price index, exchange rate, discount rate, and the price year in this study.

#### 3.2.3. Production output projections

It is stated that China's GDP in 2020 will be quadruple that of its GDP in 2000 in the Report of 16th Party Congress. Based on related researches (Sinton and Ku, 2000), we assume China's GDP will maintain its fast growth momentum in the 2000s, with an annual growth

rate set to be 7.5% in each year from 2000 to 2010. Then the growth speed will slow down, with an annual growth rate set to be 6.5% from 2010 to 2020, and then 5.5% in each year from 2020 to 2030.

Due to each sectors' own characteristics, some sectors are set to maintain a parallel development trend with economic development, while some others will differ. See Table 3 for detailed information.

## 4. Results

### 4.1. Energy consumption

#### 4.1.1. Overall energy consumption

Fig. 3 shows the projected development of energy consumption in five target sectors in China from 2000 to 2020. In all three scenarios, it is simultaneously estimated that the aggregate energy consumption of five target sectors will increase due to dramatic economic development and high demand for a better standard of living, but different scenarios will vary in their growth rates. The energy consumption in 2000 was 24,465 PJ. In the "Pre-2000 Policy" scenario, energy consumption in 2010 grows to 40,077 PJ, and in 2020 to 59,827 PJ at an average annual growth rate of 4.6%. Energy consumption under the "Recent Policy" scenario in 2010 reaches 38,380 PJ in 2010 and 55,914 PJ in 2020, with an annual growth rate reduced

to 4.2%. As the most aggressive mitigation options are assumed to be used in the "Advanced Options" scenario, energy consumption in each given year is the lowest under all scenarios—35,815 PJ in 2010 and 48,618 PJ in 2020—with an annual growth rate of 3.5%. Compared with other existing studies on future energy scenarios of China, the annual growth rate of energy consumption from our study (4.6% in "Pre-2000 Policy" scenario and 3.5% in "Advanced Options" scenario) is higher than most of them. See Appendix for details. This can be explained by our excessive attention to the recent developments and trends in macro-economy and energy-consuming sectors in China.

#### 4.1.2. Sectoral energy consumption

From a sectoral perspective, Fig. 4 has given us some useful information. In 2000, electricity accounted for the major share (56%) of all energy consumed in the five sectors, followed by the iron and steel sector, cement sector, transport sector, and, finally, the pulp and paper sector. When comparing the projections in 2000 with the projections in 2020, it is obvious that the sectoral structure regime remains—the electricity sector has, is, and, will

Table 2
General assumptions in scenario definition

|  |  | 2010 | 2020 |
|---|---|---|---|
| Whole energy efficiency improvement ratio per annum | Pre-2000 Policy scenario | 1‰ | 1.5‰ |
|  | Recent Policy scenario | 2‰ | 2.5‰ |
|  | Advanced Options scenario | 3‰ | 3.5‰ |
| Fuel price index (price of 2000 is 1) | Coal | 1.1 | 1.2 |
|  | Fuel oil | 1.2 | 1.3 |
|  | Natural gas | 3 | 3.5 |
|  | Electricity | 1.2 | 1.3 |
| Exchange rate | US$1 = 8.2784 Yuan RMB |  |  |
| Discount rate | 10% |  |  |
| Price in this study | All prices in this study are in 2000 |  |  |



Fig. 3. Aggregate energy consumption in different scenarios from 2000 to 2020.

Table 3
China's GDP and sectors' production assumptions in the analysis

| Year | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|
| GDP's annual growth ratio | 7.50% |  |  | 6.50% |  |
| GDP (billion dollar) | 1081 | 1552 | 2227 | 3096 | 4181 |
| Production in electricity sector (TWh) | 1369 | 1841 | 2313 | 3179 | 4046 |
| Production in iron and steel sector (Mt) | 131 | 210 | 289 | 328 | 364 |
| Production in cement sector (Mt) | 718 | 882 | 1045 | 1132 | 1220 |
| Production in pulp and paper sector (Mt) | 30.5 | 38.4 | 48.3 | 60.7 | 76.4 |
| Production in transport sector (billion km) | 814 | 1489 | 2196 | 2741 | 3300 |

Note: Production in the transport sector takes the aggregate annual traveled mileage of all vehicles as the production indicator.
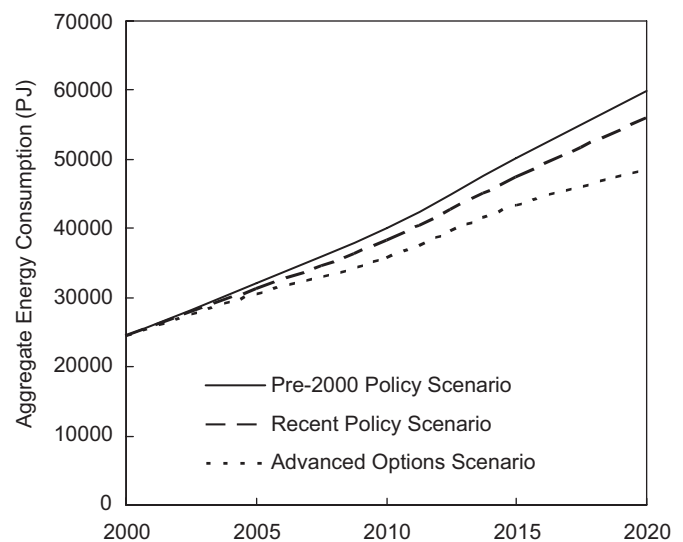
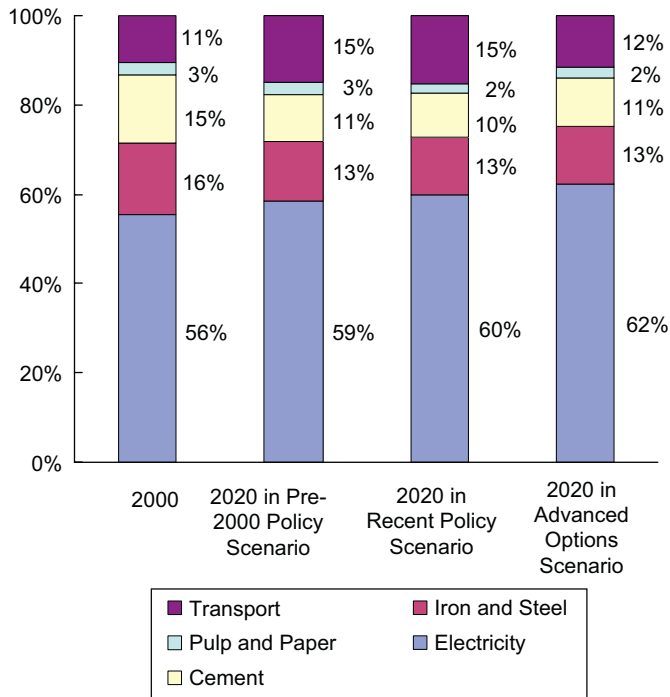Fig. 4. Comparison of sectoral structure in aggregate energy consumption in different scenarios.



Fig. 5. Comparison of energy structure in aggregate energy consumption in different scenarios.

continue to take a leading role in energy consumption. Furthermore, in 2020, the electricity sector will account for an even larger percentage of total energy consumption than in 2000 because the emissions reduction rate in the electricity sector is comparatively lower than in the other sectors (see Tables 6 and 7). The transport sector is also worthy of note in that it is likely to see a large increase in energy consumption from 2000 to 2020 under the "Pre-2000" and the "Recent Policy" scenarios, resultant from the fast growth in vehicle ownership. However, if proper mitigation options have been exercised in the transport sector, the share of energy consumption could be controlled to stay around the 2000 level, as shown in the "Advanced Options" scenario.

### 4.1.3. Energy structure in overall energy consumption

From the perspective of energy structure, Fig. 5 supplies us some interesting information. It is obvious that from 2000 to 2020 the energy structure will not see big changes. Coal will remain the dominant fuel, which is largely determined by the abundance of coal in China. There are few differences in the 2020 energy structure under the "Pre-2000 Policy" scenario and the "Recent Policy" scenario because the policies in the two scenarios do not have critical differences. However, in the "Advanced Options" scenario, as significant emission reduction technologies are utilized in the transport sector such as advanced engine technology—the direct injection gasoline/diesel engine—oil consumption in 2020 will see a sharp decrease compared with the 2020 values in the other two scenarios, resulting in
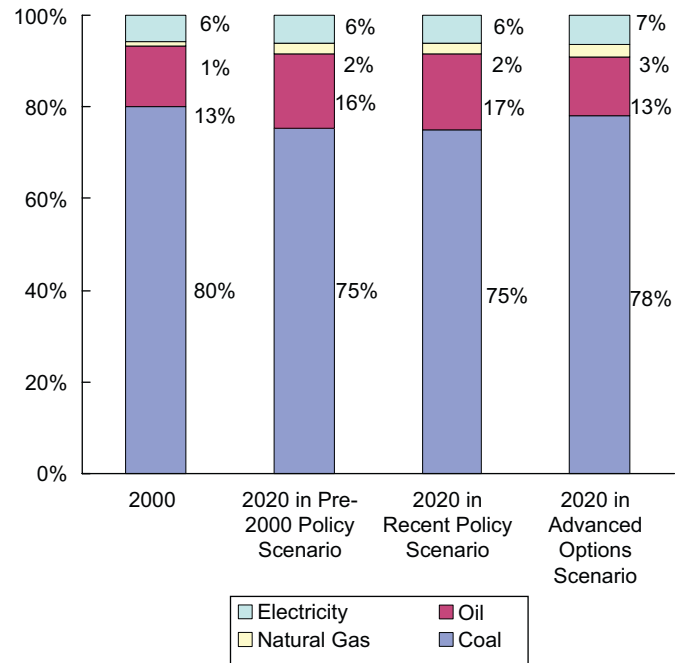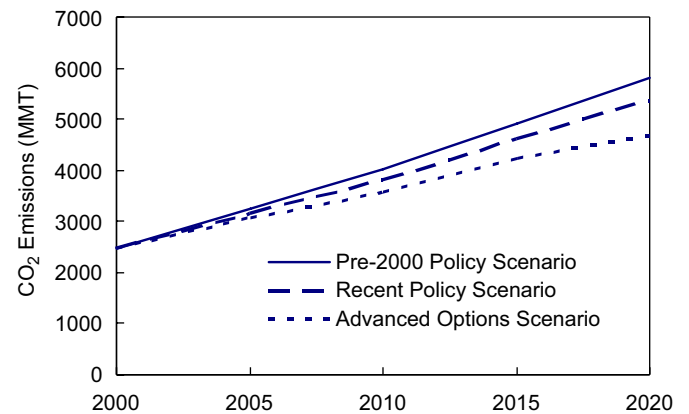


Fig. 6. Comparison of $CO_2$ emission in different scenarios.

the overall increase in other fuel's share in the total energy structure.

### 4.2. $CO_2$ emission

#### 4.2.1. Overall $CO_2$ emission

Fig. 6 shows $CO_2$ emissions from 2000 to 2020 under different scenarios. $CO_2$ factors in our study are directly taken from the LEAP database, which are based on IPCC guidelines for national greenhouse gas inventories. Similar to energy consumption, $CO_2$ emissions are estimated to increase in all scenarios, but at different growth speeds. $CO_2$ emissions in 2000 in all five sectors were 2487 MMT. In 2020, emissions under the "Pre-2000 Policy" scenario will reach 5795 MMT, under the "Recent Policy" scenario emissions will be lower—5367 MMT, and under the

"Advanced Options" scenario emissions is at its lowest—4689 MMT. Table 4 compares $CO_2$ emissions under different scenarios in important years. Compared with other existing studies on future carbon dioxide scenarios of China, the annual growth rate of carbon dioxide from our study (4.3% in "Pre-2000 Policy" scenario and 3.2% in "Advanced Options" scenario) is higher than most of them. The case is similar to the annual growth rate of energy consumption in Section 4.1.1. See Appendix for details.

### 4.2.2. Emission contributor analysis

When we analyze emissions under the "Pre-2000 Policy" scenario exclusively, the outcome gives us the main emissions growth contributors if no control options have been exercised in China. See Table 5 for reference. It is shown that from 2000 to 2020 under the "Pre-2000 Policy" scenario 3308 MMT of absolute emission growth is contributed, mostly, by the electricity sector—58%, followed by cement, transport, iron and steel, and, finally, pulp and paper. However, when we look at the sectoral emission growth rate we also find quick growth in transport emissions, which means if no controls were made in this sector, it could eventually become another dominant contributor to overall emissions.

From the perspective that climate policies are to be made according to the contributor to emission growth under no policy circumstances, electricity and transport sectors should both be identified as key control targets, due to their contribution or potential contribution to emissions.

### 4.2.3. Emissions reduction potential

We can deduce the emissions reduction potential when comparing emissions under different scenarios. In 2010,

China is likely to reduce 198 MMT $CO_2$ under the "Recent Policy" scenario and ~450 MMT $CO_2$ under the "Advanced Options" scenario, which is 5–11% of the emissions under the "Pre-2000 Policy" scenario (the business-as-usual scenario); and in 2020, China may reduce 428 MMT $CO_2$ under the "Recent Policy" scenario and ~1106 MMT $CO_2$ under the "Advanced Options" scenario, which is 7–19% of the emissions under the "Pre-2000 Policy" scenario. It is worthy to note that this 7% emissions reduction potential is nearly equal to the combined emissions of the iron and steel sector and the pulp and paper sector in 2000. This potential has been made possible by the unilateral efforts undertaken by China since 2000, resulting in the slowing down of the emissions growth rate. It represents an important first step towards China's contributions to the global effort in combating climate change (CCAP, 2006c). The 19% emissions reduction potential under the "Advanced Options" scenario is roughly equivalent to shutting down all electricity generators in 2000. This potential can be achieved if China pays special attention to $CO_2$ mitigation options when conducting future policy-making. From an annual reduction perspective, the "Recent Policy" scenario and the "Advanced Options" scenario can realize an annual average of 201–486 MMT of emissions reduction, which is 3.5–8.4% of China's emission in 2020 in the "Pre-2000 Policy" scenario.

Tables 6 and 7 provide detailed sectoral and overall data on emissions reduction potential. Through a comparison of results under the "Pre-2000 Policy" and the "Recent Policy" scenarios, we notice that each of the five sectors will decrease in their $CO_2$ emissions in recent policy scenario; in particular, the sectoral policies would make the cement sector the main contributor to overall absolute emission reduction, followed by the electricity sector, and the iron and steel sector. This corresponds to their aggressive energy conservation goals in China's Medium and Long-Term Energy Conservation Plan and other recent policies.

Through a comparison under the "Pre-2000 Policy" scenario and the "Advanced Options" scenario, the electricity sector will be the main contributor to overall absolute emission reduction, due to the greater availability of climate-friendly technologies, followed by transport and cement sectors.

All the comparison results will be very useful when an absolute mitigation target is to be made by China and China has to allocate breakdown targets into the various sectors. Those sectors that are the main contributors to overall absolute emission reduction should be identified as the target sectors to implement climate policies.

### 4.3. Cost

When assessing emissions reduction potential, it is necessary to consider the corresponding abatement costs. It should be noted here that as there is no mitigation option

Table 4
Comparison of $CO_2$ emission in different scenarios (2000 is base year)

|  | 2000 | 2005 | 2010 | 2015 | 2020 |
| --- | --- | --- | --- | --- | --- |
| Pre-2000 Policy Scenario | 1.0 | 1.3 | 1.6 | 2.0 | 2.3 |
| Recent Policy Scenario | 1.0 | 1.3 | 1.5 | 1.9 | 2.2 |
| Advanced Options scenario | 1.0 | 1.2 | 1.4 | 1.7 | 1.9 |

Table 5
Sectoral emission analysis in Pre-2000 Policy scenario

|  | Absolute emission growth from 2000 to 2020 (MMT) | Sectoral contribution to the absolute emission growth (%) | Sectoral emission growth rate (%) |
| --- | --- | --- | --- |
| Electricity | 1903 | 58 | 159 |
| Iron and steel | 366 | 11 | 104 |
| Cement | 480 | 15 | 71 |
| Pulp and paper | 78 | 2 | 124 |
| Transport | 481 | 15 | 247 |
| Total | 3308 | – | – |

Table 6
Comparison of emission in Pre-2000 Policy scenario and Recent Policy Scenario

| Sector | Pre-2000 Policy scenario | | Recent Policy scenario | | | |
|---|---|---|---|---|---|---|
| | 2000 Emission (MMTCO$_2$) | 2020 Emissions (MMTCO$_2$) | 2020 Emissions (MMTCO$_2$) | Emissions change from BAU (MMTCO$_2$) in 2020 | % Change from pre-2000 policy scenario | Sectoral share in total emission reduction in 2020 (%) |
| Electricity | 1199 | 3102 | 2960 | 142 | 5 | 33 |
| Iron and steel | 352 | 717 | 654 | 64 | 9 | 15 |
| Cement | 678 | 1158 | 999 | 159 | 14 | 37 |
| Pulp and paper | 63 | 141 | 111 | 30 | 21 | 7 |
| Transport | 195 | 676 | 643 | 34 | 5 | 8 |
| Total | 2487 | 5795 | 5367 | 428 | 7 | – |

Table 7
Comparison of emission in Pre-2000 Policy scenario and advanced options scenario

| Sector | Pre-2000 Policy scenario | | Advanced Options scenario | | | |
|---|---|---|---|---|---|---|
| | 2000 Emission (MMTCO$_2$) | 2020 Emissions (MMTCO$_2$) | 2020 Emissions (MMTCO$_2$) | Emissions change from BAU (MMTCO$_2$) in 2020 | % Change from pre-2000 policy scenario | Sectoral share in total emission reduction in 2020 (%) |
| Electricity | 1199 | 3102 | 2658 | 444 | 14 | 40 |
| Iron and steel | 352 | 717 | 576 | 142 | 20 | 13 |
| Cement | 678 | 1158 | 923 | 235 | 20 | 21 |
| Pulp and paper | 63 | 141 | 105 | 36 | 25 | 3 |
| Transport | 195 | 676 | 427 | 249 | 37 | 23 |
| Total | 2487 | 5795 | 4689 | 1106 | 19 | – |

Table 8
Emission reduction potential in advanced options scenario and the corresponding abatement cost in 2010, 2015 and 2020

| | Emission reduction potential (MMTCO$_2$) | Net abatement cost (million US$) | Average cost effectiveness (US$/tCO$_2$) |
|---|---|---|---|
| 2010 | 416 | 6124 | 14.7 |
| 2015 | 644 | 10,064 | 15.6 |
| 2020 | 1038 | 12,686 | 12.2 |

analysis in the pulp and paper sector, the following emissions reduction and cost information will exclude the pulp and paper sector. It is shown in Table 8 that the emissions reduction potential in each year is gradually increasing, from 416 MMT CO$_2$ in 2010, to 644 MMT CO$_2$ in 2015, and to 1038 MMT CO$_2$ in 2020. This is mainly due to the growing advancement of new mitigation technologies and the wider application of these technologies. When realizing these extents of reductions, two aspects of costs need to be considered. On the one hand, implementing "advanced options" in emissions reduction usually requires new investment on fixed assets (such as new high-tech electricity-generating units and new gas-fill stations), bringing in of new technologies, installation of accessory equipments, on-training staff, etc. On the other hand, the

application of "advanced options" could improve production efficiency, reduce energy demand, and bring in a corresponding reduction in energy costs. Therefore, "Net abatement cost" in Table 8 shows the offset result of increased mitigation costs and decreased energy costs.

The cost for reducing 1 ton CO$_2$ has experienced an inverted "U"-shape change—first climbing and then falling. This can be explained by noting that at the beginning of the emissions reduction process, some mitigation options are encouraged by the government regulation, or even forced to enter the market despite their high expenses. Along with their increasing share in the total technical hierarchy, the average emission reduction cost per ton of CO$_2$ increases; however, as the whole emissions reduction process evolves, the majority of technologies will be taken full advantage of. Although various expensive mitigation options are still in the process of expanding their "markets", the role of technology efficiency improvement has dominated in this process. Effects of the learning curve result in a decreased cost for each ton of CO$_2$ reduced. The average cost per ton CO$_2$ reduced changes from US$14.7 in 2010 to US$15.6 in 2015, and then to US$12.2 in 2020, as shown in Table 8.

Several points are worthy to clarify here about cost analysis uncertainties. First, the uncertainties of cost in this study mainly come from the inadequate data. For some mitigation options, it is viable to obtain the investment

cost, operation and maintenance cost, and the fuel cost from previous reports and studies (Hu and Jiang, 2001; CICRCCU, 2002; Zhou et al., 2003; IEA, 2003; Wang et al., 2007a, b; Cai et al., 2007). This cost information has been put into LEAP, where the options' costs each year change automatically due to annual efficiency improvement. The total costs and average cost per ton $CO_2$ reduced each year will change correspondingly, not only because of the change in separate costs but also in the different extents of technology use in different scenarios. However, in most cases, we can simply obtain part of the cost information, such as solely the investment cost. We chose to supplement the missing data by estimation based on other studies, even qualitative ones. Therefore, the uncertainty in cost

information should be noted particularly. Second, despite cost uncertainty, cost comparisons within a sector in this study are more reliable than across sectors. The emission reduction and cost comparison within a sector can give support when devising sectoral mitigation strategies, leading to selecting the most promising mitigation options. This is the reason why we do not rank mitigation options solely according to their costs regardless of their sectors in Table 9 (which will be further explained in the next section), although we do know that this ranking could probably give more useful information when making trans-sector mitigation strategies. Decreasing the uncertainties in cost information will be a major task for future research.

Table 9
Chinese emissions reduction options in 2020

| Marginal abatement cost ($/ton $CO_2$e) | Total emission reduction (MMTCO$_2$e) | Cumulative reduction (MMTCO$_2$e) | Mitigation options | Sector |
|---|---|---|---|---|
| −3.6 | 5.7 | 5.7 | CFBC (circulating fluidized bed combustion) | Electricity |
| −3.0 | 38.0 | 43.7 | Demand side management | Electricity |
| 5.7 | 25.1 | 68.8 | Reconstruction of conventional thermal power | Electricity |
| 6.0 | 29.7 | 98.5 | Supercritical/Ultra-supercritical plant | Electricity |
| 19.2 | 136.9 | 235.4 | Nuclear power | Electricity |
| 31.0 | 171.2 | 406.6 | Hydropower | Electricity |
| 32.7 | 4.2 | 410.8 | Natural gas | Electricity |
| 38.0 | 7.6 | 418.4 | Wind power | Electricity |
| 38.8 | 14.1 | 432.5 | IGCC (integrated gasification combined-cycle) and PFBC (pressurized fluidized bed combustion) | Electricity |
| 53.3 | 5.0 | 437.5 | CCS (carbon capture and storage) | Electricity |
| 133.7 | 11.4 | 448.9 | Solar thermal | Electricity |
| −3.6 | 3.6 | 452.5 | Establish energy management center | Iron and steel |
| 3.0 | 9.1 | 461.6 | Advanced coke oven | Iron and steel |
| 5.4 | 24.6 | 486.2 | Advanced blast furnace technology | Iron and steel |
| 8.2 | 43.6 | 529.8 | Adjust ratio of iron/steel | Iron and steel |
| 30.4 | 3.5 | 533.3 | Dry coke quenching | Iron and steel |
| 31.6 | 10.8 | 544.1 | Advanced sinter machine | Iron and steel |
| 34.9 | 4.4 | 548.5 | Advanced direct steel rolling machine | Iron and steel |
| 52.7 | 25.6 | 574.1 | Smelt reduction technology | Iron and steel |
| 61.0 | 7.6 | 581.7 | Advanced converter | Iron and steel |
| 131.4 | 5.7 | 587.4 | Advanced electric arc furnace | Iron and steel |
| −4.5 | 23.5 | 610.9 | Preventative maintenance | Cement |
| −3.8 | 21.5 | 632.4 | Use of waste derived fuels | Cement |
| −2.4 | 19.5 | 651.9 | Process management and control | Cement |
| −1.9 | 11.3 | 663.2 | Kiln shell heat loss reduction | Cement |
| 0.2 | 8.2 | 671.4 | High-efficiency motors and drives | Cement |
| 0.9 | 10.2 | 681.6 | Active additives | Cement |
| 1.5 | 14.3 | 695.9 | Composite cement | Cement |
| 3.8 | 49.1 | 745.0 | Conversion to multi-stage pre-heater kiln | Cement |
| 4.1 | 34.8 | 779.8 | Combustion system improvement | Cement |
| 6.6 | 28.6 | 808.4 | High-efficiency roller mills | Cement |
| 9.7 | 10.2 | 818.6 | High-efficiency powder classifiers | Cement |
| 12.7 | 3.7 | 822.3 | Efficient transport systems | Cement |
| −18.4 | 19.1 | 841.4 | Transmission technologies | Transportation |
| −12.0 | 43.8 | 885.2 | Vehicle technologies | Transportation |
| −11.9 | 136.0 | 1021.2 | Engine technologies | Transportation |
| −11.1 | 3.8 | 1025.0 | Engine-transmission-vehicle technologies | Transportation |
| 2.6 | 2.8 | 1027.8 | Bus rapid transit | Transportation |
| 21.5 | 10.3 | 1038.1 | Fuel switch | Transportation |

## 4.4. Assessment of mitigation options

### 4.4.1. General assessment of mitigation options

Each sector has a list of mitigation options analyzed with the exception of the pulp and paper sector due to data limitation. In the electricity sector, developing hydro-power plants could help achieve the most emission reduction—171.2 MMTCO$_2$e in 2020. Each ton of CO$_2$e reduced by this option costs US$31. But it is not the cheapest mitigation option. Replacing conventional generating units with circulating fluidized bed combustion units even generate US$3.6 net benefits per ton CO$_2$e reduced. Because CFBC technology already passed the R&D and pilot periods and has been totally commercialized, the benefits from increased energy efficiency and fuel saving can even surpass the costs to buy, install, and run it. However, CFBC technology has a comparatively limited emission reduction effects in China's electricity sector, because in the scenario setting, according to existing plans, regulations, and other studies, we make the judgment that CFBC will have a limited penetration rate in the units hierarchy. Detailed information about cost and emission reduction of each option by sector is given in Table 9, from which we could find out the least-expensive mitigation option and the option which is the biggest contributor to emission reduction within sectors. They are as follows: establishing an energy management center, adjusting the ratio of iron/steel in the iron and steel sector, preventative maintenance, combustion system improvement in cement sector, and improving transmission technologies and improving engine technologies (in the transport sector).

### 4.4.2. Assessment of low-cost mitigation options

In each sector there are some low-cost mitigation options. In IPCC AR4 (IPCC, 2007), the figure SPM5 "Global economic mitigation potential in 2030" has divided mitigation options by the following categories: <US$0, <US$20, <US$50, and <US$100/tCO$_2$-eq. In our study, we define the low-cost mitigation options as options costing less than US$10/tCO$_2$-eq. We had also analyzed a sub-group of these low-cost options, which cost even less (US$<5/tCO$_2$-eq).

As shown in Tables 10 and 11, mitigation options that cost less than US$5/tCO$_2$ are able to reduce 454.3 MMT CO$_2$, which makes up 44% of the total emissions reduction potential (1038 MMT) under the "Advanced Options" scenario. Options costing less than US$10 can reduce 616.1 MMT CO$_2$, which represents 59% of the total reductions potential. This implies that low-cost mitigation options can play a very important role in helping China realize the total mitigation potential.

From a sectoral perspective, it is obvious that mitigation options costing less than US$5 largely exist in the cement and transport sectors because emissions reduction by these mitigation options take up 82% and 95%, respectively, in each of their sectoral emissions reduction potentials. Options costing less than US$5 in cement sector include

Table 10
Assessment of mitigation options costing less than US$5 in 2020

|  | Emission reduction achieved by options costing less than US$5 in 2020 (MMT) | Share in sectoral emission reduction potential (%) |
| --- | --- | --- |
| Electricity | 43.7 | 10 |
| Iron and steel | 12.7 | 9 |
| Cement | 192.4 | 82 |
| Transport | 205.5 | 95 |
| Total | 454.3 | – |
| Share in total reduction potential in advanced options scenario in 2020 | 44% | – |

Table 11
Assessment of mitigation options costing less than US$10 in 2020

|  | Emission reduction achieved by options costing less than US$10 in 2020 (MMT) | Share in sectoral emission reduction potential (%) |
| --- | --- | --- |
| Electricity | 98.5 | 22 |
| Iron and steel | 80.9 | 58 |
| Cement | 231.2 | 98 |
| Transport | 205.5 | 95 |
| Total | 616.1 | – |
| Share in total reduction potential in advanced options scenario in 2020 | 59% | – |

preventative maintenance, use of waste-derived fuels, process management and control, kiln shell heat loss reduction, high-efficiency motors and drives, active additives, composite cement, conversion to multi-stage pre-heater kiln, and combustion system improvement (ranked by their costs). And options costing less than US$5 in transport sector include developing transmission technologies, vehicle technologies, engine technologies, engine-transmission-vehicle technologies, and bus rapid transit (also ranked by their costs). The iron and steel sector also shows mitigation cost advantage in the analysis of mitigation options costing less than US$10, which accounts for 58% of its sectoral emissions reduction potential. These options are establishing an energy management center, utilizing advanced coke oven, using advanced blast furnace technology, and adjusting the ratio of iron/steel (ranked by their costs). Therefore, when cost limit of a climate policy is set to be less than US$5/tCO$_2$, the cement and transport sectors should get priority consideration; when cost limit is less than US$10, the iron and steel sector can become another target sector to reduce emissions. And those options listed above should form the implementation strategy to comply with the climate policy. In all, when

China is facing cost constraints, the transport, cement, and iron and steel sectors should become the target sectors in reducing emissions at a low cost.

### 4.5. Policy implications summary

In all the above results, analysis includes many perspectives to make climate policies. The contributor to emission growth or the contributor to emission reduction is considered solely from the emission perspective. However, perspectives like the lowest average mitigation cost, the contributor to emission reduction under a cost limit, include cost—another key factor to consider in order to help support climate policy making. We summarize these discussions in Table 12, which gives an overview of sector preference when creating climate policies from different perspectives. When synthesizing all perspectives' analysis results, we find out that transport, and cement and electricity sectors are always ranking high in any perspective, so that they will be the most "favorite" sectors to make climate policies.

The existence of other policy-making perspectives should also be mentioned here, e.g. in which sector(s) would the GHG mitigation policies have the most co-benefits in reducing other air pollutants. Because in developing countries, GHG mitigation issues are not as high on the political agenda as problems related to reducing common air pollutants such as $SO_2$, $NO_x$, and $PM_{10}$. Therefore, the co-benefits of GHG mitigation policies are worthy to be considered as one of the policy-making perspectives. It was estimated that by implementing co-generation option in the electricity sector in the Shanxi Province of China, 0.3 million tons of $CO_2$ will be reduced, and 1200 tons of TSP and 2600 tons of $SO_2$ will be mitigated at the same time (Aunan et al., 2004). Several other studies have carried out researh on the GHG mitigation measures or energy policies and their co-benefits (Aunan et al., 2006; Chen et al., 2006; Cifuentes et al., 2001; Aaheim et al., 1999; Wang and Smith, 1999). A parallel study concerning the co-benefit analysis of measures in the five target sectors in our study

will result in a new ranking of prior sectors to implement GHG mitigation policies. However, due to time and data limitation, this study did not include the co-benefit analysis but only considers the GHG emission reduction effects and corresponding costs of mitigation options and policies. Nevertheless, involving co-benefit analysis would be a meaningful task for further study.

### 5. Conclusion

Energy consumption and $CO_2$ emission in China's five major sectors are projected to increase under all three scenarios due to economic development and increased social demand. Scenarios may vary in their growth path in energy consumption and $CO_2$ emissions, but the structure of sectoral contribution to consumption and emissions will not witness big changes, and nor will the structure of energy sources in China.

China is now undertaking domestic unilateral actions to pursue a "harmonious society" and "sustainable development". If these actions in "Recent Policy" scenario are fully implemented, they will contribute to sizeable emissions reductions. But current policies still have not dealt with climate change mitigation options because there are no clear climate change policies in China at present. In light of this, the analysis under the "Advanced Options" scenario provides strong support and insight for climate policy making. Under the "Advanced Options" scenario, China could have an estimated 486 MMT annual emissions reduction when compared with the "Pre-2000 Policy" scenario (8.4% of 2020 emission in "Pre-2000 Policy" scenario), each year, and a further 285 MMT emission reduction compared with the "Recent Policy" scenario (5.3% of 2020 emission in "Recent Policy" scenario), each year.

Cost information should be an important consideration when devising climate policies. How much emission reduction potential can be achieved will be limited by the costs of bringing about the reduction. To implement the entire "Advanced Options" scenario would cost China

Table 12
Summary of sector preference with different policy perspectives

| | Contributor to emission growth when no climate policies were to be made | Contributor to emission reduction achieved by recent policies | Contributor to emission reduction achieved by advanced mitigation options | Sector with the lowest average mitigation cost | Contributor to emission reduction achieved by options costing less than US$5/tCO$_2$ in 2020 | Contributor to emission reduction achieved by options costing less than US$10/tCO$_2$ in 2020 |
|---|---|---|---|---|---|---|
| Electricity | ***** | **** | ***** | *** | *** | ** |
| Iron and steel | ** | *** | ** | ** | ** | *** |
| Cement | *** | ***** | *** | **** | **** | ***** |
| Pulp and paper | * | * | * | _a | _a | _a |
| Transport | **** | ** | **** | ***** | ***** | **** |

*Note*: Sector with more "*" means sector with higher preference to implement climate policies.
[a]Cost analysis in China's pulp and paper sector is not included in this research.

US$14.7/tCO$_2$ in 2010 and US$12.2/tCO$_2$ in 2020. However, if mitigation costs are the main consideration when making climate policies, sector and technology priority can be deduced from the analysis in Section 4.4.

This study also offers support and insight for decision makers to devise climate policies from different perspectives. Under each perspective, all the five sectors have been ranked by their policy preference. Also within each sector, a range of mitigation options has been identified, which can help China achieve significant additional emissions reductions.

At least two limitations in this study should be noted here—cost uncertainties and to-be-expanded policy perspectives. Problems like incomplete cost within sectors and deficient cost comparability among sectors usually come along with the bottom-up multi-sectoral GHG mitigation analysis. More work needs to be done on data collection and to increase the credibility of cost information. Besides, this study only takes those policy-making perspectives related to GHG emission and GHG mitigation costs. Co-benefit analysis of sectoral GHG mitigation options is another meaningful policy-making perspective, especially for developing countries. Probable action to include co-benefit analysis is to collect more data concerning the co-benefits of each mitigation options, such as the mitigation effects of common air pollutants. Overcoming the two limits would form the major tasks for our research in the next step.

Summing up from all the above analysis, China has achieved a lot in CO$_2$ mitigation through various measures since 2000. We advocate that her unilateral action in the emissions reduction field should be recognized and encouraged. If additional reductions were required, sector-based mitigation policies would be a very good option and selecting proper policy-making perspective(s) and identifying the most cost-effective mitigation measures within sector and across sectors would be the key information needed to devise these policies.

## Appendix A

Here we present the comparison results of parallel studies from both domestic and international study groups on China's future energy and carbon dioxide scenarios. It is obvious from Table A1 that the annual growth rate of China's final energy consumption in two or three decades (or even 60 years in the National Response Strategy study) ranges from 2.2% to 4.2% in BAU cases in different studies, and from 1.8% to 3.6% in CO$_2$ control cases. The annual growth rate of China's carbon dioxide emission ranges from 2.6% to 3.7% in BAU cases, and from 1.71% to 2.9% in CO$_2$ control cases. In terms of the huge base of energy consumption in China and the long time-span, the judgments are very different from each other. Generally speaking, the annual growth rates of both energy consumption and CO$_2$ emissions in our study in BAU (4.6% and 4.3%) and CO$_2$ control cases (3.5% and 3.2%) are the highest up to now. This is because the base year of our study is the latest among all studies listed below, and we have considered a lot of recent developments and trends in macro-economy and energy-consuming sectors in China.

Table A1
Annual growth rate of energy consumption and CO$_2$ emissions in different studies

| Studies | Timeline | Business as usual cases | | Carbon dioxide control cases | |
| --- | --- | --- | --- | --- | --- |
| | | Energy (%) | Carbon dioxide (%) | Energy (%) | Carbon dioxide (%) |
| Tsinghua (Guo, 2003) | 1999–2030 | 2.2 | n.a. | n.a. | n.a. |
| APERC (2002) | 1999–2020 | 2.7 | n.a. | n.a. | n.a. |
| National Response Strategy (Sinton and Ku, 2000) | 1990–2050 | 3.1 | 2.6 | 2.7 | 2.1 |
| Environmental Considerations (Sinton and Ku, 2000) | 1990–2020 | 3.2 | 3.1 | 2.8 | 2.7 |
| Country Study (Sinton and Ku, 2000) | 1990–2030 | 3.3 | 3.2 | 2.4 | 1.9 |
| ALGAS (Sinton and Ku, 2000) | 1990–2020 | 3.7 | 3.7 | 3.0 | 2.9 |
| Sustainable Energy Scenarios in 2020 (Zhou et al., 2003) | 1998–2020 | 3.79 | 3.60 | 2.43 | 1.7 |
| Issues and Options (Sinton and Ku, 2000) | 1990–2020 | 4.1 | 3.7 | 3.6 | 2.3 |
| EIA (2003) | 2000–2025 | 4.20 | n.a. | 1.80 | n.a. |
| Our study (in 5 sectors) | 2000–2020 | 4.6 | 4.3 | 3.5% | 3.2% |

*Note*: Those studies that have used LEAP as modeling tools are APERC(2003), Guo(2003), Zhou (2003), and our study.

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