INTERNATIONAL DEVELOPING COUNTRY ANALYSIS AND DIALOGUE

Greenhouse Gas Mitigation in China: Scenarios and Opportunities through 2030

Tsinghua University of China

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I. Introduction

I.A Purpose and Description of Project

I.A.1 Background

At the annual United Nations Framework Convention on Climate Change (UNFCCC) meeting in Montreal in November 2005, Parties agreed to begin formal discussions under both the Kyoto Protocol and UNFCCC on the future international climate policy structure for the post-2012 period. A key element of this discussion will be what role developing countries will undertake in the international response to climate change. In many developing countries discussions about, as well as concrete policy steps to, reducing GHG emissions are already being undertaken, often out of concern over such issues as energy security, air quality, and economic development.

In February 2005, with financial support from the United Kingdom's Department for International Development (DFID), the Tinker Foundation, and the Hewlett Foundation, the Center for Clean Air Policy (CCAP) and leading partner organizations in four key developing countries (Brazil, China, India, and Mexico) launched the ***Assisting Developing Country Climate Negotiators through Analysis and Dialogue*** project. For this ongoing project, this team is working in concert to develop a comprehensive analysis of greenhouse gas (GHG) projections and potential mitigation options, costs, co-benefits, and implementation policies in these four countries. The project represents an important step in the discussions on the post-2012 international response to climate change, by providing concrete analysis and results to help both the internal deliberations in these four countries and the international community. This project has two phases, briefly described later in this section.

The in-country partners in this project consist of:

- a multi-disciplinary team from Brazil that cooperated on the recent Brazilian National Communication, including Haroldo Machado Filho, Special Adviser of the General Coordination on Global Climate Change at the Ministry of Science and Technology, Emilio Lèbre La Rovere, leading the team of the Center for Integrated Studies on Climate Change and the Environment (Centro Clima) at the Institute for Research and Postgraduate Studies of Engineering at the Federal University of Rio de Janeiro (COPPE/UFRJ), Thelma Krug of the InterAmerican Institute for Global Change Research, and Magda Aparecida de Lima, Luiz Gustavo Barioni, and Geraldo Martha of the Brazilian Agricultural Research Institute (Embrapa);
- a team from the Institute for Environmental Systems Analysis within the Department of Environmental Science and Engineering at Tsinghua University of China;
- The Energy and Resources Institute (TERI) of India; and
- the Centro Mario Molina of Mexico.

The results of Phase I have been presented in a series of reports. The reports for Brazil, China and India were released in November 2006. The report for Mexico will be released in 2007. CCAP has also prepared an integrated report, "**Assisting Developing Country Climate Negotiators through Analysis and Dialogue Project: Final Phase I Report**," which compares and contrasts the results achieved across the former three countries. This report presents the results of Phase I (GHG Mitigation Option and Cost Analysis) of the project analysis for China.

I.A.2 Phase I. GHG Mitigation Option and Cost Analysis

In Phase I of this project, the team conducted individual GHG emission mitigation analyses for major economic sectors. In China, the sectors analyzed were electricity; cement; iron and steel; pulp and paper; and transportation. Specifically, each country analysis included the following elements.

- ***Development of a current overview of each economic sector***, including annual number of units and production capacity, production, fuel consumption, GHG emissions, energy intensity, and GHG emissions intensity.
- ***Development of long-term (through the year 2025 or 2030) individual GHG emission projections*** under several baseline scenarios for each economic sector. This includes annual scenarios of production, fuel consumption, GHG emissions, energy intensity, and GHG emissions intensity.
- ***Development of detailed marginal abatement cost curves*** for key technologies and mitigation approaches in each sector. This includes the total GHG emissions reduction potential and cost (per metric ton GHG reduced) for 2010, 2015 and 2020.
- ***Evaluation of the impact of implementation*** of select packages of GHG mitigation options. The results to be provided include the annual changes (through 2030) in energy consumption and intensity, GHG consumption and intensity, total costs and production costs, as well as co-benefits.
- ***Assessment of economy-wide cost and economic impacts*** of mitigation packages on parameters such as GDP, employment, consumer prices, structure of economy, and distribution, using macroeconomic models and optimization frameworks that incorporate the detailed cost and GHG emission reduction potential data for key technologies.
- ***Preliminary analysis of potential domestic policies for implementation*** of each mitigation option, including the domestic legal and regulatory framework, political/economic/technical/legal barriers to implementation, potential key actors and institutions involved, and potential funding approaches.
- ***Evaluation of potential international policy options and the implications of the results*** for each economic sector for specific international approaches.

The GHG mitigation analysis was conducted using country-specific scenarios for annual population and gross domestic product (GDP). These and other major assumptions used are detailed in Section II.D.1. The teams developed two alternative GHG reference case scenarios for each sector, partly based on the A2 and B2 scenarios in the Intergovernmental Panel on Climate Change (IPCC) *Special Report on Emissions Scenarios* (SRES). The A2 and B2 scenarios were chosen because the teams felt that these represented divergent scenarios that each had a reasonable probability of representing the future reality. The A2 scenario is characterized by relatively lower trade flows, slow capital stock turnover, and slower rates of technological change; the B2 world is characterized by comparatively greater concern for environmental and social sustainability.[1] However, for the China analysis only one scenario was conducted based on expert in-country judgment on probable future trends.

It was also desired to develop scenarios that would display the impact of policies and measures undertaken in the past five years; these may include national energy and other policies, as well as projects undertaken as part of the Clean Development Mechanism (CDM) of the Kyoto Protocol. Accordingly, each of the two baseline scenarios was further divided into a scenario assuming implementation of only those policies and projects announced prior to 2000—**"Pre-2000 Policy" scenario**—and another scenario with implementation of all policies announced before 2006—**"Recent Policy" scenario**. Both scenarios begin in 2000. A scenario was then developed that assumes implementation of select packages of GHG mitigation options in years after 2005—called the "**Advanced Options" scenario**. Where appropriate, each country analysis conducted up to four variations of the Advanced Options scenario based on the potential cost effectiveness (measured in $/metric ton CO2e reduced) of the mitigation measures analyzed. The first three Advanced Options scenarios assumed implementation of all measures costing, respectively, <$0 per tonne, <$5/tonne, and <$10/tonne. The fourth scenario was the most aggressive, and considered all feasible (in the team's judgment) mitigation options.

[1] IPCC *Special Report on Emissions Scenarios*, Chapter 4, "An Overview of Scenarios." Available at http://www.grida.no/climate/ipcc/emission.

An important component of this project is an ongoing series of consultations, meetings and workshops to ensure the involvement of key governmental, industry and non-governmental officials and institutions China. Regular contact with policymakers provided a direct link to the government and policy process in each country, and has helped to ensure a realistic analysis and the evaluation of the most appropriate set of mitigation options and policies. At the start of the technical analysis, a workshop was held in Beijing by Tsinghua University and CCAP in July 2005 to obtain feedback and guidance from government policymakers and other stakeholders. This information was incorporated into the analysis. In March 2006, at another two-day workshop held in Beijing, the results were presented to a large group of government officials and representatives from industry, universities, think tanks, and non-governmental organizations. The stakeholders also provided significant input and guidance regarding the mitigation options and policies to be analyzed for Phase II of the project (see below).

An additional important foundation of the project is that it links directly with international climate change negotiators through CCAP's *Dialogue on Future International Actions to Address Global Climate Change*—the Future Actions Dialogue or FAD (Box 1) — the leading international dialogue on climate policy over the last five years. Preliminary results of this project have been presented at various FAD meetings and final results will be presented at future meetings of the group to help shape and inform these deliberations.

Box 1. Dialogue on Future International Actions to Address Global Climate Change

The Future Actions Dialogue brings together key senior negotiators from 15 developing and 15 Annex I countries several times each year to discuss options for future international response to climate change. This project includes six components:

(1) a series of joint dialogue meetings among high-level negotiators from developed and developing country Parties and select company representatives;
(2) a series of dialogue meetings, back to back with joint dialogue meetings, for only developing country negotiators to build capacity, develop policies that countries can implement to meet both climate and national sustainable development goals, and facilitate an exchange of ideas that will lead to more fruitful discussions with industrialized countries;
(3) regional workshops to broaden the network of countries and individuals that understand and contribute to the design of post-2012 options;
(4) in-depth analysis to identify, elaborate, and test options for designing climate change mitigation actions by industrialized and developing countries;
(5) working groups of interested Dialogue participants to explore issues in-depth in between meetings; and
(6) production of FAD working papers and a final compendium that presents the comprehensive analytical findings and policy recommendations developed throughout the project.

For more information on the process, including presentations and papers from the meetings see: www.ccap.org/international/future.htm

I.A.3 Phase II. Policy and Implementation Strategy

In the next phase of the project, to be conducted from mid-2006 through 2007, CCAP and its in-country partners will build upon the work and policy connections developed during Phase I. In consultation with in-county policymakers CCAP and its partners will select a number of the most promising options for GHG mitigation and conduct a more detailed and in-depth analysis of issues associated with implementation. This will include an evaluation of the implications of specific international climate change policy options for GHG mitigation in these four countries; development of a suite of potential policies and approaches for implementation of each option; and comprehensive and in-depth analysis of the key actors, barriers and co-benefits associated with each. Phase II will include a series of workshops in each country to obtain the views of and share results with domestic

policy makers and stakeholders. It will culminate in two international workshops, one in Latin America and one in Asia, to disseminate the results of the project to a wider regional audience and expand its policy relevance by allowing other countries to gain from the experience of this project. The results of Phase II for each country will also be available in a set of individual reports.

I.B Report Structure

This report begins in Chapter II with an overview of China, including population and economic statistics and a profile of its historical energy consumption and GHG emission trends. The chapter concludes with a summary of the macro assumptions, analytical methodologies and computer modeling tools used in the analysis. Chapters III through VII present the results of the GHG mitigation option and cost analysis for the individual sectors, beginning with electricity. This is followed in Chapter VIII with results of the macroeconomic modeling and analysis. The report concludes with a discussion of the likely mitigation options and implementation policies in China that may be explored in Phase II of the project.

II. Country Overview

In this section, we provide a brief description of key statistics of China.

II.A Population, Economy[2], and Emissions

II.A.1 Population and Gross Domestic Product

In 2000, China's population was about 1.26 billion, accounting for more than a fifth of the world population.[3] In that same year, China's gross domestic product (GDP) was approximately 1.1 trillion USD, accounting for 3% of the world economy. Chinese GDP per capita was about $865 in 2000, which is less than one fifth of the world GDP per capita of 5,217 USD (see Table 2.1).

Industry[4] sector contributed the largest share of value added to the Chinese national economy in 2000: its US $543 billion accounted for 50% of the economy-wide value added, led by the manufacturing sector with $375 and 35% of the economy-wide value added. Service[5] sector of $361 billion attributed 33% of the national value added, followed by agricultural[6] sector of $177 billion attributing 15% of the national value added. The global shares of Chinese economy in these sectors were 6% for industry, 2% for services, and 15% for agriculture.

Table 2.1 Population and gross domestic product of China in 2000.

	Population		GDP		GDP per capita	
	Billion	% World	Trillion US$	% World	US$	rel. % world
China	1.26	21%	1.1	3%	856	16%
WORLD	6.05	100%	31.6	100%	5,217	100%

Source: World Development Indicator 2005 (World Bank, 2005)

II.A.2 International Trade and Role/Position in the World Economy

China's international trade in goods accounted for approximately 40% of its GDP[7] in 2000. China was a net exporter of merchandise goods, exporting about $220 billion and importing $200 billion. Manufactures made up most of the traded merchandise, accounting for 32.5% of China's GDP (18% by exports and 14% by imports) and 8% of world's total traded manufacture goods. Fuel imports, food exports, and ores and metals imports made up the next large shares of merchandise trades, but each accounted for only marginal proportion of China's GDP at around 1% – 2%. Although accounting for not a large share of the domestic GDP, China's agricultural raw material and ores and metals trades accounted for relatively large shares, at 10% and 8.7%of the world's traded goods of respective categories.

Table 2.2. China's merchandise trading by category in 2000

	Exports			Imports		
	Billion US$	% of GDP	% of World Trading	Billion US$	% of GDP	% of World Trading
Merchandise TOTAL	**219.7**	**20.8%**	**3.9%**	**198.5**	**18.8%**	**3.4%**
Agricultural Raw Material	2.4	0.2%	2.3%	9.3	0.9%	7.8%
Food	11.9	1.1%	3.1%	7.9	0.8%	2.0%
Fuel	6.9	0.7%	1.2%	18.2	1.7%	3.0%
Manufactures	193.8	18.3%	4.5%	150.3	14.2%	3.4%
Ores and Metals	4.2	0.4%	2.6%	11.2	1.1%	6.1%
Other	0.5	0.0%	0.3%	1.5	0.1%	1.0%

Source: World Development Indicator 2005 (World Bank, 2005)

[2] In this section, all financial figures are in constant 2000 USD.
[3] Note that in this chapter and in those following , data for a given historical year (e.g., 2000) may have been taken from different sources. Identical parameters for the same year may therefore differ in different sections.
[4] Industry includes mining, manufacturing, construction, electricity, water and gas (World Bank, 2005).
[5] Services include wholesale and retail trade (including hotels and restaurants), transport, and government, financial, professional, and personal services such as education, health care, and real estate services (World Bank, 2005).
[6] Agriculture includes forestry, hunting, fishing, cultivation of crops, and livestock production (World Bank, 2005).
[7] Trade in goods as a share of GDP is the sum of merchandise exports and imports divided by the value of GDP, all in current U.S. dollars.

In 2006, China is expected to produce 3.8 million barrels of oil per day (bbl/d), and consume 7.4 million bbl/d.[8] China will thus continue to rely on imports to meet nearly half (3.6 million bbl/d) of its total demand. The US Energy Information Administration also forecasts that China's increase in oil demand in 2006 will represent 38 percent of the world total increase. Angola and Saudi Arabia are China's two largest oil suppliers, with Iran, Russia and other Middle East and African countries supplying most of the remainder.

In terms of financial flow, net foreign direct investment (FDI)[9] of $33 billion accounted for about 3% of China's GDP in 2000, almost exclusively driven by the FDI inflows. FDI inflows have grown in recent years along with China's rapidly growing GDP, reaching up to over 48 billion USD in 2004 and remaining at 3% of its GDP. With portfolio and other investment inflows and outflows, the total private capital flow accounted for 11.4% of its GDP, which is less than half of the world's gross private capital flow at 28.4% of its GDP.[10] Official development assistance and official aid[11] accounted for a very little part of the financial flow in China (only 0.1% of the GDP in 2000).

Table 2.3. Key statistics of financial flow in and out of China in 2000

	Foreign Direct Investment					Gross Private Capital Flows	Official Development Assistance and Official Aid	
	Net	Net inflows		Net outflows				
	BoP*, Billion US$	BoP*, Billion US$	% of GDP	BoP*, Billion US$	% of GDP	% of GDP	Billion US$	% of GDP
China	33.0	33.9	3.2%	0.8	0.1%	11.4%	1.5	0.1%
World	134.7	1,335.5	4.9%	1,200.8	4.3%	28.4%	51.4	0.2%

*BoP: Balance of Payment

Source: World Development Indicator 2005 (World Bank, 2005)

II.A.3 Geography

Despite the robust growth of its economy, China is suffering a bigger and bigger disparity between its rural and urban areas.

- Urban-rural income gap

A survey conducted by the Economic Research Institute of the Chinese Academy of Social Sciences shows that the income gap between rural and urban residents in China has kept growing in the past five years, and China has become one of the countries with the largest urban-rural gap in the world. A report based on the nationwide survey shows that the average income per capita of urban residents was 3.1 times that of farmers in 2002, much higher than 2.8 in 1995. Statistics show that in 2003, the income of farmers in China averaged 2,622 yuan (US$316.67) while that of urban residents averaged 8,500 yuan (US$1,026.57), more than three times that of their rural counterparts. However, even this does not tell the real disparity between urban and rural citizens. The income of urban citizens concerned does not count the welfare they have access to, including medical care, unemployment insurance and minimum living relief. Most farmers have no access to these. What's more, they have to pay the educational cost themselves while the central government covers most of such costs for urban residents. With all these factors concerned, the urban residents' income should be four, five or even six times of that of the rural residents.

[8] Energy Information Administration, US Department of Energy. Country Analysis Briefs: China. http://www.eia.doe.gov/emeu/cabs/China/Background.html

[9] Foreign direct investment (FDI) are the net inflows of investment to acquire a lasting management interest (10 percent or more of voting stock) in an enterprise operating in an economy other than that of the investor. It is the sum of equity capital, reinvestment of earnings, other long-term capital, and short-term capital as shown in the balance of payments (World Bank, 2005).

[10] Gross private capital flows are the sum of the absolute values of direct, portfolio, and other investment inflows and outflows recorded in the balance of payments financial account, excluding changes in the assets and liabilities of monetary authorities and general government. The indicator is calculated as a ratio to GDP in U.S. dollars.

[11] Net official development assistance (ODA) consists of disbursements of loans made on concessional terms and grants by official agencies of the members of the Development Assistance Committee (DAC), by multilateral institutions, and by non-DAC countries to promote economic development and welfare in countries and territories in part I of the DAC list of recipients (World Bank, 2005).

- Migration issues

Rural- urban labor migration in China nowadays is becoming one of the most obvious as well as influential social factors which is profoundly changing the current system and the society as a whole. There were approximately 120 million rural-urban migrants in 2002, a number exceeding the total population of most countries.

The resulting migration wave has alarmed both urban governments and the central government of China. Local host governments have become negative or even hostile toward migrants who pour into the cities. Urban leaders have questioned how the migrants could be accommodated by infrastructure facilities already under extreme pressure. Concerns about the high urban crime and fertility rates in the cities have been exacerbated, as migrants are thought to disproportionately contribute to both. Government leaders also have worried about how to pacify potential resentment between migrants and urbanites who view migrants as competitors in the job market.

II.A.4 Poverty and Development

The poverty of China's rural areas is a problem that arose over long years in the past. Alleviating and eliminating poverty remains a long-term historical task for China. The development-oriented poverty alleviation drive in rural China early in the 21st century is a rare historical opportunity, but it still faces serious challenges and problems.

China today is blessed with many favorable conditions, some of them much more favorable than in the past, in its poverty alleviation drive. Great attention has been paid to the work by governments at various levels; support has been given by all sectors of society; and the cadres and ordinary people of the poor regions are working hard with one heart and one mind. These are the most important conditions for guaranteeing the steady progress of the work.

The main difficulties and problems for China in the early period of the 21st century in the field of poverty alleviation are as follows: First, though the income of the poverty-stricken people has been obviously improved, the current standard for poverty relief in China is very low. Second, restricted by unfavorable natural conditions, weak social insurance system and their own poor comprehensive ability, the people who now have enough to eat and wear may easily sink back into poverty. Third, although the development-oriented poverty reduction drive has greatly changed the poverty and backwardness of the vast impoverished rural areas, there has been no qualitative change either in the basic production and living conditions of the poverty-stricken peasant households, or in the social, economic and cultural backwardness in those areas. Fourth, because of its large population, China will face employment pressure for a long period to come. This pressure is bound to adversely affect the employment of the impoverished population, so much so that many effective aid-the-poor measures will not play the roles they should play. Fifth, people who still do not have enough to eat and wear generally live in areas with adverse natural environments, a low level of social development and underdeveloped social services, where the contrast between input and result is very sharp.

China is a developing country, and it has a long way to go to shake off poverty. The basic solution of the problem of food and clothing of the poverty-stricken population in rural areas is the result of only one phase in the country’s effort to accomplish this historic task. Subsequently, it will still take a long period of hard work to enable the people in the poor areas to first live a comfortable life and then a well-off life. With the progress of the reform and opening-up and the modernization drive and the steady increase of China's comprehensive national strength, our development-oriented poverty reduction program for the rural areas is bound to be crowned with new success.

II.A.5 Sustainability and Development

With the rapid development benefiting from its reform and opening policy in the past decades, China is going to have more and more significant impacts upon world sustainability. It will also play an increasing role in the world economy and politics along with the process of globalization.

The Chinese government has just publicized the Program of Action for Sustainable Development in China in the Early 21st Century. This Program, based on past achievements and experience and taking into account new requirements for sustainable development in the new century, specifies the objectives, principles, priority areas and safeguard measures for the country's sustainable development in the early 21st century.

After a decade of efforts, China has achieved remarkable progress in sustainable development.

- Economic development

China has maintained sustained, rapid and healthy growth of its economy. As a result, the country's overall national strength has built up considerably, with its GDP exceeding 1 trillion US dollar. China today is the largest recipient of direct foreign investment in the developing world and the sixth largest trading power in the world. People's livelihood and quality of life have witnessed significant improvement. Furthermore, economic growth is increasingly based on more sustainable ways, relying on enhanced efficiency rather than greater input of resources. The economic structure is being gradually optimized.

- Social development

The trend of excessive population growth has been checked; science, technology and education have made positive headway; and remarkable progress has also been made in social security, poverty eradication, disaster relief and prevention, medical care, and narrowing the regional gap in development.

- Ecological conservation, environmental protection and rational exploitation of resources

The central government has greatly increased spending in ecological conservation and environmental protection; the pattern of energy consumption is being gradually optimized; measures for controlling water pollution have been stepped up for key water systems; breakthrough progress has been made in curbing air pollution; comprehensive use of resources has significantly improved; and the ecological environment has improved to some extent thanks to retiring fragile farmlands and switching them to conservation purposes, such as planting trees and grass, and expanding floodwater storage.

- Capacity-building for sustainable development

The strategy of sustainable development has been incorporated into various programs and plans by central government ministries and local governments. Public awareness of sustainable development has markedly increased, and relevant laws and regulations have been enacted and enforced.
Since the promulgation of the first Environmental Protection Law in 1979, China has adopted and enacted more than 20 statutes on pollution control, natural resource conservation, and human health and safety. In addition, dozens of regulations, procedures and initiatives, as well as hundreds of standards have been passed. Most recently, the Air Pollution Control and Prevention Law had been amended, the Environmental Impact Assessment Law had been into effect in 1st September, 2003, and was followed by another statute, and the Clean Production Law.

However, China still faces quite a few challenges in implementing sustainable development. The greatest challenges are: a conflict between rapid economic growth and voluminous consumption of resources and ecological deterioration; social development lagging behind economic development; widening disparities between different regions in social and economic development; constraints posed by a large population and scarce resources; and inconsistencies between some existing laws, regulations and policies and actual needs for sustainable development.

Major problems urgently needed to be resolved include: the comprehensive quality of life of the population needs improvement; aging of the population is accelerating; the social security system is inadequate; the pressure on employment is heavy; the economic structure is less than rational; the operation system of the market economy needs to be improved; clean energy has a low share in the

total energy consumption; infrastructure is under developed; the information infrastructure for the national economy is of a low level; a serious level of waste exists in the exploitation of natural resources; environmental pollution is serious; ecological deterioration is still not curbed; legislation on resources management and environmental protection needs improvement.

With increasing globalization of the world economy, the international community is enhancing its understanding of and stepping up its efforts for sustainable development and common development. China should, after its accession to the WTO, give full play to the advantage of its socialist market economic system. In particular, China should give full play to the role of government in organizing and coordinating the implementation of the sustainable development strategy and properly handle the relationship of economic globalization and sustainable development. China should also, based on the achievements of the Johannesburg world summit on sustainable development, actively participate in international cooperation, and safeguard the country's fundamental interests, including its economic and ecological security.

China is facing contradictions and problems in the course of the rapid economic development over the years, such as the widening gaps between urban and rural areas, among different regions, the pressure of higher unemployment rate and lack of a sound social security network. Such issues have further been compounded by population expansion, escalation of conflicts between economic development and ecological environment and natural resources, a backward mode of economic growth, poor performance and low competitiveness of the overall economy. Having fully thought over the dilemma situations, the new leadership group, headed by President Hu Jintao, has brought forward the new Scientific Development Concept to implement a series of sound actions.

The scientific concept of development, with the goal of building a well-off society by 2020 and the modernization of China by 2050, calls for "people-centered development, which is comprehensive, coordinated and sustainable, for the promotion of overall harmonic development of economy, society and human beings."

It also stresses "coordinated development between urban and rural areas, among different regions and between economic and social development, harmony between human beings and nature and coordination of domestic development and opening to the outside world" as means of pushing forward reform and progress.

II.A.6 Country's Role to Date in Climate Policy Negotiations

Since the end of the 1980s, when climate change was brought to the global political agenda, China has gone from generating a surplus of energy to becoming an importer of oil. The change is a symptom of a rapidly industrializing nation and comes hand-in-hand with many of the signs of a nation already suffering from the effects of climate change.

Recent figures show that China is the second most important emitter of greenhouse gasses in the world, after the United States. Research shows that its population and environment are likely to suffer the effects of extreme weather events made more frequent by climate change, that rising temperatures and changing rainfall will affect food production and that energy consumption — a major source of emissions — will continue to rise over the coming decades.

Yet China, as a developing nation, is not bound to limit its emissions under the Kyoto Protocol, and will not do so at the expense of its development. The government says developed nations must bear the responsibility for historical rises in concentrations of greenhouse gases in the atmosphere. Despite this, the Chinese government is aware of the complexities and effects of climate change. Although its primary motivation is not to align itself with international climate change policy, it is adopting measures to diversify its sources of energy and to increase energy efficiency, which could slow the steep rise of its emissions.

At the international level, China saw climate change negotiations as an integral part of its foreign policy, and a terrain on which it, and other developing countries, would need to protect development rights and opportunities.

China has responded positively to international initiatives to reduce greenhouse gas emissions, such as carbon capture and renewable energy development. In the forthcoming post-Kyoto negotiations, China is likely to be more flexible and open to international cooperation. Although China labels itself a developing country, the image it wishes to cultivate — of a large and responsible country — will probably make it more flexible in international negotiations.

II.A.7 National and Sectoral GHG Emissions and Global Contribution

Among non-Annex I countries, China is the largest emitter of GHGs.[12] The People's Republic of China Initial National Communication on Climate Change reports that China's GHG emissions in 1994 were 3,650 $MMTCO_2e$, 73% from CO_2. With a population of nearly 1.2 billion, per capita emissions were 3.0 $MTCO_2e$ in that year, less than half the global average. Thus, although large in absolute terms, China's per capita emissions continue to be low. In 2000, China accounted for about one-seventh of the global and less than one-third of the non-Annex I country GHG emissions. CO_2 emissions in 2000 were estimated at 3,090 million metric tons CO_2 ($MMTCO_2$), in large part contributed by the electricity sector.

On a sectoral basis, electricity generation in China accounts for about 40% of national CO_2 emissions, as well as 15% of global and 40% of the non-Annex I electricity sector emissions. China's industrial sectors, most notably cement and iron and steel, are also significant emitters and account for major shares of sectoral GHG emissions globally. In 2000, the Chinese cement sector (including electricity use) accounted for one-fifth of domestic CO_2 emissions and contributed 36% of global and 56% of non-Annex I cement sector emissions; the 10% of national CO_2 emissions from China's iron and steel sector accounted for 30% of global and almost two-thirds of non-Annex I emissions in that sector.

II.B Historical summary & explanation of China' national energy and emissions profile

II.B.1 Total annual fuel consumption by sector and fuel type

Table 2-1.China's fuel consumption by sector/PJ

Year	farming, forestry , animal husbandry, fishery and water conservancy	industry	construction	transport, storage, post and tele-communication service	wholesale and retail trade and catering services	residential consumption	others	total
1990	1421	19812	355	1331	366	4631	1017	28927
1993	1401	23798	387	1638	560	4601	1594	33997
1994	1498	25762	396	1650	542	4513	1624	35961
1995	1615	28194	393	1717	592	4631	1325	38452
1996	1676	29396	425	1756	665	5188	1606	40738
1997	1732	29337	346	2210	700	4807	1377	40504
1998	1697	27667	472	2418	747	4220	1527	38745
1999	1709	26612	404	2708	824	4279	1612	38130
2000	1697	26260	419	2907	847	4367	1676	38188

[12] Includes CO_2 and other greenhouse gases.

Table 2-2. China's fuel consumption by fuel type

Year	Total consumption(PJ)	Share(%)			
		Coal	Oil	Gas	Hydropower
1990	28927.00	76.2	16.6	2.05	5.14
1991	30416.72	76.1	17.1	2.00	4.80
1992	31995.54	75.7	17.5	1.90	4.90
1993	33997.28	74.7	18.2	1.90	5.20
1994	35960.92	75.0	17.4	1.90	5.70
1995	38452.10	74.6	17.5	1.80	6.10
1996	40738.12	74.7	18.0	1.80	5.50
1997	40503.66	71.5	20.4	1.80	6.30
1998	38745.18	69.6	21.5	2.20	6.70
1999	38129.71	68.0	23.2	2.20	6.60
2000	38188.32	66.1	24.6	2.50	6.80

II.B.2 Energy intensity (per unit of GDP) from 1990 to 2000

China has changed dramatically since the country adopted liberalization and economic reforms in the late 1970s. Growth of nation's economy and improvement of living standards for over two decades results in great energy consumption.

Table 2-3.Energy consumption and energy consumption intensity of China

Year	Energy consumption（PJ）	Energy consumption intensity(GJ/$)
1990	28927.88	0.13
1991	30416.72	0.12
1992	31995.54	0.10
1993	33995.23	0.08
1994	35971.76	0.06
1995	38445.06	0.05
1996	40722.88	0.05
1997	40385.84	0.04
1998	38749.28	0.04
1999	38135.28	0.04
2000	38187.44	0.04
2001	39540.3	0.03
2002	43440.9	0.03
2003	49178.82	0.03

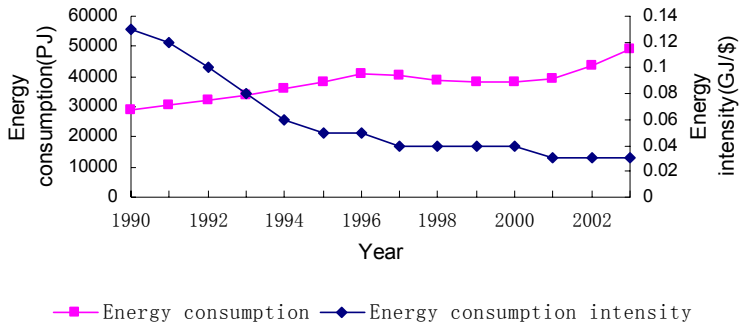

Figure 2-1.Energy demand and energy intensity of China
Source: China Statistical Yearbook 2003

China's energy demand kept growing till middle 90s mainly for two reasons:

The first, there has been a general shift in the structure of the economy away from primary to higher value-added products, and to a less degree from energy-intensive heavy industries to light industry and service sectors.

The second, older generating equipments are retired and more efficient power plants are introduced. Actually, for two decades energy use has grown only half as fast as the economy. From 1980~2000, the amount of energy consumption has only doubled while China's gross domestic product (GDP) has been quadrupled. But after 2000, especially from 2004, this trend of energy intensity has reversed. Table 2-4 shows energy consumption elasticity of China from 1990 to 2004[13]. From 2002, the energy consumption elasticity is more than 1. So China faces the challenge of maintaining economic growth with lower energy intensity.

Table 2-4. China's ΔE/ΔGDP

China's ΔE/ΔGDP	
1990	0.48
1991	0.56
1992	0.37
1993	0.45
1994	0.44
1995	0.63
1996	0.59
1997	-0.09
1998	-0.52
1999	-0.21
2000	0.02
2001	0.43
2002	1.08
2003	1.53
2004	1.51

Source: China Statistical Yearbook, 2005

For the recent increasing trend in energy consumption, increased coal consumption plays the most important role, as Figure 2-2 shows.

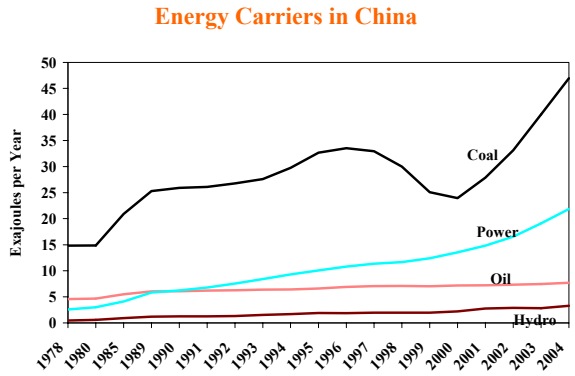

Figure 2-2.Energy carriers in China
Source: China Statistical Yearbook, 2005

[13] Data from 1997 to 2000 is odd, and may be a statistical problem.

II.B.3 Annual GHG emissions inventory for 2000

Table 2-5.China's Carbon Dioxide Emission by Source (Million Tonnes of Carbon)

	Fossil Fuels					Total
Year	Coal	Oil	Gas	Subtotal	Others	Emissions
2000	498.7	164.2	17.6	761.6	81.2	842.8
Share%	59.17	19.48	2.09	90.37	9.63	100%

II.B.3.i <u>Total national GHG emissions/sequestration by sector</u>

When accounting CO_2 emissions for cement and iron and steel, we should calculate both emissions from energy activities and industrial process. Asterisk implies emissions from electricity that is consumed at the same site or plant where it is generated, and not transmitted across the local grid. CO_2 emissions and the respective shares for each sector in 2000 are shown in the table and pie chart below.

Table 2-6.Structure of China's CO2 emission in 2000

Target Sectors	Electricity	Iron &Steel	Cement	Pulp &Paper	Transportation
CO_2 Emission ($MtCO_2$)(2000)	256.65*/1199	351.53	678.4	62.67	195.2

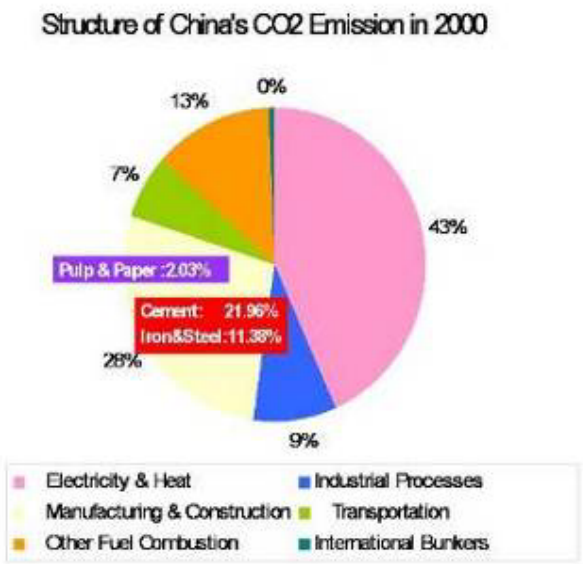

Figure 2-3. Structure of China's CO2 emission in 2000

II.B.4 Emissions Intensity (per unit of GDP and per capita) from 1990 to 2000

Table 2-7. Emission intensity from 1990 to 2000

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Per unit of GDP emission (tCO2/thousand dollars)	11.17	10.13	8.69	7.10	5.61	4.86	4.37	3.94	3.57	3.14	2.86
Per capita emission(tCO2)	2.09	2.16	2.24	2.35	2.46	2.64	2.71	2.64	2.49	2.24	2.20

Note : Current value
Source: Carbon Dioxide Information Analysis Center, 2002.

II.C Comparison with rest of world above areas

II.C.1 Ranking

Recent figures show that China is the second most important emitter of greenhouse gasses in the world, after the United States.

II.C.2 Qualitative similarities and differences

Table 2-8.Carbon Dioxide Emissions from Fossil Fuel Combustion, Cement Production (MtC)

Year	China	India	Japan	USA	FSU [1]	Total
1990	683	194	304	1,327	1,013	6,327
1991	722	207	310	1,325	977	6,426
1992	763	221	313	1,328	554	6,297
1993	810	230	307	1,406	504	6,311
1994	865	244	321	1,431	435	6,481
1995	937	257	323	1,433	418	6,632
1996	979	285	332	1,455	411	6,790
1997	968	292	330	1,502	394	6,897
1998	924	302	320	1,514	387	6,890
1999	849	307	326	1,516	392	6,742
2000	843	306	334	1,542	398	6,869

II.D Background for overall analysis

II.D.1 Discussion of all cross-cutting macro assumptions used and sources for assumptions

- *Population*:

As Family Plan was carried out from 1980s, the growth rate of Chinese population slowed down after the previous increase before 1987, with peak annual growth of 16.61%. In this project, we assume the annual growth rate of Chinese population will decrease year by year, and the population will reach 1.52 billion till 2030 (see table).

Table 2-9. China's population assumptions in the analysis

Year	2000	2005	2010	2015	2020	2030
Annual growth ratio	7.85‰		6.5‰		4.4‰	
Population（billion）	1.267	1.31	1.35	1.40	1.45	1.52

- *GDP*

It is said China's GDP in 2020 will quadrupled as it is in 2000 considering the Report of 16th Party Congress. We refer to a series of literature on Chinese energy and carbon scenarios and assume China's GDP will maintain the fast growth of the 1990s, so the annual growth rate is set at 7.5% during 2000 to 2010. Then the growth rate will slow down, with the annual growth rate is set at 6.5% during 2010 to 2020, and 5.5% during 2020 to 2030.

Table 2-10.China's GDP Assumptions and electric sectoral production in the Analysis

year	2000	2005	2010	2015	2020	2030
Annual growth ratio	7.5%		6.5%		5.5%	
GDP（billion dollar）	1080.7	1551.53	2227.44	3095.7	4181.19	7142.09

- *Policies scenarios*

We utilize LEAP model to analyze the abatement potentials, which is driven by a set of assumptions and scenarios which can be defined in this project as reference baseline scenario, recent policy scenario and new policy scenario.

- *Baseline scenario pre 2000*

The baseline scenario pre 2000 employed here is a conservative projection of China's energy intensive sectors' future that closely tracks previous Chinese forecasts. The scenario assumes that sector's relative policies will not change radically compared to the situations before 2000, although some technologies are projected to improve gradually. It is the least technology advanced scenario among the three.

- Baseline scenario between 2000 and 2005

In Baseline scenario between 2000 and 2005, we will evaluate projected emissions using combination of measures and policies in place before the end of 2005, and taking into account the Report of 16th Party Congress, the Tenth Five-Year Plan as well as relative industrial long term development policies and plans. The policy takes more consideration for environmental protection issues. The step of scale enlargement and technology advancement of present plants is faster than that in upper scenario.

- *Mitigation scenario*

The new policy scenario emphasizes sustainable development most, and even takes account of climate change issues. Here we assume a relative radical phase that China invests a lot to adopt more advanced technologies with lower energy intensity and less consideration of financing or technical barriers.

We change technology combination structures in the three scenario creations basing on expert consultation and literature survey to directly reflect the impacts of different policy tendencies. Implemented policies and measures will be discussed in each sector section in details.

- *Baseline setting for mitigation potential calculation*

Mitigation scenarios are compared to the Pre-2000 baseline. It should also be noted that China has already realized the significance of sustainable development issues; a series of statutes has been promulgated to guarantee environmental protection in China, dozens of regulations, procedures, and standards focusing on environmental issues have been passed and take substantial effect until 2005. Their impact can be seen in the scenario simulating the trend under policies undertaken through 2000 to 2005 (recent policy scenario).

It is important to be noted that at the early year of 2006, China promulgate the 11th Five Year Plan. The object of the 11th Five Year Plan is to double the GDP per capita in 2010 from the 2000 level while reducing energy consumption per unit of GDP by 20% in 2010 from the 2005 level .But it was not assumed in either of the baselines.[14] If it is included in scenario definition, the energy consumption of two baseline scenarios will be lower because this objective is very ambitious. The primary energy consumption sectors such as electricity and steel industry will be adjusted.[15]

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[14] The energy conservation objective from the 11th Five Year Plan in China is also being disputed..

[15] During the "11th Five-Year Plan Guidelines", adjustment of the industrial structure is the main task and is significant for energy conservation objective. It includes two-layer meanings: One is raising the level of industrial technology, The "Proposal" points out: To realize the adjustment of the industrial structure, "the key is to comprehensively enhance independent innovative capability, strive to master core technology and key technology, strengthen ability for the transformation of scientific and technological achievements and improve the overall technological level of industry". Second is developing key industries. The "Proposal" points out that the important tasks for adjustment of the industrial structure is to develop advanced manufacturing industry, increase the proportion of the service trade and strengthen infrastructure construction for basic industries.

It suggests policy support to boost localization of major technological equipment, especially breakthroughs in high-efficient and clean power generating units and transmission equipment, large petrochemical installations, advanced transportation equipment, high-grade numerical-control machine tools, equipment for automatic control and integrated circuits, and advanced power devices.

The principle of the 11th Five-Year Plan is consistent with our scenario analysis including industrial restructure and technology advancement. If it works out as planned the scenario definition in our analysis will be more feasible because the objective of the plan and mitigation scenario will be overlapped. But the specific impact of the plan on our analysis especially electricity, steel, transport need more meticulous analysis.

- *Other assumptions*

Exchange rate:1 US dollar=8.27 RMB
Discounting rate=10%

II.D.2 Analytical approach and methodology used

Developing a national abatement strategy requires a macro perspective of the principal options for GHGs abatement. It also requires specific information on the associated costs and potentials of individual GHGs abatement initiatives. The costs associated with the increasing supply of a given GHGs abatement initiative can be illustrated by its Marginal Abatement Cost (MAC) curve. MAC curve provides the different marginal abatement costs for all GHGs abatement initiatives in the sector.[16] By evaluating the sector MAC curves, a national strategy can be developed that selects various levels of different GHGs abatement options so as to yield a promising set of GHGs abatement initiatives.

II.D.3 Computer models and other tools used

LEAP model is a scenario based energy-environment accounting tool developed by the Stockholm Environment Institute-Boston.[17] LEAP has been used in previous research to conduct technology-level bottom-up analysis to estimate China's electricity sector future energy consumption and production with given alternative assumptions on economic development, technology, price and so on. In this project, we build up sophisticated simulations and data structures concerning the electricity sector's technology levels, energy demand, cost and corresponding CO_2 emission information. The scenario analysis time extension covers through 2000 to 2030 with 2000 as the baseline year.
The logical operating framework in LEAP model is described in Fig. 2-4, which can be summarized as five steps: sectoral production projection, corresponding energy demand, CO2 emissions, total costs, energy savings and CO2 abatement potentials calculation.

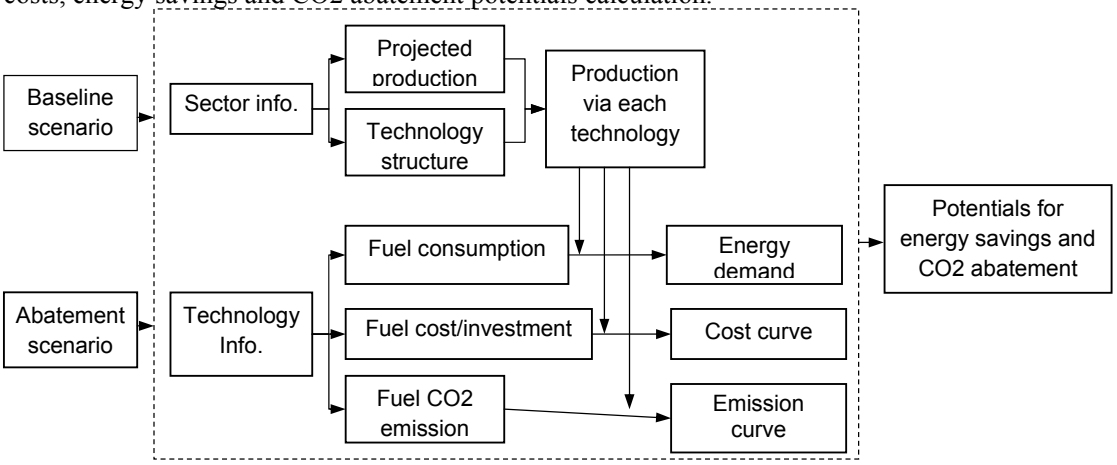

Figure 2-4. Logical operating framework for LEAP model

- Sectoral production

Sectoral production is projected consistent with historical generation data and China's economy development trend.[18] Technology structures are set basing on available data collection with adjustments according to policy tendencies we would like to emphasize in different scenarios. Basing on the above information, we get the separated production via each technology

$$P_{i,j} = P_j \times \tau_{i,j} \qquad (1)$$

[16] Methods for Developing Cost of Emission Reduction Initiative (CERI) Curves
[17] Stockholm Environment Institute, Tellus Institute. LEAP:Long Range Energy Alternatives Planning System,User Guide for LEAP 2005[EB/OL]. http://forums.seib.org/leap/documents/Leap2005UserGuideEnglish.pdf
[18] China Statistics Bureau. China Statistics Yearbook 2004□M□.Beijing :China Statistics Press, 2004. (in Chinese)

P_j is sectoral production in year j, $\tau_{i,j}$ is the production share of technology i among the total output in year j, $P_{i,j}$ is the separated production by technology i in this year.
With additional investigated parameters,[19] such as fuel consumptions, cost and CO2 emission factors, investment and operating cost for each kind of plants, we can calculate projected sectoral energy demand, costs, and CO_2 emissions in the target time extension.

- Energy demand

$$E_j = \sum_n \sum_i e_{n,i,j} \times P_{i,j} \qquad (2)$$

E_j is the total energy demand for sector in year j, $e_{n,i,j}$ is the energy consumption of fuel type n used in technology i for unit production.

- CO_2 emission

$$CE_j = \sum_n \sum_i f_{n,i,j} \times e_{n,i,j} \times P_{i,j} \qquad (3)$$

CE_j is total CO_2 emission of sector in year j, $f_{n,i,j}$ is CO2 emission factor of fuel type n through technology i for unit production.

- Costs

$$C_j = \sum_i \left[(\sum_n (e_{n,i,j} \times p_{n,j}) + fc_{i,j}) \times P_{i,j} \right] \qquad (4)$$

C_j is the total costs for sector in year j, $p_{n,j}$ is unit price for fuel n in year j, $fc_{i,j}$ is fixed price for unit production.

- Energy savings and CO_2 abatement potentials

By comparing the results driven by different scenarios, we acquire the energy saving potentials and CO2 abatement potentials in any target year or during the whole target period which will be input data in the next step marginal cost curve analysis.

II.E List of sectors to be covered in analysis

We choose five energy intensive sectors as analytical targets: electricity, iron & steel, cement, pulp & paper, transportation. Electricity sector, which plays the leading role of energy conversion and supply, is the largest CO_2 emitter in China. Iron & steel sector is one of the most important energy intensive industrial sectors, and contributes ten percent of the country's total CO_2 emission. Cement sector is important, with its CO_2 emissions coming from limestone decomposition in production process almost equal with fuel consumption. Pulp & paper causes severe water pollutions. Environmental co-benefits can be realized through sector's energy efficiency improvement and CO_2 emission reduction. Transportation has huge potential and soon will become large energy consumer and CO_2 emitter.

[19] HU Xiulian, JIANG Kejun, et al. Evaluation of Technology and Countermeasure for Greenhouse Gas Mitigation in China□M□.Beijing: China Environmental Science Press, 2001. (in Chinese); and ZHOU Dadi, et al. China Sustainable Energy Scenarios in 2020 □M□. Beijing: China Environmental Science Press,2003.（in Chinese）

III. Sector Analysis and Results: Electricity

III.A Sector Overview

III.A.1 Summary

III.A.1.i Total Output/Production

Table 3-1.China's Electric Power Output

	Installed Capacity（GW）	Power Generation（TWh）
1990	137.89	621.3
1991	151.47	677.5
1992	166.53	754.2
1993	182.91	838.4
1994	199.89	913.8
1995	217.22	994.2
1996	236.54	1065
1997	254.24	1119.8
1998	277.29	1143.1
1999	298.77	1217.6
2000	305.14	1368.5
2001	338.61	1470.6
2003	391.40	1905.2
2004	440.70	2187.0
2005*	508.41	2474.7

Data resource: Electricity statistics year book 2005; I* presentation from Zhaoyong of Current Status of Electric Power Sector in China on March 26, 2006. Beijing.

China's electric power industry has developed very rapidly over the past two decades as a result of economic development and rising incomes. Total national installed capacity increased from 69.13 gigawatts in 1981 to 508.41 gigawatts in 2005, an average annual growth rate of 8.7%. From Figure 3-1, readers can see that tremendous growth occurred after 2000. Both the installed capacity and power generation goes beyond the historical trend before 2000. If we make generation projections according to the development trend between 2000 and 2005, the analysis results will be much more aggressive. So we make modest assumptions tracking the previous trend before 2000 in this project. The capacity and generation assumptions may be more conservative compared to the actual value between 2000 and 2005.

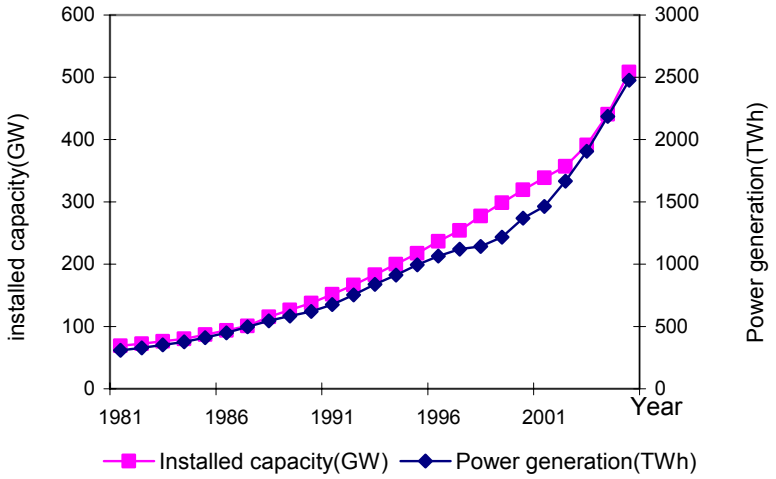

Figure 3-1.Development of China's electric power system

III.A.1.ii Revenues, share of GDP

China's system for power tariffs is both complex and economically inefficient. Both producer and consumer tariffs are based on Catalogue Prices which are approved by the central government. For each locality these define the tariff for eight or more classes of users, at three different voltages. Provincial and local governments levy further charges. The details of the tariff system and extensive discussion of its weaknesses have been documented elsewhere (World Bank, 1994; Shao et al., 1997; Andrews-Speed et al., 1999). The most important deficiencies are:

The power generators as a whole are not receiving consistent incentives to reduce costs because no procedures for a merit order exist.

III.A.1.iii Role of sector in overall economy as source of inputs to other sectors

Between 1996 and 2000, the 9th Five-Year period, electricity demand grew at an average of 6.3 percent annually. It is expected to exhibit an average annual growth rate of 5 percent during the 10th Five-Year period (2001–05). As is shown in Table 3-2, total electricity consumption in 2002 was 1,620 TWh, which was a 10.3 percent increase from consumption of 1,468 TWh in 2001. With the economy growing at a rapid pace thanks to economic reforms, the industrial sector consumed the most electricity of all sectors in 2002, accounting for 72 percent of total consumption. By contrast, the primary sector was a distant second at 4.8 percent.

Table 3-2.Total Electricity Consumption by Sector

	2002(TWh)	2001(TWh)	Growth Rate(%)	2002 Share(%)
Total Consumption	1620	1468	10.3	100.0
Industry	1422	1284	10.7	87.8
Industrial	1167	1049	11.2	72.1
Light	252	221	14.0	15.6
Heavy	915	827	10.5	56.5
Agriculture & Fishery	78	76	2.4	4.8
Construction	16	14	10.3	1.0
Transportation	33	29	12.6	2.0
Service	52	45	14.0	3.2
Other	76	69	8.9	4.7
Residential	198	183	7.7	12.2
Urban	114	106	6.9	7.0
Rural	84	77	8.7	5.2

Source: State Power Corporation (totals may not add due to rounding)

III.A.1.iv Role in exports, international trade

China's energy sector is self-sufficient. Exports and imports of energy products are small compared to overall consumption, although the amount of imported oil and gas products and exported coal are expected to rise. China’s self-sufficiency strategy has led it to depend heavily on coal for national energy needs.

III.A.2 Quantitative and qualitative characterization of sector

III.A.2.i **Power plants by fuel type in year 2000**

Table 3-3.Annual breakout by fuel type electricity sector in 2000

Fuel	Number of Plants (or generator units)*a	Capacity (MW)*a	Share of Total Sector Capacity (%)	Generation (TWh)*a	Share of Total Sector Generation (%)	CO2 Emissions (million metric tons)*b	Share of Total Sector CO2 (%)	Average Efficiency (%)	Average CO2 Intensity (kg CO2/kWh)*b
Coal	3546	212780	69.73%	1038.1	75.90%	1156.8	96.49%	35 ~ 45%	1.11
Gas	127	5118	1.68%	27.37	2.00%	13.0	1.08%	40 ~ 58%	0.47
Oil	497	5415	1.77%	41.1	3.00%	29.1	2.43%	45 ~ 50%	0.71
Thermal Plants Subtotal	4170	223313	73.18%	1106.57	80.90%	1198.9	–	–	–
Hydro	1209	79352.2	26.01%	243.134	17.80%	–	–	60 ~ 80%	–
Nuclear	11	2100	0.69%	16.7	1.20%	–	–	25 ~ 35%	–
Wind	530* (data in1998)	375.2	0.12%	0.5	0.04%	–	–	10 ~ 20%	–
Other Renewable	-	-	-	1.46	0.10%	–	–	5 ~ 15%	–
Total		305140.4	100%	1368.5	100%	1198.9	100%		

Data resource:*a Electricity statistic year book 2005; *b calculated results from LEAPChina model;*c data from internet: http://finance.sina.com.cn/stock/e/20050328/18481466678.shtml

III.A.2.ii Table with breakdown of facilities by range of average CO2 intensity

Table 3-4. Distribution of coal-fired plants by CO2 intensity in 2000 *

CO2 Intensity Range (metric ton/TWh)	Number of Plants/Units	Total Capacity (MW)	Share of Total Capacity (%)	Total Annual Generation (TWh)	Share of Total Generation (%)	CO2 Emissions (million metric tons)	Share of Sectoral total CO2 (%)
>1.25	2415	37405	17.58%	79.9	7.70%	109.1	9.10%
1.20-1.25	355	53934	25.35%	64.4	6.20%	81.4	6.79%
1.0-1.20	514	36598	17.20%	354.0	34.1%	438.8	36.60%
<1.0	262	84835	39.87%	539.8	52.0%	527.5	44.00%
Total	3546	212780	100%	1038.1	100%	1156.8	96.49%

* Estimated from data from Table 3-3 and results from LEAPChina model.

III.A.2.iii Table with breakdown of facilities by range of production capacity

Table 3-5.Electricity capacity range Distribution of coal-fired power plants by capacity in 2000*

Unit Capacity Range (MW)	Number of Plants/Units	Total Capacity (GW)	Share of Total Capacity (%)	Total Annual Generation (TWh)	Share of Total Generation (%)	CO_2 Emissions (million metric tons)	Share of Sectoral Total CO2 (%)	Average CO2 Intensity (kg CO2/kWh)
>600	20	22129	10.40%	130.8	12.60%	113.9	9.50%	0.87
300-600	242	62706	29.47%	409.0	39.40%	413.6	34.50%	1.01
200-300	193	36598	17.20%	189.5	18.25%	232.6	19.40%	1.23
100-200	321	33641	15.81%	164.5	15.85%	206.1	17.19%	1.25
50-100	355	20293	9.54%	64.4	6.20%	81.5	6.80%	1.27
<50	2415	37405	17.58%	79.9	7.70%	109.1	9.10%	1.36
Total	3546	212780	100%	1038.1	100%	1156.8	96.49%	1.11

* Estimated from data from Table 3-3 and results from LEAPChina model.

III.A.2.iv In-depth discussion and explanation of above breakdowns

China is making efforts to close thermal power plants with a unit capacity of 50 megawatts or less to improve efficiency, reduce pollution, and stabilize the power supply system. Many recently built coal plants have relatively high efficiencies because Chinese policy requires new coal-fired units to be 300 megawatts or larger to improve efficiency. Domestically manufactured 300-megawatt and 600-megawatt sub-critical and super critical units are becoming the backbone of the generation system. This stands in contrast to the many small, inefficient plants built quickly in the late 1980s and early 1990s to meet soaring demand. The share of electric power produced from large units will increase significantly since 2000 in the scenarios, although the addition of many very small (less than 50-megawatt) units has offset some of these efficiency gains. Pressurized Fluidized Bed Combustion (PFBC) and Integrated Gasification Combined-Cycle (IGCC) systems use coal but operate at higher efficiencies and generate fewer emissions than traditional coal-fired power plants. They would help solve the country's power problems while continuing to use domestic coal, but so far the costs and technical barriers of these systems prevent their widespread adoption.

China has the most abundant hydropower resources in the world, with an estimated potential of 380 gigawatts. China has aggressive program to build large hydropower stations in the next two decades, mainly to diversify power generation, help flooding control as well as irrigation. These plants are intended for the middle and upper reaches of the Yangzi, Yellow, and Lancang Rivers. China is constructing the world's largest hydro project, the massive Three Gorges Dam, in Hubei province with total installed capacity of 18.2 gigawatts. The plant is scheduled to be fully operational by 2009 after an investment of at least 25 billion US dollar. At that time, it will supply about 3 percent of the country's power needs. However, hydropower projects are expensive and capital intensive and can lead to mass resettlement of residents, loss of farmland and wildlife, and ecosystem damage. There is strong international opposition to the huge project of Three Gorges Dam. We suppose the share of hydro power generation grows modestly in our analysis.

Regarding technology advancement and international pressure on CO_2 mitigation, China will make efforts to exploit utilizing clean fuel source as important internal energy strategy.

China's estimated total natural gas reserves amount to 38 trillion cubic meters (over 1,450 Petajoules). Proven reserves, however, range from 1.2 to 5.3 trillion cubic meters (roughly 50 to 200 Petajoules) Additional reforms to exploration and development will be needed to further refine this estimate. After decades of bypassing natural gas development, China has focused greater attention on gas in the last few years as a relatively clean fuel source. China's first liquefied natural gas terminal project in Guangdong, DaPeng station will start to operate in April 2006, and will include one or two large combined-cycle power plants. More importantly, it signaled a shift in thinking about energy imports and environmental quality that would call for additional terminals in other coastal cities.

Until recently, China had ambitious plans to develop nuclear power, but high cost, waste disposal, and the risk of accidents present environmental challenges of a different magnitude than other technologies have combined with a slowdown in power demand to limit its future growth potential. China started commercial nuclear power production in 1992 with the 300-megawatt Qinshan station which was developed to reach 2.9-gigawatt total installed capacity at present. The Daya Bay nuclear station, with two imported 900-megawatt units, began operation in 1994. By the end of 2005, Tian Bay nuclear station with two 1.06-gigawatt units came on-line, and is expected to generate 14 Twh annually.

China also has abundant renewable energy resources, including reserves of 253 gigawatts of wind power and biomass energy resources estimated at an annual supply of 220 million tons of coal-equivalent. Despite the promising resources, these technologies have not been widely adopted mainly because of high costs, market distortions, and technical barriers.

III.A.2.v <u>Ownership patterns of sector</u>

The Chinese power sector went through three major phases prior to 2003, which can be divided into roughly the following periods:1949–1985,1986–1997,1998–Present

A. First phase (1949–1985):

State-run as part of centrally planned economy. During the first phase, the Chinese electricity industry was vertically integrated, government-owned and –operated. The Ministry of Power was the main regulatory arm of the central government. The industry followed a five-level management system with the central government overseeing the highest level. Regional, provincial, municipal, and county power bureaus managed the second through fifth levels, respectively.

Each higher-level bureau supervised the operations of its subordinates. The central government was the planner, investor, regulator, manager, and operator of the power industry. In addition, the government was the sole provider of capital for capacity expansion or construction of generation projects through budgetary allocations and government loans.

However, the capital provided by the government was generally insufficient to fully fund all necessary generation projects; the inadequate funding led to nationwide power shortages. Surging electricity demand brought about by economic reforms further exacerbated the power shortage

problem. Realizing the constraints that power shortages placed on the nation's economic and social development, the Chinese government was ready for industry reforms, mainly in raising capital for capacity expansion.

B. Second phase (1985–1997):

State-run and gradual opening of generation market In 1985, the State Council implemented the ''Provisional Regulations on Promoting Fund-Raising for Investment in the Power Sector and Implementing Different Power Prices.'' The main objective of this reform was to encourage investment in the country's power sector in order to ease the worsening power shortages.

Several steps were taken to achieve this goal:

1. For the first time non-central government economic entities—regional governments, local companies, and foreign investors—were allowed to invest in the power sector.

2. The government-modified tariffs to assure profits from generation investment. A 12–15 percent rate of return on investment was allowed. This gave incentives to investors in order to promote power generation construction to alleviate the power shortages that were severely damping China's economic growth.

3. Power project funds were set up and collected 0.02 yuan per kWh on electricity consumption nationwide. These funds were used for capacity expansion by provincial governments.

4. Lastly, a tax rebate was implemented to help improve corporate balance sheets.

This reform was successful and attracted large amounts of money from both local and foreign investors. According to the State Power Corporation (which was formed in 1997), approximately 70 percent of the US$ 101.3 billion total investment received during the 9th Five-Year plan (1995–2000) went to fund new generation projects. Also, investment from foreign entities accounted for approximately 17 percent of the total funding for new project construction.

C. Third phase (1998–2002):

Separation of government functions from corporate functions and testing of generation market competition through provincial pilot programs.

The State Power Corporation was formed in 1997 to run the power industry independently. It owned about 46 percent of total generation assets and 90 percent of transmission assets. In 1998, the Ministry of Power was dissolved. Three governing bodies, the State Economic and Trade Commission (SETC), the State Development and Planning Commission (SDPC)[20], and the Ministry of Finance (MF), assumed its governing functions. In a nutshell, the SETC was responsible for creating and enforcing industry rules and regulations and industry operating standards, and at the same time, balancing demand and supply within utility service territories. The SDPC was responsible for formulating the industry's strategic planning, power project construction and funding, and pricing policies, while the MF was essentially the industry's financial monitoring and enforcement agency.

In essence, the three agencies played the role of government watchdogs while the State Power Corporation was the autonomous operator of the power sector. The creation of these entities separated the responsibilities and functions of the government from those of a commercial enterprise within the power industry. In addition, the country's power sector took a major step toward slowly opening up to competition, at least in the generation market.

III.B Emissions Overview of Sector

III.B.1 Background and discussion of emissions

China is the largest emitter in the world of greenhouse gases after the United States. It accounts for just over one-seventh of the world's emissions (14.7 per cent in 2000; in comparison, the United

[20] The SETC no longer exists, and that most of its functions are now in NDRC, which is the current name of former SPDC.

States emitted 20.6 per cent of global emissions in the same year). According to researchers at the US-based Pew Centre on Global Climate Change, China is likely to be the number one emitter in twenty years.

For electricity sector, China has fueled sectoral robust growth with plentiful supplies of domestic coal. Thermal power plants (fired with coal, petroleum, or natural gas) accounted for almost three-quarters of China's installed capacity in 2000. Hydropower provided about 25 percent and nuclear power less than 1 percent of capacity. Oil and natural gas combined accounted for less than 6 percent of total power generation in 2000, see Fig.3-2 . Nearly all of the sector's CO2 emissions come from coal-fired generators, and they are also the largest sources of CO2 emissions in China. In 2000, China's electricity sector is estimated to account for 8.56% [21]of nation's total energy consumption, so future growth for China's electricity sector will take considerable consequent affects on both China and the global energy saving and environment problems.

Unlike some other countries, a significant share of China's coal-fired generator capacity is relatively small units. For example, nearly three out of every four such generators is less than 50 MW, and these generators account for about 20% of total electric capacity. The technology substitution assumptions of scenarios in this analysis are mainly generated from the plants distribution status in 2000 and China's policy trends.

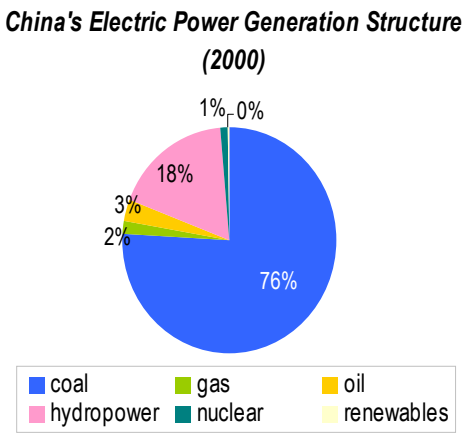

Figure 3-2. Composition of China's electric power generation in 2000

III.B.2 Annual GHG emissions inventory for a recent year

III.B.2.i <u>Total emissions by source</u>

Table 3-6.Electric sector CO2 emission by fuel type in 2000 (MMtCO2)

	Oil	Gas	Coal	Total
Emission	29.1	13.0	1157	1199

III.B.3 Historical annual fuel consumption and GHG emissions trends over time

Table 3-7. Fuel consumption of China's thermal-power plants (PJ)

Year	Coal	Oil	Gas
2000	12913	427.9	255.3

[21] Taking no account of supply for other sectors

III.B.4 Relative contribution of each sector in 2000

Table 3-8.Share of total national energy consumption and emissions

Target Sectors	Electricity	Iron &Steel	Cement	Pulp & Paper	Transportation
Share of China's total energy consumption (2000)	8.56%*	9.95%	7.86%	1.67%	
CO2 Emission (MtCO2)(2000)	256.65*	322.58	416.55	50.19	

Table 3-9. Share of total world sector emissions in 2000

Electricity			
Countries	$MtCO_2$	% of Developing Countries	% of World
China	1199	40%	15%

III.C Background Assumptions for Sector Analysis

III.C.1 Baseline with policies adopted before 2000

III.C.1.i <u>Policies under Consideration</u>

- *Increasing capacity to deliver power to the consumer*

A great portion of capacity is composed by smaller units which are characterized by low operational reliability and low efficiency. A large number of inefficient, unreliable units cause higher pollution and higher operational reserve requirements. Inadequate investment in power transmission and distribution capacity, at local, regional and national levels, meaning that power cannot be transmitted from locations with a surplus to those with a deficit. The unsuitable structure of the power generating capacity in many locations renders the generators unable to satisfy peak demand. The State Power Corporation has identified strategic areas for investment. This can be seen in the drive to construct mine-mouth power stations and to direct investment at the transmission and distribution networks. China attempts to carry out generation structure innovation, is determined to eliminate inefficient plants and introduce advanced technology to enhance the power generation efficiency.

The country has created an energy efficiency center - Beijing Energy Efficiency Center (BeCon) in 1994 with financial support from the U.S. The Chinese government needs to make a more extensive commitment to the establishment of an institutional framework to support energy efficiency and renewable energy development.

- *Improving the energy efficiency of end-users*

The energy efficiency of end-users is clearly a high priority in a country where economic growth is constrained, at least locally, by the availability of energy and this is illustrated by the passing of the Energy Conservation Law in 1997.

- *Ownership and Management reformation*

The State Power Corporation was formed in 1997 to run the power industry independently. It owned about 46 percent of total generation assets and 90 percent of transmission assets. In 1998, the Ministry of Power was dissolved.

Three governing bodies, the State Economic and Trade Commission (SETC), the State Development and Planning Commission (SDPC), and the Ministry of Finance (MF), were created to assume its governing functions. In a nutshell, the SETC was responsible for creating and enforcing industry rules and regulations and industry operating standards, and at the same time, balancing demand and supply within utility service territories. The SDPC was responsible for formulating the industry's strategic planning, power project construction and funding, and pricing policies, while the MF was essentially the industry's financial monitoring and enforcement agency.

In essence, the three agencies played the role of government watchdogs while the State Power Corporation was the autonomous operator of the power sector. The creation of these entities separated the responsibilities and functions of the government from those of a commercial enterprise within the power industry. In addition, the country's power sector took a major step toward slowly opening up to competition, at least in the generation market.

- *Market system renovation*

Before 1985, the central government was the sole investor in the power sector, and the lack of adequate government funding was the main cause of severe power shortages. The government-modified tariffs allow profits from generation investment. A 12–15 percent rate of return on investment was allowed. This gave incentives to investors in order to promote power generation construction to alleviate the power shortages that were severely limiting China's economic growth.

In 1984 the government allowed state owned enterprises to sell their over-quota surplus at prices within a 20% range over the state set prices. In Feb. 1985, the 20% limit was removed and prices for their surplus could be negotiated freely between buyers and sellers. At that point, the dual pricing system is generally considered as a positive, cautious step towards a full market price. Moreover, it is widely thought that introducing the dual pricing system can, among other purpose, encourage material and energy conservation and improved management, thus introducing economic efficiency in the use of the resources.

- *Nuclear power development*

China started commercial nuclear power production in 1992 with the 300-megawatt Qinshan station which was developed to reach 2.9-gigawatt total installed capacity at present. The Daya Bay nuclear station, with two imported 900-megawatt units, began operation in 1994.

- *SO_2 and NO_x control*

Key environmental issues concerned with electric power generation are SO_2 and NO_x control. According to the regulations and laws carried out by Chinese government and SEPA[22], we take consideration of SO_2 and NO_x control cost in the total cost assessments of each individual thermal power plant.

III.C.1.ii Assumptions about the Effectiveness of Policies

It's the least technology advanced scenario among the three. Measures mainly focus on demand side management and reconstruction of conventional thermal power. The share of clean fuel and renewable generation keeps growing modestly.

The recent baseline scenario employed here is a conservative projection of China's electricity power future that closely tracks previous Chinese forecasts. The scenario assumes that sector's relative policies will not change radically, although some technologies are projected to improve gradually.

III.C.2 Baseline with policies adopted between 2000 and 2005

III.C.2.i Policies under Consideration

- *Industry structure and ownership reformation*

The Chinese government is in the early stages of formulating a fundamental long-term restructuring of its electric power sector, embodied in the National Power Industry Framework Reform Plan promulgated by the State Council in early 2002. As with many other countries' reform programs, generating assets are being largely separated from transmission and distribution. The State Power

[22] Cleaner production standard ---Coal-fired power plant, 1990.

Emission standard of air pollutants for thermal power plants(GB13223-1996)

Corporation was broken up in December 2002 as the government tried to end the monopoly in the country's generation market. The State Power Corporation was divided into five generation companies (Huaneng Group, Huadian Power, Guodian Power, Datang Power Group and China Power Investment Company) and two power grid operators (State Power Grid Company and South China Power Grid Company). Each one of the generation companies took over less than 20 percent of the generation facilities of the former State Power Corporation.

The government will take more notice on restructure, competition and regulator, strategic option for deepening China's electricity reform. China's power industry will be more open to outside world with accession to WTO. Investors worldwide are welcome to participate in Chinese power construction.

- *Improving the energy efficiency*

In recent years China has successively introduced a batch of 300 MW, 500 MW 600 MW and 800 MW supercritical units. Through debugging and improvement these units have been operating smoothly with higher availability and efficiency gained. It has laid a certain foundation for China to develop home-made supercritical pressure units.

- *Tenth Five-Year Plan*

Targets of the 10th Five-Year Plan (2001-2005): total investment 900billion RMB, of which 40% for grid construction. Shut-down 14.2 GW of small thermal units. To reach 395 GW installed capacity, 1830 TWh generation, realize basic national inter-connection by 2005. Build west-to-east power transmission corridors, enhance regional & provincial grids. Continue urban & rural network construction and innovation. Strengthen construction of secondary system protection, communication and automatic control). To fully tap the potential of existing capacity. To promote the development of hydro-electric power. To optimize thermal power development. To develop nuclear power properly. To develop renewable energy in accordance with local conditions. To place equal emphasis on development and energy conservation. To attach great importance on environmental protection. To deepen the structural reform in power sector.

- *Nuclear power*

China's 10th Five-Year Plan incorporates the construction of nuclear power plants, though the timeline for contracts has been extended. Many of the major developments taking place in the Chinese electricity sector recently involve nuclear power. China's total installed capacity for nuclear power generation increased from 2 GW in the beginning of 2002 to 15 GW as of mid-2005. The first generation unit of the Lingao nuclear power plant in Guangdong province began commercial operation in May 2002, with a capacity of 1-GW. The second 1-GW generating unit began operating in January 2003. An additional 600-MW generating unit at the Qinshan nuclear power plant in Zhejiang province began operation in February 2002, and another 600-MW unit at the same site came online in December 2002. A new 6-GW nuclear complex is planned for construction at Yangjiang in Guangdong province, to begin commercial operation in 2010. A second generating facility also is planned for Daya Bay. Chinese government policy emphasizes nuclear power generation as a source of clean electricity generation and a means of reducing dependence on fossil fuels. China plans a total of 40 GW of nuclear generating capacity to be completed by 2020, it will reach 4 percent of total installed capacity at that point.

- *Renewable Energy Law*

The Standing Committee of the National People's Congress (NPC) endorsed the Renewable Energy Law on February 28, 2005. Effective from Jan.2006, the law requires power grid operators to purchase electricity generated by registered renewable energy producers. The law also offers financial incentives, such as a national fund to foster renewable energy development, and discounted lending and tax preferences for renewable energy projects.

China's new law sets the stage for the widespread development of renewables, particularly for commercial scale renewable generating facilities. Through this legislation, the State officially

encourages the construction of renewable energy power facilities. China's electricity grid is obligated to purchase all the electricity generated by approved renewable energy facilities located in its service area.

- *Hydro-electric power*

China is constructing the world's largest hydro project, the massive Three Gorges Dam, in Hubei province with total installed capacity of 18.2 gigawatts. The plant is scheduled to be fully operational by 2009 after an investment of at least 25 billion US dollar. At that time, it will supply about 3 percent of the country's power needs.

- *Wind Power*

For the sake of promoting wind power construction, the Chinese government has issued a Circular on Questions Concerning Advancement of Renewable Energy Resources in 1999, in which the preferential policy of renewable energy, in particular, wind power projects was set forward that bank-loaned projects would be given a fiscal subsidiary of 2 per cent and wind power projects putting Chinese-made equipment to use would be given a preferential treatment of 5 per cent on return rate of investment.

III.C.2.ii Assumptions about the Effectiveness of Policies

Power plants with less efficiency are forced to close. The step of scale enlargement and technology advancement of present thermal power plants is faster than that in baseline scenario. International advanced technologies such as IGCC and PFBC with carbon capture and storage are well introduced and implemented by the end of 2030. Nuclear and hydropower's great potentials are exploited substantially.

In this scenario, we will evaluate projected emissions using combination of measures in place before the end of 2005. Taking regards of Report of 16th Party Congress, Tenth Five-Year Plan as well as relative industrial long term development policies and plans. The policies adopted in this scenario take more consideration for environmental protection.

III.C.3 Description of analytical approach and methodology used.

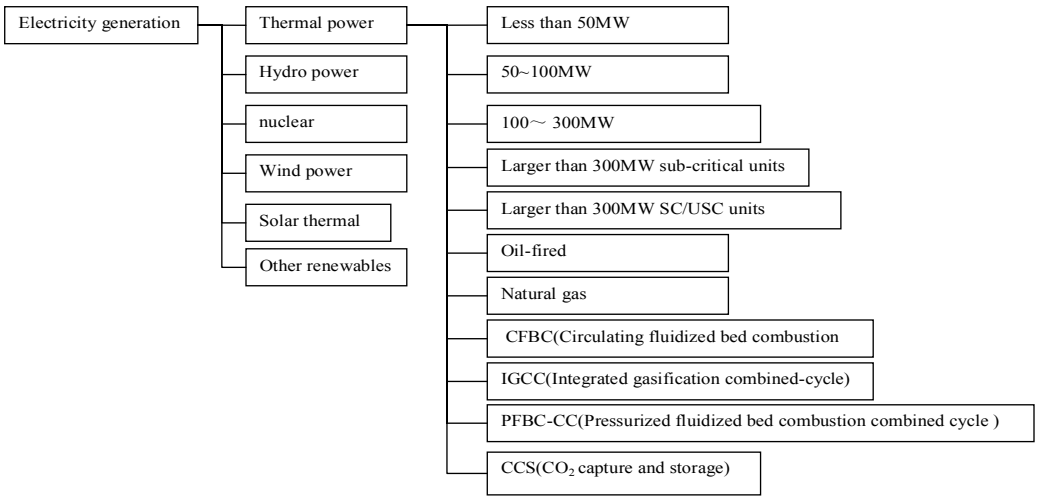

Figure 3-3 Data structure for China's electric technology analysis

In terms of input data of LEAP model, we use tree analysis to describe the industrial technology information of electricity sector. The generating equipments are classified by fuel types at the primary

level, the thermal power plants fueled by coal are further classified by their generating capacities with consideration of technology advancement. The simplified analysis structure is showed in Fig 3-3

III.D Baseline (business-as-usual) Forecasts for sectors

III.D.1 Production/output forecast

It is said China's GDP in 2020 will quadrupled as it is in 2000 in the Considering the Report of 16th Party Congress. We refer to series of literatures on Chinese energy and carbon scenarios[23] and assume China's GDP will keep the fast growth in 2000s, the annual growth rate is set to be 7.5% during 2000 to 2010. Then the growth speed will slow down, the annual growth rate is set to be 6.5% during 2010 to 2020, 5.5% during 2020. And electric sectoral production is projected consistent with economy development, see Table 3-10. The forecast trend of generation in the whole target analysis period is shown in Fig 3-4.

Table 3-10. China's GDP and Electric Production Assumptions in the Analysis

Year	2000	2005	2010	2015	2020	2025	2030
Annual Growth Ratio	7.50%		6.50%		5.50%		
GDP（billion dollar）	1081	1552	2227	3096	4181	5465	7142
Sectoral Production (Twh)	1368.5	1841	2313	3179	4046	5664	7282

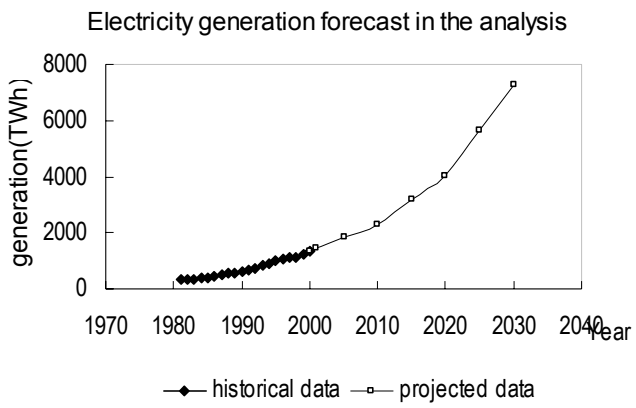

Fig 3-4 Electricity generation forecast in the analysis

III.D.2 Energy and fossil fuel consumption (by type) forecast

For the energy consumption forecasts in baseline scenarios, we list the results from LEAPChina model analysis, see Table 3-11 and Table 3-12.

Table 3-11. Energy consumption under 2000 baseline scenario

Year	Total Energy Consumption (PJ)				Energy Intensity (PJ/TWh)
	Coal	Oil	Gas	Total	
2000	12913	427.9	255.3	13596	9.93
2005	16617	508.4	420.6	17546	9.53
2010	19935	554.4	625.6	21115	9.13
2015	26779	579.9	919.3	28278	8.90
2020	33282	506.0	1245	35033	8.66
2025	45362	383.7	1876	47621	8.41
2030	56737	75.9	2581	59394	8.16

Data resource: analysis results from LEAPChina model.

23 Energy and Carbon Scenarios for China:Review of Previous Studies and Issues for Future Work

Table 3-12. Energy consumption under 2005 baseline scenario

Year	Total Energy Consumption (PJ)				Energy Intensity (PJ/TWh)
	Coal	Oil	Gas	Total	
2000	12913	428	255	13596	9.93
2005	16595	470	421	17486	9.50
2010	19882	458	626	20965	9.06
2015	26154	497	919	27570	8.67
2020	31785	464	1245	33494	8.28
2025	43510	354	1876	45740	8.08
2030	54670	76	2581	57327	7.87

Data resource: analysis results from LEAPChina model.

III.D.3 Annual GHG forecast

III.D.3.i <u>Total GHG emissions</u>

The corresponding CO2 emissions and emissions intensities related to fuel combustion are calculated; see Table 3-13 through Table 3-16, below.

Table 3-13. CO2 emission for China's electric sector under 2000 baseline scenario (MMtCO2)

	2000	2005	2010	2015	2020	2025	2030
Coal	1157	1512	1809	2424	3006	4087	5099
Oil	29.1	34.6	37.8	39.5	34.5	26.1	5.20
Gas	13.0	20.8	30.9	45.4	61.5	92.6	127.5
Total	1199	1567	1877	2509	3102	4206	5231
Emission intensity (kg CO2/kWh)	0.88	0.85	0.81	0.79	0.77	0.74	0.72

Data resource: analysis results from LEAPChina model.

Table 3-14. CO2 intensity by fuel type for China's electric sector under 2000 baseline scenario (kg CO2/kWh)

	2000	2005	2010	2015	2020	2025	2030
Coal	1.11	1.14	1.14	1.16	1.18	1.18	1.19
Oil	0.71	0.79	0.91	0.91	0.93	0.92	0.69
Gas	0.47	0.47	0.46	0.46	0.46	0.46	0.46
All Fuels	0.88	0.85	0.81	0.79	0.77	0.74	0.72

Table 3-15. CO2 emission for China's electric sector under 2005 baseline scenario(MMtCO2)

	2000	2005	2010	2015	2020	2025	2030
Coal	1157	1510	1803	2366	2866	3914	4906
Oil	29.1	32.0	31.2	33.8	31.6	24.1	5.20
Gas	13.0	20.8	30.9	45.4	61.5	92.6	127.5
Total	1199	1563	1865	2445	2960	4031	5038
Emission intensity (kg CO2/kWh)	0.88	0.85	0.81	0.77	0.73	0.71	0.69

Data resource: analysis results from LEAPChina model.

Table 3-16. CO2 intensity by fuel type for China's electric sector under 2005 baseline scenario (kg CO2/kWh)

	2000	2005	2010	2015	2020	2025	2030
Coal	1.11	1.14	1.14	1.13	1.12	1.13	1.14
Oil	0.71	0.72	0.74	0.79	0.88	0.85	0.69
Gas	0.47	0.47	0.46	0.46	0.46	0.46	0.46
All Fuels	0.88	0.85	0.81	0.77	0.73	0.71	0.69

III.E GHG Mitigation Options and Costs

III.E.1 Selection criteria for consideration of mitigation options

The major GHGs abatement options suggested here are important for the electric sector, and are consistent with sectoral development goals and relevant policies.

Therefore, they have significant potential for GHGs emissions reduction and their implementation is feasible. In the next parts, we firstly listed the corresponding description and development of each individual option, and then we give the technology structure assumptions in three scenarios for your information. For some options such as demand side management and reconstruction of conventional thermal power we didn't provide detailed measures information due to lack of data, so we make general assumptions of the total CO2 mitigation percentages they can achieve in target years.

III.E.2 Overview of each mitigation option evaluated

III.E.2.i Description, including technologies required

- *Demand side management*

Besides the energy supply sector, the energy end-use sectors have many technical measures to improve energy efficiency. This part contains industrial boiler, motor, transportation, residential, iron and steel sector, etc. Commonly used equipment such as boilers and motors are the most important ones and has the largest potential for energy savings. Technical options for improving boiler efficiencies may include fuel preparation, advanced combustion technologies and auxiliary equipment, as well as process control.

Output of China's electricity mostly depends on generation capacity. Although demand-side measures will reduce total outputs, the decline of demand will stimulate new demand. Fluctuation is common in both demand and supply for electricity market. Here we assume the outputs in three scenarios to be the same mainly for accelerating horizontal comparisons.

- *Circulating Fluidized bed combustion (CFBC)*

Generally CFBC is structured by the boiler and the high temperature cyclone. The intrafurnace gas velocity is as high as 4 to 8 m/s. Coarse fluidizing medium and char in the flue gas are collected by the high temperature cyclone, and are recycled to the boiler. The recycle maintains the bed height and increases the denitration efficiency. To increase the thermal efficiency, a preheater for fluidizing air and combustion air, and a boiler feed water heater are installed.

CFBC's advantages can be described as Wide range of fuel adaptability, low pollution, high combustion efficiency, space saving and high maintenance ability. There has been a long history for development of CFBC in China since 1960s. Although it's efficiency is much lower than clean coal combustion technologies such as IGCC and PFBC-CC, the negative marginal abatement cost will be key driving force for promotion of CFBC plants in all three scenarios.

- *Reconstruction of conventional thermal power*

It mainly focuses on four aspects: replacement and renovation of medium and low-pressure unit, new installation of large-scale unit, comprehensive renovation of existing large-scale unit, increases of cogeneration unit.

The regulation of closing less efficient medium and small plants has been carried out since early 1990s, but didn't work effectively because of loose implementation and supervision. There is still long way to go for China in this aspect. Also, Chinese government made the announcement that mainstream added equipments from 1990s should be big thermal plants more than 30 MW, so reconstruction of conventional thermal power plants will take great effect in CO2 mitigation.

- *Supercritical/Ultra supercritical plants*

Supercritical units operate at higher temperatures and pressures than sub-critical units, the higher pressures increase turbine efficiency and power output, so less coal is used to produce the same amount of electricity.

Ultra-supercritical plants use new advanced clean coal technology, allowing operation at elevated steam temperatures and pressures. Ultra-supercritical technologies are expected to become more prevalent in China because they can boost the efficiency of coal-based electricity generation by more than 50 percent, while maintaining superior environmental performance.

With break through the barriers of technologies, SC and USC will play important role in CO2 abatement area.

- *IGCC (integrated gasification combined-cycle),PFBC (pressurized fluidized bed combustion)*

IGCC systems are extremely clean, and are much more efficient than traditional coal-fired systems. IGCC uses a combined cycle format with a gas turbine driven by the combusted syngas from the gasifier, while the exhaust gases are heat exchanged with water/steam to generate superheated steam to drive a steam turbine. The result is an integrated gasification combined-cycle configuration that provides ultra-low pollution levels and high system efficiencies.

Pressurized fluidized-bed combustion (PFBC) technology uses a combustion process similar to that of AFBC, but the boiler operates at higher than atmospheric pressure (0.5 to 2 MPa), the gas is cleaned downstream from the PFBC boiler, and the gas is expanded in a gas turbine. It can provide advanced environmental characteristics including: SOx reduction through the in-bed desulfurization; NOx reduction through the low temperature combustion (about 860OC); Dust reduction by CTF; and CO2 reduction by increased efficiency.

As this two advanced technologies are not spread widely, there is still a period for them to be commercialized. So in the scenarios, we assume they are gradually utilized after 2010.

- *CCS*

The application of CO_2 capture and storage technologies to fossil fueled energy conversion processes raises a prospect for the implementation of technologies that contribute to near zero emissions of all forms of pollutant emissions and greenhouse gases into the atmosphere. CCS is not a silver bullet; other mitigation options are necessary to achieve the desired stabilization levels. In the analysis of CCS, it was assumed that the incremental cost of adding CCS is same regardless of plant type (IGCC, gas-fired CC, etc.) For CCS is not maturely developed even in the developed country. It is really hard to forecast CCS' abatement potential and marginal reduction in China in the near future. We optimistically suppose it will be taken on line and make effects after 2020 or later because of technical barrier and lack of capital. Here in Fig 3-5 we provide the stationary CO2 sources and geological storage opportunities in China's sedimentary basins.

- *Hydropower generation*

There is grate hydropower potentials in Southeast China. But no more than 25% is exploited because it's far from the center load areas. The payback period to build hydropower stations is long, so the thorny issue to develop hydropower generation in China is lack of money. Here in the mitigation scenario, we suppose the potential for hydropower is more utilized for the assistance of CDM projects, and the power generation percentage in total national generation increases from 17.77% to 24.8%.

- *Nuclear power*

Nuclear power has an important role, especially in the coastal areas remote from the coalfields and where the economy is developing rapidly.

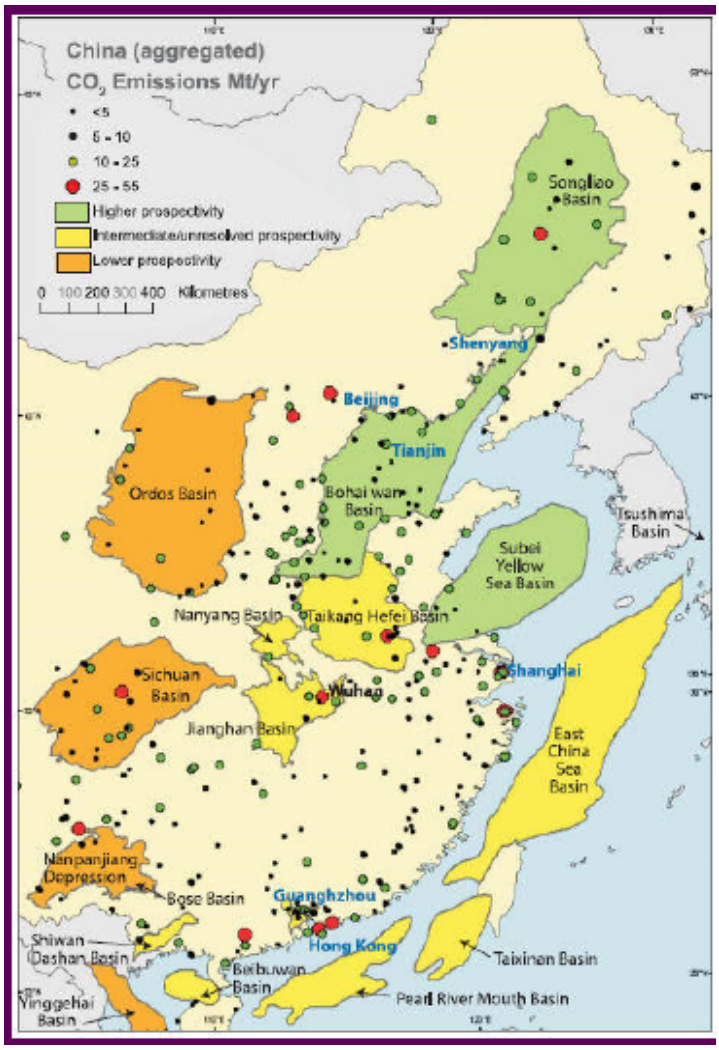

Figure 3-5. Stationary CO2 Sources & Geological Storage Opportunities in China's sedimentary Basins

- *Natural gas*

So far, natural gas takes only 2.5% more or less in our national energy consumption, and is mainly used in industrial process heating. Unless other countries, proportion of electricity generated from natural gas is quite low. So natural gas isn't an leading choose in our assumptions.

- *Other Renewable energy*

China is rich in wind energy resources[24]. By estimates of China Meteorology Research Institute the exploitable wind energy on the nationwide land totals around 253 GW, and the offshore wind energy is about 750 GW. Both of them add up to about 1000 GW. And the wind energy is widely distributed throughout the country. It is shown that China is provided with adequate conditions to develop wind power industry.

China has a very good solar resource, averaging above 4kWh/m^2/day, in some areas, particularly in the west of the country, solar radiation levels are high, population densities are low, and prospects for provision of mains electricity through grid extension in the foreseeable future are small.

[24] The transmission cost for hydropower, wind power and solar thermal power generation theoretically should be discussed, but we make rough general assumptions because lack of relative information.

III.F Analysis of GHG mitigation scenarios

Regarding the descriptions above related to each option, we provide the technology structure in three scenarios for your information, see Table 3-17.

Table 3-17.Generation proportion by different technologies under three scenarios(%)

		2000 baseline scenario				2005 baseline scenario				Mitigation scenario			
		2000	2010	2020	2030	2000	2010	2020	2030	2000	2010	2020	2030
Thermal power plants	<50MW	12.63	0	0	0	12.63	0	0	0	12.63	0	0	0
	50~100MW	6.85	6.4	5.5	4	6.85	6	5	3	6.85	5.4	4	2
	100~300MW	52.35	48.3	36.6	23.7	52.35	47.4	31.5	19.2	52.35	43.3	23.9	6.9
	Sub-critical units	3	5	7	10.5	3	5.5	8	12.5	3	5.8	8.3	12.6
	SC/USC units	0	8.5	12.3	15.7	0	9.1	13.4	16.2	0	9.5	14.5	17.2
	CFBC	1.03	3.5	7.8	12.3	1.03	3.7	8.5	13.3	1.03	3.9	9.4	15.6
	IGCC	0	0.3	0.9	1.9	0	0.3	1	2	0	0.3	1.5	2.4
	PFBC	0	0.3	0.8	1.4	0	0.3	1	1.6	0	0.3	1.4	2.3
	Oil-fired	3	2.3	1.2	0.1	3	1.9	1.1	0.1	3	1.8	0.9	0.1
	Natural gas	2	2.9	3.3	3.8	2	2.9	3.3	3.8	2	2.9	3.3	3.8
	CCS mitigation（$MtCO_2$）	0	0	0	0	0	0	0	0	0	0	5	60
Hydro power		17.8	19.3	20.1	20.2	17.8	19.3	21	21.3	17.8	21.5	22.8	24.8
Nuclear		1.2	2.6	3.4	5.1	1.2	2.9	5	5.6	1.2	4.5	8.5	10.6
Wind power		0.04	0.5	1	1.2	0.04	0.6	1.1	1.3	0.04	0.7	1.4	1.6
Other renewables		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total		100	100	100	100	100	100	100	100	100	100	100	100

III.F.1 Marginal abatement cost curve ($/metric ton GHG reduced vs. total GHG reductions)

The marginal cost for each option is calculated through its mitigation effect compared to average value of current thermal power plants. For instance, we gain the operational cost, fuel cost, and maintenance cost for each option[25]. We calculate CO2 emission basing on the fuel consumption information. Then we use the difference of total cost for certain option and average value of current thermal power plants times the difference of their CO2 emissions to obtain the marginal abatement cost for this certain mitigation option. Also, we do adjustments by checking the related literature of marginal abatement cost for mitigation measures and options[26,27]when the calculated results seem to be unreasonable.

[25] Wanghao. The potential in GHG Emission Mitigation and its Cost Benefit Analysis for Electric Power Sector of China under Clean Development Mechanism of Kyoto Protocol [D]. 1999. Tsinghua, Beijing.

[26] WANG Weizhong, GUO Risheng, ZHOU Hailin, et al. The Methodology Guidelines of Clean Development Mechanism[M]. Beijing: Social Science Literature Press, 2005.(in Chinese)

[27] WU Zongxin. WEI Zhihong, ZHANG Aling, et al. Asia Least-cost Greenhouse Gas Abatement Strategy [M]. Manila:Asian Development Bank,1998.

III.F.1.i 2010

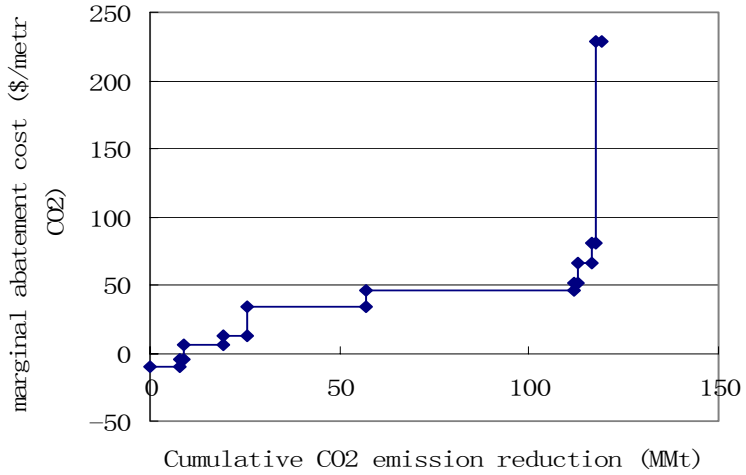

Figure 3-6.Marginal abatement cost curve of China's electricity sector in 2010

Table 3-18. Cost of mitigation options and relevant emission reduction in 2010

No.	Measures	Marginal Mitigation Cost (US$/tCO2)	Total Emission Reduction (MMt CO2)	Total Cost (million US$)	Cumulative Emission Reduction (million metric tons CO_2e)	Cumulative Net Cost (million US$)	Average Cumulative Cost Effectiveness (US$/metric ton CO_2e)
1	Demand side Management	-9.86	7.59	-74.8	7.59	-74.8	-9.86
2	CFBC	-4.55	1.21	-5.52	8.80	-80.3	-9.13
3	Reconstruction of Conventional Thermal Power	6.59	10.3	68.1	19.1	-12.3	-0.64
4	Supercritical Plant	12.5	6.58	82.0	25.7	69.7	2.71
5	Nuclear Power	34.2	31.1	1063	56.8	1133	20.0
6	Hydropower	46.0	54.9	2526	111.7	3659	32.8
7	Natural Gas	50.8	1.11	56.6	112.8	3715	32.9
8	IGCC &PFBC	66.4	3.54	235.1	116.4	3950	33.9
9	Wind Power	80.8	1.32	106.3	117.7	4057	34.5
10	Solar Thermal	229.3	1.52	348.1	119.2	4405	37.0

III.F.1.ii 2015

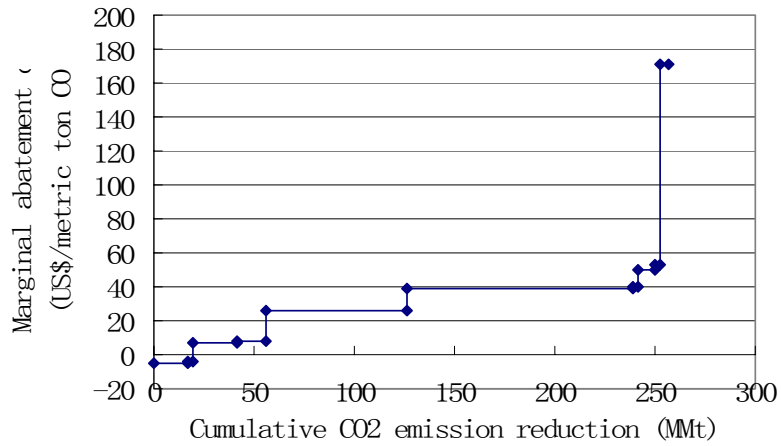

Figure 3-7.Marginal abatement cost curve of China's electricity sector in 2015

Table 3-19. Cost of mitigation options and relevant emission reduction in 2015

No.	Measures	Marginal Mitigation Cost (US$/tCO2)	Total Emission Reduction (MMt CO2)	Total Cost (million US$)	Cumulative Emission Reduction (million metric tons CO_2e)	Cumulative Net Cost (million US$)	Average Cumulative Cost Effectiveness (US$/metric ton CO_2e)
1	Demand Side Management	-5.28	17.0	-89.7	17.0	-89.7	-5.28
2	CFBC	-4.04	2.62	-10.6	19.6	-100.3	-5.11
3	Reconstruction of Conventional Thermal Power	6.67	22.2	148.3	41.9	48.0	1.15
4	Supercritical Plant	8.3	14.4	119.6	56.3	167.6	2.98
5	Nuclear Power	26.0	69.8	1816	126.0	1984	15.7
6	Hydropower	38.6	113.4	4373	239.4	6356	26.6
7	Natural Gas	40.3	2.40	96.7	241.8	6453	26.7
8	IGCC &PFBC	50.5	8.1	408	249.9	6861	27.5
9	Wind Power	53.0	3.1	161.8	252.9	7022	27.8
10	Solar thermal	171.3	3.5	598	256.4	7620	29.7

III.F.1.iii 2020

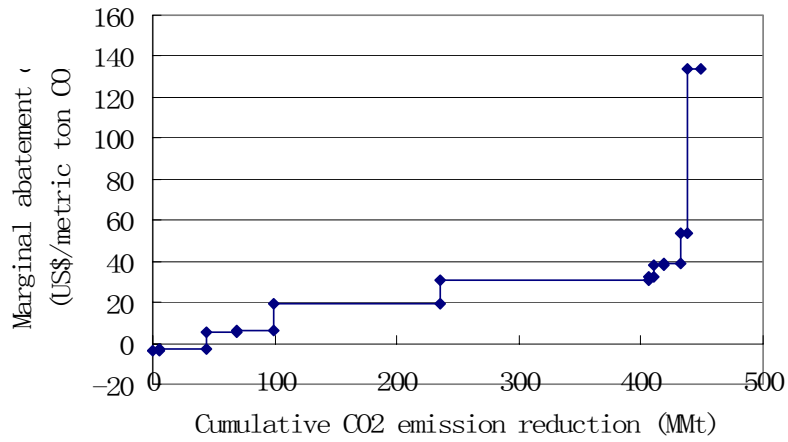

Figure 3-8.Marginal abatement cost curve of China's electricity sector in 2020

Table 3-20. Cost of mitigation options and relevant emission reduction in 2020

No.	Measures	Marginal mitigation cost (US$/tCO2)	Total emission reduction (MMt CO2)	Total Cost (million US$)	Cumulative Emission Reduction (million metric tons CO_2e)	Cumulative Net Cost (million US$)	Average Cumulative Cost Effectiveness (US$/metric ton CO_2e)
1	CFBC	-3.63	5.71	-20.7	5.71	-20.7	-3.63
2	Demand Side Management	-2.96	38.0	-112.6	43.7	-133.3	-3.05
3	Reconstruction of conventional thermal power	5.72	25.1	143.6	68.8	10.3	0.15
4	Supercritical plant	5.99	29.7	177.7	98.5	188.0	1.91
5	Nuclear power	19.2	136.9	2629	235.5	2817	12.0
6	Hydropower	31.0	171.2	5306	406.6	8123	20.0
7	Natural gas	32.7	4.18	136.8	410.8	8260	20.1
8	Wind power	38.0	7.61	289.1	418.4	8549	20.4
9	IGCC &PFBC	38.8	14.1	546.1	432.5	9095	21.0
10	CCS	53.3	5.00	266.5	437.5	9362	21.4
11	Solar thermal	133.7	11.4	1526	448.9	10888	24.3

III.F.2 Advanced Options (Mitigation) Scenario #1: All Zero- or Negative Cost Mitigation Options

This mitigation scenario includes CFBC (circulating fluidized bed combustion) and demand side management.

III.F.2.i Results from the mitigation scenario

Table 3-21. Annual fuel consumption, emissions and intensity forecast for electricity sector

Year	Total Production (TWh)	Total Fuel Consumption （PJ）				CO2 emissions (million tones)	Fuel Intensity (PJ/kWh)	Emissions Intensity (kg CO2 / kWh)
		Coal	Fuel Oil	Natural Gas	All Fuels			
2000	1368.5	12913	427.9	255.3	13596	1199	9.93	0.88
2005	1840.6	16579	507.4	419.8	17506	1564	9.51	0.85
2010	2312.7	19841	552.2	623.1	21016	1868	9.09	0.81
2015	3179.2	26568	576.0	913.1	28058	2489	8.83	0.78
2020	4045.7	32811	499.8	1230	34541	3058	8.54	0.76
2025	5664	44595	378.1	1848	46822	4135	8.27	0.73
2030	7282.3	55613	74.6	2537	58225	5128	8.00	0.70

Table 3-22. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions (MMTCO_2e)				CO_2 Intensity (kg CO2/kWh)			
	Coal	Oil	Natural Gas	Total All Fuels	Coal	Oil	Natural Gas	Total All Fuels
2000	1157	29.1	13.0	1199	1.11	0.71	0.47	0.88
2005	1509	34.5	20.8	1564	1.14	0.78	0.46	0.85
2010	1800	37.6	30.8	1869	1.14	0.90	0.46	0.81
2015	2405	39.2	45.1	2489	1.15	0.91	0.46	0.78
2020	2963	34.1	60.7	3058	1.16	0.94	0.45	0.76
2025	4018	25.7	91.2	4135	1.16	0.91	0.45	0.73
2030	4998	5.11	125.3	5128	1.16	0.70	0.45	0.70

III.F.3 Advanced Options Scenario #2: All mitigation options costing less than $5 per metric ton

This mitigation scenario includes CFBC (circulating fluidized bed combustion) and demand side management (SAME AS ABOVE)

III.F.4 Advanced Options Scenario #3: All mitigation options costing less than $10 per metric ton

This mitigation scenario includes CFBC (circulating fluidized bed combustion)， demand side managementSupercritical/Ultra supercritical plant and Reconstruction of conventional thermal power.

Table 3-23. Annual fuel consumption, emissions and intensity forecast for electricity sector

Year	Total Production (TWh)	Total Fuel Consumption （PJ）				CO2 emissions (million tones)	Fuel Intensity (PJ/kWh)	Emissions Intensity (kg CO2 / kWh)
		Coal	Fuel Oil	Natural Gas	All Fuels			
2000	1368.5	12913	427.9	255.3	13596	1199	9.93	0.88
2005	1840.6	16579	507.4	419.8	17506	1561	9.51	0.85
2010	2312.7	19841	552.2	623.1	21016	1862	9.09	0.81
2015	3179.2	26567	576.0	913.1	28056	2475	8.82	0.78
2020	4045.7	32808	499.8	1230	34538	3033	8.54	0.75
2025	5664	44592	378.1	1848	46818	4094	8.27	0.72
2030	7282.3	55608	74.6	2537	58220	5069	7.99	0.70

Table 3-24. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)				CO_2 Intensity (kg CO2/kWh)			
	Coal	Oil	Natural Gas	Total All Fuels	Coal	Oil	Natural Gas	Total All Fuels
2000	1157	29.1	13.0	1199	1.11	0.71	0.47	0.88
2005	1506	34.5	20.8	1561	1.13	0.78	0.46	0.85
2010	1794	37.6	30.8	1862	1.13	0.90	0.46	0.81
2015	2391	39.2	45.1	2475	1.14	0.91	0.46	0.78
2020	2938	34.1	60.7	3033	1.15	0.94	0.45	0.75
2025	3977	25.7	91.2	4094	1.15	0.91	0.45	0.72
2030	4938	5.11	125.3	5069	1.15	0.70	0.45	0.70

III.F.5 Advanced Options Scenario #4: All Feasible Mitigation Options[*]

Table 3-25. Annual fuel consumption, emissions and intensity forecast for electricity sector

Year	Total Production (TWh)	Total Fuel Consumption （PJ）				CO2 emissions (million tones)	Fuel Intensity (PJ/TWh)	Emissions Intensity (kg CO2 / kWh)
		Coal	Fuel Oil	Natural Gas	All Fuels			
2000	1368.5	12913	427.9	255.3	13596	1199	9.93	0.88
2005	1840.6	16138	460.4	420.6	17019	1520	9.25	0.83
2010	2312.7	18733	433.9	625.6	19792	1758	8.56	0.76
2015	3179.2	24105	447.3	919.3	25471	2253	8.01	0.71
2020	4045.7	28579	379.5	1245	30203	2658	7.47	0.66
2025	5664	37664	295.2	1876	39835	3488	7.03	0.62
2030	7282.3	45409	75.90	2581	48066	4184	6.60	0.57

Table 3-26. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)				CO_2 Intensity (kg CO2/kWh)			
	Coal	Oil	Natural Gas	Total All Fuels	Coal	Oil	Natural Gas	Total All Fuels
2000	1157	29.1	13.0	1199	1.11	0.71	0.47	0.88
2005	1468	31.40	20.8	1520	1.10	0.71	0.46	0.83
2010	1698	29.50	30.9	1758	1.07	0.71	0.46	0.76
2015	2177	30.50	45.4	2253	1.04	0.71	0.46	0.71
2020	2571	25.80	61.5	2658	1.01	0.71	0.46	0.66
2025	3375	20.10	92.6	3488	0.98	0.71	0.46	0.62
2030	4051	5.20	127.5	4184	0.94	0.71	0.46	0.57

[*] In electricity and in all other sectors, Advanced Options Scenario #4 includes all options from the marginal abatement cost curve.

III.F.6 Co-benefits

Mitigation Option	Water quality improvements	Increased economic productivity and competitiveness	Job creation	Technology development and transfer	Infrastructure development	Enhanced energy security and independence	Air quality improvement
Demand side management	☆☆	☆☆		☆	☆☆		☆
CFBC (Circulating Fluidized bed combustion)	☆	☆		☆			☆
Reconstruction of conventional thermal power	☆	☆☆		☆	☆☆	☆	☆
Supercritical plant	☆	☆		☆			☆
Nuclear power	☆☆☆	☆☆☆		☆☆	☆	☆	☆☆
Hydropower	☆☆	☆☆		☆☆	☆	☆	☆☆
Natural gas	☆☆☆			☆			☆☆
IGCC (integrated gasification combined-cycle)PFBC (pressurized fluidized bed combustion)	☆	☆		☆	☆	☆	☆
IGCC-CCS		☆☆		☆☆	☆	☆	☆☆☆
Wind power	☆☆	☆☆☆		☆☆	☆	☆	☆☆
Solar thermal	☆☆☆	☆		☆	☆		☆☆

Note:More☆ means specific mitigation option will produce more co-benefits

IV. Sector Analysis and Results: Iron & Steel

Iron and steel industry is a pillar industry for China's sustaining economic development. It is an essential basic industry, a major energy consuming sector and source of greenhouse gases and other pollutants. At present ,although there are several modern steel enterprises with advanced technology and equipment such as Baosteel , the general and average level of technology in China's iron and steel industry is about 10 or more years behind than those of industrialized countries, and the energy consumption of per ton of steel is much higher than that of industrialized countries. Its energy consumption and CO_2 emissions account for about 10% of the country's total. The industry has achieved great progress in energy conservation and emission reductions, but because of the general backward technology, there are still huge potentials for China's iron and steel industry to improve energy efficiency and mitigate greenhouse gases and other pollutants. These energy conservation measures will also help iron and steel enterprises reduce cost, enhance economic benefit and strengthen their market competitiveness. During this process, industry structure adjustment and technology advancement will play an important role in emission reduction.

IV.A Sector Overview

IV.A.1 Summary

IV.A.1.i <u>Total output/production</u>

China's iron and steel industry has gone through rapid development since 1990. At 1996, output of crude steel of China's iron and steel broke through 100 million tons. From then on China has become the largest steel-producing country of the world. The following table is the output of different productions of China's iron and steel industry including crude steel , steel product, pig iron, coke and ferroalloy. In the statistic for iron and steel industry, coke is special. Because besides being the input for iron making, coke is also used in many other industrial sectors. In this table output of coke is the total of China's all coke enterprises. But in the sector's energy consumption analysis, only that part of coke used for iron and steel is calculated. For example, at the year of 2000, total output of coke is 121.84 million tons. At that year, the average ratio of coke and pig iron into blast furnace is 0.437. So the demand of coke for iron-making is 13101×0.437=5725 million tons.

Table 4-1. Different output of China's iron and steel industry

Year	Crude Steel (million metric tons)	Steel Product (million metric tons)	Pig iron (million metric tons)	Coke (million metric tons)	Ferroalloy (million metric tons)
1990	66.35	51.53	62.37	73.27	2.38
1991	71.00	56.38	67.65	73.51	2.46
1992	80.94	66.94	75.89	79.85	2.66
1993	89.54	70.80	87.38	93.15	2.93
1994	92.61	84.28	97.41	114.29	3.40
1995	95.36	89.80	105.29	135.02	4.32
1996	101.24	93.38	107.21	136.46	4.33
1997	108.91	99.87	115.11	139.02	4.04
1998	114.59	107.38	118.52	128.19	3.55
1999	123.95	121.02	125.33	120.46	43.81
2000	128.50	131.46	131.01	121.84	4.03

Data source: China Steel Statistics 2001

The major challenge for China's iron and steel industry is the decentralization of the whole industry. The following table shows the proportion of different scales enterprises in total annual output. There are still many medium and small scale enterprises in steel market with backward technology and manufactural equipments. This structure is the main cause of China's iron and steel industry's lower energy efficiency. This energy efficiency status can be illuminated by several important ratios in the industry.

Table 4-2. Proportion of different scales enterprises in total annual steel output

Year	Proportion of different scales enterprises in total annual steel output, (%)			
	>5 million tons	3-5 million tons	1-3 million tons	<100 million tons
1990	11.80	19.56	31.69	36.95
1991	11.01	19.75	31.97	37.27
1992	25.46	5.88	29.70	38.96
1993	30.81	3.44	30.09	35.66
1994	31.05	3.28	31.75	33.92
1995	30.95	3.46	29.81	35.78
1996	28.59	4.00	34.44	32.97
1997	27.86	6.64	35.50	30.00
1998	28.00	8.95	39.23	23.82
1999	26.41	16.31	36.27	21.01
2000	27.08	19.49	38.40	15.03

Data source: China Steel Statistics 2001

Table 4-3 .Several important ratios in iron and steel industry

Year	Several important ratios %				
	Iron/steel	Yield of steel product	Proportion of Electric furnace steel	CC ratio	Steel plate add steel tube/total rolled steel
1990	0.94	0.78	21.4	22.3	37.0
1991	0.95	0.79	21.1	26.5	37.2
1992	0.94	0.83	21.8	30.0	37.4
1993	0.97	0.86	23.2	33.9	36.7
1994	1.05	0.91	21.2	39.5	36.6
1995	1.10	0.94	19.0	46.5	39.2
1996	1.06	0.92	18.7	53.3	39.5
1997	1.06	0.91	17.6	60.7	41.0
1998	1.03	0.94	15.8	68.8	38.6
1999	1.01	0.98	15.7	78.1	39.4
2000	1.02	1.02	15.9	82.5	41.86

Data source: China Steel Statistics 2001

These ratios show that product structure may have impact on energy consumption. For example, ratio of iron and steel is the ratio of the output of iron and steel. Pig iron is a kind of high energy intensive product and more output means more energy consumption. When the steel output is fixed, increasing the output of pig iron (that is to say, increasing the ratio of iron and steel) means the increase of average energy consumption per ton of steel. Increasing of proportion of electric furnace steel to total steel will decrease the energy consumption per ton of steel because electric furnace steel will shorten the whole process of steel making. But this ratio will be limited to the acquirability of waste steel. Other ratios also have energy conservation significance. From the above table, China's iron and steel industry has made some progress in energy conservation but some indicators are still at low level even retrogresses.

IV.A.1.ii Employment

Total work force of iron and steel industry is decreasing, from 3152.3 thousand at 1990 to 2515.9 thousand at 2000, along with the increasing of production output. So the productivity of the industry has been improved. The productivity indicator -ton crude steel per employee per year -varied from 21.05 at 1990 to 51.08 at 2000.

Table 4-4. Employment and productivity of iron and steel industry

Year	1990	1995	1996	1998	2000
Work force of iron & steel industry (thousand employee)	3152.3	3423.4	3329.8	2880.5	2515.9
Productivity (ton crude steel per employee per year)	21.05	27.86	30.40	39.78	51.08

Date source: China Iron and Steel Yearbook 2000

IV.A.1.iii Revenues, share of GDP

In the following table, at the year of 2000, iron and steel's proportion of the total gross industrial output added value is 3.28% and share of GDP is only 1.45%. But energy consumption of iron and steel industry is about 10%.Although the share of this industry in total GDP is smaller than ever, it is still an essential basic industry of China's economic. Because it provide steel product, an essential kind of raw material, for the construction of infrastructure and industrial production facilities.

Table 4-5. Output value of iron and steel industry

Year	GIOV of Iron & steel (billion USD)	GIOAV of Iron& steel (billion USD)	China's total GIOAV (billion USD)	Iron & steel's proportion in total GIOAV(%)	GDP(billion USD)	Iron & steel's proportion in GDP(%)
1990	15.83	3.84	82.84	4.64	224.05	1.71
1991	16.75	4.54	97.69	4.64	261.14	1.74
1992	19.20	6.13	124.23	4.93	321.78	1.90
1993	21.55	13.83	170.85	8.10	418.37	3.31
1994	22.34	13.37	233.86	5.72	564.84	2.37
1995	21.93	14.72	298.59	4.93	706.39	2.08
1996	24.27	10.94	351.31	3.11	820.02	1.33
1997	24.46	10.63	391.53	2.72	899.48	1.18
1998	22.39	9.85	403.31	2.44	946.38	1.04
1999	25.10	10.87	423.84	2.56	991.34	1.10
2000	41.88	15.69	477.99	3.28	1079.96	1.45

Note: GIOV: Gross Industrial Output Value
GIOAV: Gross Industrial Output Added Value
GIOV of Iron&teel industry is calculated at 1990 fixed price, others are calculated at current prices
Date source: China Steel Statistics 2000, 2001; China Statistical Yearbook 2001

IV.A.1.iv Role of sector in overall economy as source of inputs to other sectors

As we know, steel product is a kind of main raw and processed materials and is required in the whole economic system. Industry and construction sectors account for the most steel product demand. But along with the adjustment of economic structure, the steel product demand structure is also adjusted. Proportion of construction sector's demand is higher. China has 1.3 billion people and most of them expect improvements in their quality of life -- for instance, they want a bigger house. So during the foreseeable medium and long term, construction sector's demand of steel product will all through be increasing and so total demand of steel product will keep at high level. Then the supply of energy and other resources will under the pressure of this high demand.

Table 4-6. Main receptive sectors for iron and steel's output

Year	Construction (%)	Industry (%)	Transport, Post and Telecommunication Services (%)	Others(%)
1993	29.68	64.21	1.20	4.91
1994	35.84	61.33	1.86	0.97
1995	33.87	63.65	1.62	0.86
1996	38.22	59.62	1.52	0.64
1997	38.45	59.70	1.32	0.53

Data source: China Steel Statistics 1994-1999

IV.A.1.v Role in exports, international trade

Iron and steel industry is a competitive industry sector internationally. Although China is the largest steel production country, output of China's iron and steel industry can't meet the total domestic demand. At 2000, China's share of the world's steel export market is 3.65% and 6.93% of import market. There are two reasons for this gap between demand and supply. One reason is that rapid development of China's economy brings with it a huge demand for steel product; the other is that China's steel enterprises has lower technology capacity and can't produce many kinds of advanced steel product. Before 2000 China was a net import country for steel product (Note: from 2004, China

has become net export country). But the average unit price of imports is much more than the average unit price. Although China plays an important role in the international steel market, there is still huge potential for China's enterprises to participating in international competition and that potentially means the technology advancement and improvement of energy efficiency.

Table 4-7. Imports and exports of iron and steel industry

	Imports			Export		
Year	Volume (10 thousands tons)	Value (100 million USD)	Average Unit Price (USD per ton)	Volume (1000 tons)	Value (100 million USD)	Average Unit Price (USD per ton)
1990	368.26	20.7600	563.7	208.98	6.1970	296.5
1991	332.59	23.5300	707.5	329.33	9.8560	299.3
1992	617.81	33.4800	541.9	326.70	9.9160	303.5
1993	3026.00	110.7600	366.0	112.00	5.3000	473.2
1994	2282.84	87.4400	383.0	174.35	7.4600	427.9
1995	1397.23	66.7270	477.6	592.82	23.3252	393.5
1996	1598.38	71.0039	444.2	421.53	17.5367	416.0
1997	1322.45	65.1141	492.4	461.89	19.3414	418.7
1998	1241.55	62.8677	506.4	356.60	16.8698	473.1
1999	1486.27	70.0775	471.5	368.44	14.1319	383.6
2000	1596.14	85.3589	534.8	620.60	22.2933	359.2

Data source: China Economic and Trade Yearbook 2001

Table 4-8. Exports of semi-finished and finished steel products

	Exports			Imports		
Year	China (thousand metric tons)	The World total (thousand metric tons)	China's share of the world (%)	China (thousand metric tons)	The World total (thousand metric tons)	China's share of the world (%)
1994	2566	238568	1.08	25813	234220	11.02
1995	10745	246624	4.36	14806	236515	6.26
1996	7131	245416	2.91	16537	228348	7.24
1997	8907	267819	3.33	13619	249289	5.46
1998	5863	269541	2.18	13106	255408	5.13
1999	5875	280796	2.09	16998	265073	6.41
2000	11159	305802	3.65	20710	298696	6.93

Important Note: Some of the data in this table are based on exporters' figures and understate the actual volume of imports.
Data source: Statistical Yearbook 2004.International Iron and Steel Institute.

IV.A.2 Quantitative and qualitative characterization of Iron & Steel sector

The following table shows the advancement of the typical plants of China's iron and steel industry from 1990 to 2000. There kinds of plants include iron-making blast furnace, steel-making oxygen blown converter, steel-making electric furnace continuous casting equipment and open-hearth furnace etc. Obviously there has been much advancement in the industry's plants. For instance average production capacity per blast furnace vary from 103.2 m3 at 1990 to 611.7 m3 at 2000. Continuous casting ratio is 82.5% at 2000 comparing with 22.3% at 1990. Open-hearth furnace as an old kind of steel making technology is almost eliminated, and only 2 sets remain in 2000.

Table 4-9. Advancement of Plants in China's Iron and Steel Industry

Typical Plants in iron and steel industry			1990	1993	1995	2000
Iron-making blast furnace	Number	sets	1130	1502	3228	241
	Production Capacity	m3	116595	141765	275397	147427
	Average Production Capacity per plant	m3	103.2	94.4	85.3	611.7
	Coal injection per ton iron	kg/t	37.9	41.2	42.8	117
Steel- making oxygen blown converter	Number	sets	211	240	297	212
	Production Capacity	tons	4911	5811	7175	10070
	Average Production Capacity per plant	tons	23.3	24.2	24.2	35.8
Steel- making electric furnace	Number	sets	1403	1561	3380	204
	Production Capacity	tons	6220	8297	21280	4982
	Average Production Capacity per plant	tons	4.4	5.3	6.3	24.4
Continuous casting equipment	Continuous casting machine	sets	<100	176	267	281
	Continuous casting ratio	%	22.3	33.9	46.5	82.5
Open-hearth furnace		sets	68	70	90	2

Data source: China steel statistics 2001. Data of 2000 is only for key iron and steel enterprises

Table 4-10. Classification of several typical plants of iron and steel industry

	Class of equipment	CO_2 intensity (tCO_2/t)	Total number	Total production capacity per year*1 (mt)	Share of total (%)	Total annual production *2 (mt)	Annual CO_2 *2 (mt)
Blast furnace For iron-making	Total*3	1.25	321	165.47	100.00	202.62	252.85
	>3000m^3	1.09	5	14.23	8.60	17.43	18.91
	2000-2999m^3	1.17	19	32.53	19.66	39.83	46.56
	1000-1999m^3	1.21	31	27.88	16.85	34.14	41.41
	300-999m^3	1.31	184	79.79	48.22	97.71	128.00
	101-299m^3	1.33	70	10.06	6.08	12.32	16.33
	<100m^3	1.37	12	0.98	0.59	1.20	1.64
oxygen blown converter for steel-making	Total*4	0.07	245	163.68	100.00	187.20	12.72
	>300t	-0.01	3	6.78	4.14	7.75	-0.05*5
	100-299t	-0.03	39	47.27	28.88	54.06	1.60
	50-99t	0.08	60	46.27	28.27	52.92	4.07
	11-49t	0.10	141	62.86	38.40	71.89	7.02
	<10t	0.14	2	0.50	0.31	0.57	0.08
Electric furnace for steel-making	Total*4	0.64	182	34.52	100.00	31.37	19.97
	>100t	0.48	13	10.24	29.67	9.31	4.47
	50-99t	0.67	30	12.39	35.90	11.26	7.52
	11-49t	0.73	91	10.70	31.01	9.73	7.12
	<10t	0.80	48	1.18	3.43	1.08	0.86

Note:
*1 Incomplete statistic data for large and medium key enterprises;
*2 Uncertain data, estimated from product capacity by the same proportion
*3 By volume
*4 By weight
*5 Negative energy consumption means energy recovery realized by advanced steel-making converter

Iron production is the highest energy-intensity process during iron and steel production, and accounts for nearly 40% of China's total CO2 emissions from the industry. Blast furnaces between 300-999 m^3 accounted for 50.62% of China's total CO2 emissions from blast furnace in 2003. But average capacity per plant of China's new blast furnace will above 1000m^3. The CO2 intensity of China's largest blast furnaces (>3000 m^3) is 13.06% lower than average level for all furnaces, but the largest blast furnaces account for only 8.60% of total iron production.

In the past decade, the average production of China's iron plants has greatly increased, rising by 617.11% from 1995 to 2000. A similar trend has occurred in steel-making: 47.9% of oxygen blown converters, 287.3% of electric furnaces.

The following table shows that there is huge gap between advanced and laggard plants in China's iron and steel industry:

Table 4-11.Energy efficiency of several main processes in iron and steel industry (GJ/t)

	Sintering	Coking	Iron-making	Converter furnace steel-making	Electric furnace steel-making	Steel rolling
International level 1994	1.73	3.75	12.83	-0.26	5.82	0.00
China 2002 Average	1.99	4.32	13.31	0.79	6.75	2.97
China 2003 Average	1.93	4.13	14.18	0.75	6.17	2.85
China 2004 Average	1.95	4.17	13.66	0.78	6.15	2.72
2004 advanced domestic industry	1.53	2.58	11.59	-0.11	4.29	1.57
2004 laggard domestic industry	3.18	6.72	17.34	2.20	9.54	8.41

Data source: Wang Weixing. Iron and steel enterprises' process energy consumption and energy saving potential. Metallurgy management.2005.6.(in Chinese)

There are two types of iron and steel enterprise in China: key enterprises under the direct supervision of the former Ministry of Metallurgical Industry (MMI) , and local enterprises under the supervision of provincial governments, together with other small plants and non-state-owned enterprises. Before 1980, China's metal and mineral industry was tightly controlled by the MMI, and state-owned enterprises dominated the whole industry. With the reform policy, other types of ownership have been encouraged, and the non-state sector has expanded gradually. But even now, state-owned and state-holding enterprises still dominates the whole enterprises and new industry policy promulgated at 2005 encouraged the concentration of the industry.

Table 4-12.Structure of enterprise iron and steel industry

Type of Enterprises		State-owned and State-holding Enterprises		Urban Collective-owned Enterprises	
Year	Total	Enterprises number	Share of total output value	Enterprises number	Share of total output value
2003	267	66	78.29	46	3.82
2004	306	51	70.18	36	3.57
2005	385	43	46.49	28	4.73
Share Joint Ownership Enterprises		Share Holding Enterprises		Foreign-Funded (including Hong Kong, Macao and Taiwan) Enterprises	
Enterprises number	Share of total output value	Enterprises number	Share of total output value	Enterprises number	Share of output value
6	0.60	125	35.99	20	5.67
6	1.39	167	48.82	22	7.44
6	0.11	238	62.85	32	13.84

Note: Date of different type enterprises overlaps each other.
Data source: MacroChina industrial database

IV.B Emissions Overview of Sector

IV.B.1 Background and discussion of emissions

The following figure presents a simplified schematic of the production route. As we know iron and steel industry is a major energy consuming sector and source of greenhouse gases and other pollutants. Greenhouse gas emissions in the iron and steel sector are primarily the result of burning fossil fuels during the production of iron and steel.

The whole process can be divided into three parts: iron making, steel making and steel products making. Each part has several processes and has specific energy conservation technology. During the iron making process, sintered or pelletized iron ore is reduced using coke (produced in coke ovens) in combination with injected coal or oil to produce pig iron in a blast furnace. Limestone is added as a fluxing agent. Reduction of the iron ore is the largest energy-consuming process in the production of primary steel. Smelt reduction processes are the latest development in pig iron production and omit coke production by combining the gasification of coal with the melt reduction of iron ore. Processes under development include COREX, CCF, DIOS, AISI, and HISmelt. Currently, only few technology for instance the COREX process (Voest-Alpine, Austria) is commercial.

Currently there are two main routes for the production of steel: production of primary steel using iron ores and scrap and production of secondary steel using scrap only. Oxygen blown converter and electric furnace are two major kinds of plants for current steel making. A wide variety of steel products are produced by the industry, ranging from slabs and ingots to thin sheets, which are used in turn by many other manufacturing industries. (Worrell et al., 1997).

Future energy conservation in China's iron and steel industry has two directions: one is the application of specific energy conservation technology such as coke dry quenching, coal power injection etc. The other is the adjustment of whole production process structure, for instance introducing smelt reduction process for iron making and increasing the proportion of electric furnace steel.

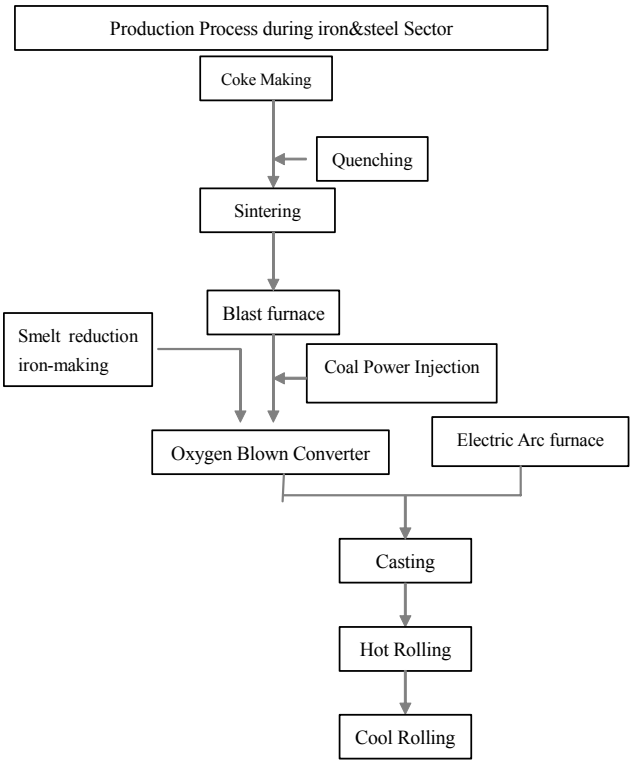

Figure 4- 1.Major processes in iron and steel industry

IV.B.2 Historical annual fuel consumption and GHG emissions trends over time

The following tables separately show total historical annual fuel consumption and CO2 emission if iron and steel industry and more detailed information by fuel type. At the year of 2000, total annual fuel consumption of China's iron and steel industry is 3888.24 PJ, rising by 34.39% from 1990. The similar trend occurs in annual CO2 emission, rising by 29.54% from 1990 to 2000.

In the total fuel consumption, coal is the most important fuel. In 2000, coal accounted for about 70% of total fuel consumption, including 46.06% coking coal and 24.95% power coal. Most of the remaining part is electricity. As all know, electricity production in China mainly depends on coal. So coal is the most important fuel type in China's iron and steel industry. This fuel structure also increases the emission per unit production.

Table 4-13. Total annual fuel consumption and CO2 emission of iron and steel industry[28]

Year	Total Annual Fuel Consumption, all Fuels (PJ)	Annual GHG Emissions ($MMTCO_2e$)
1990	2893.29	271.19
1991	3037.19	285.05
1992.	3156.18	296.77
1993	3395.04	319.85
.1994	3547.73	334.49
1995	3631.55	342.68
1996	3800.95	359.78
1997	3713.91	352.58
1998.	3760.22	357.11
1999	3771.94	359.27
2000	3888.24	351.50

Data source: Fuel consumption data is from China steel statistic 2001 and GHG emission data is estimated by author.

[28] Note: In this table, fuel consumption data is comprehensive fuel consumption, which includes energy used in iron and steel production but also other energy consumption in the industry, such as services, transportation in the factories, etc. In macro statistical data, "fuel consumption" sometimes means comprehensive fuel consumption, but in the statistical data from steel industry, "comprehensive" is distinguished from "comparable" energy consumption (fuel used for direct iron and steel production only). In this analysis we take into account all production process fuel use and corresponding assistant energy consumption, and in a sense that is comprehensive fuel consumption. According to relevant literatures (Zhou Dadi et al.,2003), the share of the energy not directly used in production in the total energy consumption is about 20%. So in the following context, if not specifically noted, energy consumption in the scenario analysis results of steel industry is comprehensive, which is also called integrated energy consumption. This energy consumption will be higher than that obtained in results calculated using only comparable production process energy (approximately 80% of the comprehensive consumption), but the extra portion of the energy consumption is also a necessary part of steel production in China's iron and steel industry.

Table 4-14. Historical annual fuel consumption and GHG emissions by fuel type

Year	Fuel Type	Annual Fuel Consumption (PJ)	Share of Total Annual Fuel Consumption (%)	Annual GHG Emissions ($MMTCO_2e$)	Share of Total Annual GHG Emissions (%)
1990	Coking coal	1459.08	50.43	135.60	50.00
	Power coal	531.21	18.36	48.48	17.88
	Electricity	686.29	23.72	72.89	26.88
	Fuel oil	187.77	6.49	12.79	4.72
	Natural gas	28.93	1.00	1.43	0.53
1991	Coking coal	1561.11	51.40	145.08	50.90
	Power coal	553.68	18.23	50.54	17.73
	Electricity	709.49	23.36	75.36	26.44
	Fuel oil	184.66	6.08	12.57	4.41
	Natural gas	30.37	1.00	1.50	0.53
1992	Coking coal	1593.24	50.48	148.07	49.90
	Power coal	564.96	17.90	51.56	17.37
	Electricity	778.31	24.66	82.67	27.86
	Fuel oil	193.47	6.13	13.17	4.44
	Natural gas	26.20	0.83	1.29	0.43
1993	Coking coal	1681.22	49.52	156.25	48.85
	Power coal	609.41	17.95	55.62	17.39
	Electricity	873.88	25.74	92.82	29.02
	Fuel oil	202.00	5.95	13.75	4.30
	Natural gas	28.52	0.84	1.41	0.44
1994	Coking coal	1776.70	50.08	165.12	49.36
	Power coal	648.53	18.28	59.19	17.70
	Electricity	898.64	25.33	95.45	28.54
	Fuel oil	196.19	5.53	13.36	3.99
	Natural gas	27.67	0.78	1.37	0.41
1995	Coking coal	1782.73	49.09	165.68	48.35
	Power coal	687.82	18.94	62.78	18.32
	Electricity	933.31	25.70	99.13	28.93
	Fuel oil	205.55	5.66	14.00	4.09
	Natural gas	22.15	0.61	1.09	0.32
1996	Coking coal	1941.91	51.09	180.47	50.16
	Power coal	708.12	18.63	64.63	17.96
	Electricity	961.64	25.30	102.14	28.39
	Fuel oil	170.28	4.48	11.59	3.22
	Natural gas	19.00	0.50	0.94	0.26
1997	Coking coal	1903.01	51.24	176.86	50.16
	Power coal	673.33	18.13	61.46	17.43
	Electricity	973.79	26.22	103.43	29.33
	Fuel oil	147.07	3.96	10.01	2.84
	Natural gas	16.71	0.45	0.83	0.24
1998	Coking coal	1869.96	49.73	173.79	48.66
	Power coal	767.46	20.41	70.05	19.62
	Electricity	973.90	25.90	103.44	28.97
	Fuel oil	132.74	3.53	9.04	2.53
	Natural gas	16.17	0.43	0.80	0.22
1999	Coking coal	1808.65	47.95	168.09	46.79
	Power coal	827.94	21.95	75.57	21.03
	Electricity	1013.14	26.86	107.61	29.95
	Fuel oil	105.24	2.79	7.17	2.00
	Natural gas	16.97	0.45	0.84	0.23
2000	Coking coal	1790.92	46.06	158.21	45.01
	Power coal	970.12	24.95	84.18	23.95
	Electricity	1009.39	25.96	101.90	28.99
	Fuel oil	94.87	2.44	6.15	1.75
	Natural gas	22.94	0.59	1.09	0.31

Data source: Fuel consumption data is from China steel statistic 2001 and GHG emission data is estimated by author based on emission factor of different fuel from IEA of China[29]

[29] HU Xiulian, JIANG Kejun, et al. Evaluation of Technology and Countermeasure for Greenhouse Gas Mitigation in China[M].Beijing: China Environmental Science Press, 2001. (in Chinese)

IV.B.3 Relative contribution of each sector in 2000

China's iron and steel industry share 9.95% of total energy consumption in 2000 and share of China's total CO2 emission is 9.88%, about 322.58 million tones.(Date source: China Statistical Yearbook 2002).Being the largest steel production country, China is also the largest emitting country in iron and steel industry, accounting for 65.22% to top 10 emitting developing countries and 30% to total world sector emission in 2000.(Date source: CCAP)

IV.C Background Assumptions for Sector Analysis

In the sector analysis for iron and steel industry, a scenario analysis method based on LEAP model has been used. In the model, abundant bottom-up technologies are included, and many kinds of policies which affect the adoption of specific technology are assumed based on current exiting industry policy.

IV.C.1 Baseline with policies adopted before 2000

IV.C.1.i Policies under Consideration

The government of China has consistently focused on energy conservation in the energy intensive industries, and iron and steel industry is one of the key industries.

By the year 2000,the Chinese government had formulated energy conservation plans from the sixth to the tenth five-year plan periods and the energy conservation plan for each year, identified concrete development goals ,key projects and principal policies for energy conservation.

Starting from 1980s, the Chinese government established and applied standards, labeling and certification of energy efficiency and effectively boosted the work on energy conservation and raising energy efficiency. Starting from 1980, government established enterprise energy balance and energy consumption standards systems in iron and steel sector. Since then, it has alloted concrete energy conservation tasks and assessed enterprises through energy conservation indexes such as integrated energy consumption per ton steel, total annual energy conservation, etc.

Since 1980s, the relevant departments successively promulgated and implemented a series of policies and regulations to direct and standardize sector development and energy conservation of iron and steel sector. In the industry technology policy some backward technologies and equipments are identified and needed to be eliminated such as mold casting, open healthy furnace, small blast furnace, small electric furnace etc. On the other way, these technology policies also boost the application of some new energy conservation technologies and equipments such as continuous casting, coke dry quenching, coal power injection, reuse of blast furnace gas, etc.

The Chinese government has drafted and implemented a series of incentive policies in terms of finance, credit and taxation toward energy conservation projects, including interest payment rebates, differential interest rates, revoking of import taxes, reductions of income tax of enterprises and accelerate depreciation, etc. These measures have been applied to energy conservation technical upgrade projects and purchase of energy conservation equipment. Furthermore, the relevant government promulgated and implemented some rules and standards about equipment design and production process energy conservation.

IV.C.1.ii Assumptions about the Effectiveness of Policies

In scenario analysis, the above policies are the basis of technology selection. And in our model, we convert this information into different proportions of selected specific technology.

From the above policies we can see major energy conservation technologies have been identified and already have high priority. But the initial goal of these policies is to encourage steel enterprises to

save energy consumption and decrease production cost. So in the assumptions of baseline scenario, these policies' effectiveness is limited.

IV.C.2 Baseline with policies adopted between 2000 and 2005

IV.C.2.i Policies under Consideration

Starting from 2000, based on existing polices, measures and standards, some new polices with more ambitious objective are promulgated and implemented.

In 2004, the National Development and Reform Commission promulgated "China medium and long term energy conservation plan". Iron and steel sector is listed in the key area of energy conservation. In this plan energy consumption indicators of per unit main product including steel are enacted from year 2000 to 2020. The basic principle is "at 2010,in the mass reach or near the advanced world level of the early year of the 1990s, thereinto large and medium sized corporation reach the advanced world level of the early years of this century; reach or near the advanced world level in the 2020."

In 2005, NDRC promulgated "China iron and steel industry development policy" This new policy indicates a further restructuring of the steel industry in the future. The policy is a guideline for the long-term development of China's iron and steel industry aiming to increase the concentration of steel production by the large State-owned steel makers such as Baosteel and to boost the industrial upgrading of the steel sector through new technologies and management and production efficiency.

The policy covers very detailed aspects of the steel sector, from corporate management to government macro-controls. The new policy sets new requirements for steel makers in China in a number of different areas including the scale of production and efficiency, technical expertise, energy consumption and environmental protection performance. So a large number of medium and small-sized steel companies are facing being closed down or be merged by larger steel enterprises. Minimally, these medium and small-sized steel companies need to upgrade their old steel production equipments.

According to the policy, a raft of market measures such as tax rebates will also be introduced to promote the high value-added steel production.

IV.C.2.ii Assumptions about their effectiveness

Comparing with the policies before 2000, policies adopted between 2000 and 2005 had some characteristics. These new policies emphasize on sustainable development and the restructure of the industry. Energy conservation is a kind of indicator for the increasing of the industry's competition capacity not only a way for production cost decreasing.

These new policies have some medium and long-term development objectives and these objectives including the future industry structure and share of specific technology are the basis of model's future scenarios definition.

But these policies still haven't dealt with climate change mitigation options, because there have been no clear climate change policies in China. The objective of these new polices is ambitious, but there is a large emission reduction potential in China's iron and steel industry, and mitigation is the focus of our analysis.

IV.C.2.iii Assumptions about the Clean Development Mechanism in the sector

There is huge CDM project potential in China's iron and steel industry. But because of the high transaction cost and comparative small capital size of CDM projects, there is some barriers existing in CDM projects development in iron and steel industry. And currently in China, projects in renewable

energy exploitation and landfills gas recovery and utilization have higher priority. So, in this project, CDM will not play an important role in iron and steel sector.

IV.C.3 Sources for assumptions

In the scenarios definition, our main task is to confirm the technologies' development trend, and the proportion of specific technology. The above polices and their measures and objectives are the main sources for our assumptions. Then we used other similar research for useful related information. These research reports include: Research Report of Structure Adjustment Strategy and Related Policy for China High Energy Intensity Industries (China Information Center for Resources Conservation and Comprehensive Utilization), China Sustainable Energy Scenarios in 2020 (ZHOU Dadi, et al.) and Evaluation of Technology and Countermeasure for Greenhouse Gas Mitigation in China(HU Xiulian, JIANG Kejun, et al.)

IV.C.4 Description of analytical approach and methodology

In the LEAP model, data structure of iron and steel industry is layered based on the industry's technology characteristic. The first layer is divided by different processes. Traditional process includes coke making, sintering, blast furnace iron making, oxygen blown converter steel making, casting, hot rolling and cool rolling. The final production is steel product. Coke dry quenching and coal power injection in the blast furnace are separated. Then in the whole process, electric furnace and smelt reduction iron making technology are included. The second layer of data structure is the classification of facilities in each process according to their scale and level of advancement. In scenario definition, the proportion of different facilities should be adjusted. On the third layer, for each kind of facility, model links unit production energy consumption factor, CO2 emission factor and cost factor and gather all energy consumption from bottom to up.

In the analysis of iron and steel industry, total emission includes industrial process emission from CaCO3 in the production of iron making.

IV.D Baseline (Business as usual) Forecasts for sector

IV.D.1 Production/output forecast

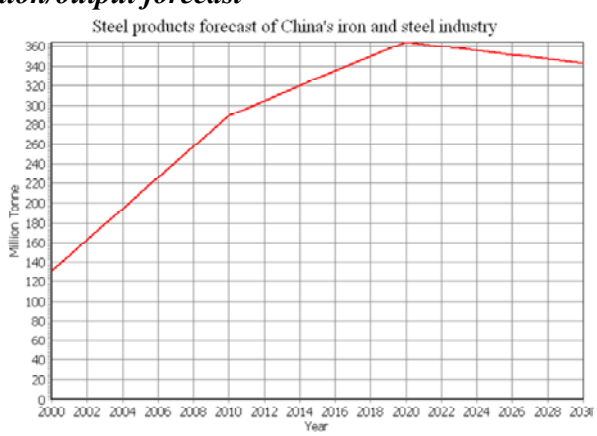

Figure 4-2.Output forecast of steel product in China's iron and steel industry

The industry's output forecast is the first stage of whole analysis process. But it is difficult to forecast the output of China's iron and steel industry into medium and long term. The following figure shows the forecast results. Before 2010, due to the Beijing Olympic Games and other large construction projects, domestic demand of steel product will increase rapidly, then after 2010 the increase will be slow and reach the peak at 2020. From then on production will keep at steady level and decrease

slowly. China's domestic demand is mostly met by domestic production, so the production trend is similar to the demand trend. [30]

According to this assumption, total steel products of China during 2000 and 2030 will be 9.147 billion tons. As a reference we can see the total accumulative steel assumption amount. During 1901 and 2004, accumulative steel assumption amount of USA is 8.2 billion tons, Former Soviet Union is 6.0 billion tons, Japan is 3.8 billion tons and China is 3.0 billion tons (Luo, 2005). So although there exits many uncertainties in steel production output forecast, we can judge that the rough trend is reasonable.

IV.D.2 Energy and fossil fuel consumption forecast

In our analysis, one important assumption is all scenarios have the same production forecast, and we don't divide the baseline scenarios into A2 and B2 scenarios. Two baseline scenarios have similar trend for energy consumption and CO2 emission. But due to some new industry policies, energy consumption and GHG emission of baseline between 2000 and 2005 will lower than baseline pre 2000. The following figures show the initial forecast results.

Before 2010, increase of production is the main driving force for energy consumption and all fuels consumption keep increasing rapidly. Then, technology advancement will play more important role in total energy consumption especially along with the slow decreasing of production.

From comparison of energy consumption of different processes, energy consumption in blast furnace iron making account for the largest proportion especially in the near future. In the longer term, along with the industry restructuring (more electric furnace steel and more smelt reduction iron) and the advancement of blast furnaces, this proportion will be lower.

Because of the adoption of more advanced facilities which have higher priority in those new policies between 2000 and 2005, the energy consumption of the baseline (2000-2005) will be lower than baseline pre 2000 at each year. And the industry's restructure will also more rapid.

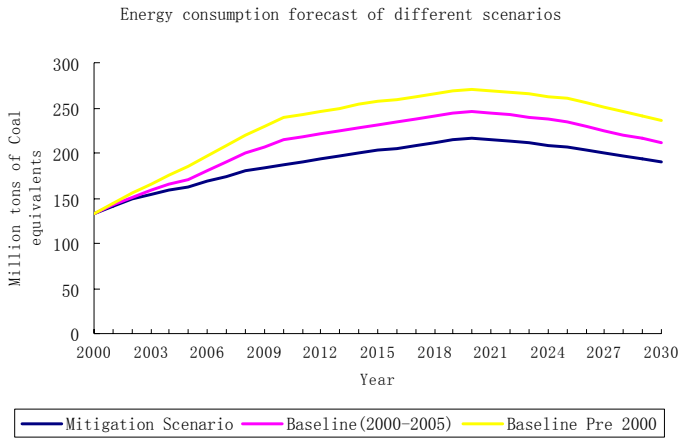

Figure 4-3.Energy consumption forecast of different scenarios

[30] It is difficult to forecast the output of China's iron and steel industry into the medium and long term. In the forecast of the steel production output, in order to simply the analysis process and acquire the core trend one important assumption is that output will be driven by domestic demand and import and export are not included. At present and in the future China's huge steel products demand will mainly rely on domestic production, and import will have only a small impact. In the following analysis, one important assumption is that all scenarios have the same production forecast. Such an assumption can ignore the uncertainties from production forecast and help the researcher focus on the analysis of the differences among scenarios, which is mainly due to industrial restructuring and technological advancing. So the slight absolute decline in production post-2020 is due to a drop in domestic demand leads to a steady and decline gradually trend post 2020, because 2020 is an important landmark year for China's development aiming to reach the level of moderately developed countries.

The figure with cumulative energy conservation between two baseline scenarios shows this huge potential. From 2000 to 2030, total energy conservation between these two baseline scenarios will be about 19 PJ; even not taking account of mitigation measures for climate change, the commitment of current sustainable development industry policies will thus bring a huge energy conservation and corresponding GHG emission reduction. For China's iron and steel industry, there is heavy historic burden and the commitment of current policy faces many barriers. This is a good starting point for the restructure of the whole industry, and is also a good basis for carrying out mitigation measures dealing with climate change.

The following figures about annual GHG emission forecast show the same trend.

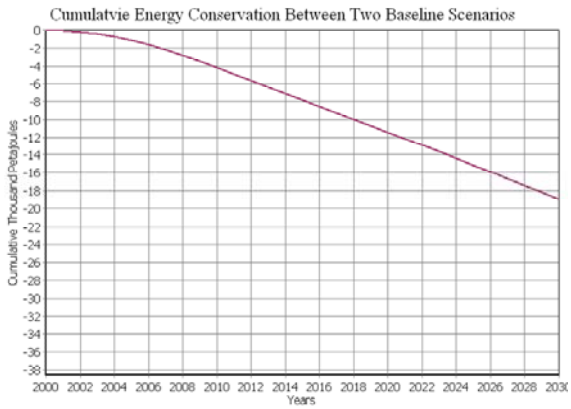

Figure 4-4. Accumulative energy conservation between two baseline scenarios

IV.D.3 Annual GHG forecast

IV.D.3.i <u>Total GHG emissions</u>

CO2 emissions in baseline pre 2000 increase from 351.50 million tonnes in 2000 to 632.78 million tonnes, at 2010. Then the growth rate will slow and reach the peak of annual emission at 2020, 717.46 million tonnes. Then annual emission keeps decreasing, and drops to 626.59 million tonnes at 2030.

Similar trend occurs for baseline with policies between 2000 and 2005. At 2010, emissions are 567.18 million tonnes, 65.6 million tonnes lower than baseline pre 2000. At 2020 and 2030, the emissions are respectively 653.92 and 559.13 million tonnes, and differences between two baselines are respectively 63.54 and 67.46 million tonnes.

The cumulative CO2 emission reduction between two baselines from 2000 to 2030 will be 1691.33 million tonnes.

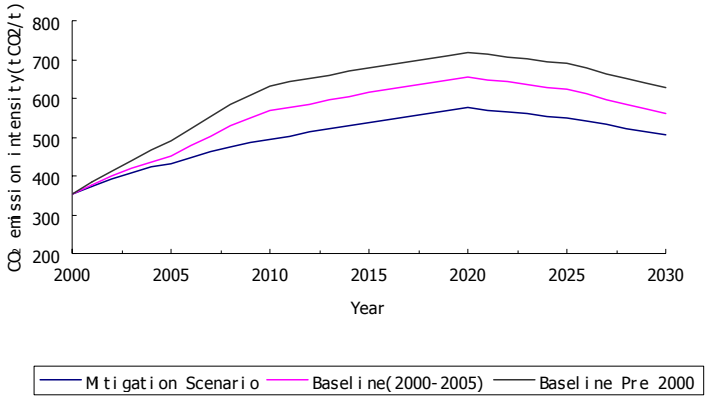

Figure 4-5.CO_2 emission forecast of different scenarios

Table 4-15 compares CO2 emission of different scenarios.CO2 emission of 2000 is assumed to be 1.00, then at 2010, emissions of three scenarios are respectively 1.80 times,1.61 times and 1.41 times to the emission of 2000. At 2020, the peak of annual emission, emissions are, respectively 2.04 times ,1.86 times and 1.64 times to the emission of 2000. In the meantime, steel product of 2020 is 2.78 times to 2000. This is mainly due to the reduction of emissions intensity through technological progress leads to.

Table 4-15 Compare of CO_2 emission of different scenarios (CO_2 emission of 2000 is 1.00)

Year	2000	2010	2020	2030
Baseline（Pre 2000)	1.00	1.80	2.04	1.78
Baseline(2000-2005)	1.00	1.61	1.86	1.59
Mitigation Scenario	1.00	1.41	1.64	1.44

IV.D.4 Energy intensity and CO_2 intensity forecast (per unit of output)

Total energy consumption and CO2 emission will be affected by industry output and technology advancement and at the early years the output increasing is the main driving force. So energy intensity and CO2 intensity are more appropriate in the description of technology advancement.
The following two figures show the change trend of energy intensity and CO2 emission intensity of three different scenarios.

For each baseline, energy intensity and CO2 intensity keep descending. Before 2010, the declining of intensity indicators is faster then the trend curve is more smooth. This trend accords with the judgment of many industry researchers, because currently relatively backward general technology level of China's iron and steel industry means greater scope for progress. Then the technology advancement will be difficult because the cost will rise sharply and the benefit will not always be obvious. In addition the products structure will also change and the industry will produce more advanced steel products. That means deeper processing for products and more energy consumption. For the industry this change is encouraging because the industry's competitiveness capacity will be upgraded, but on the other hand the energy consumption and emission intensity will be higher.

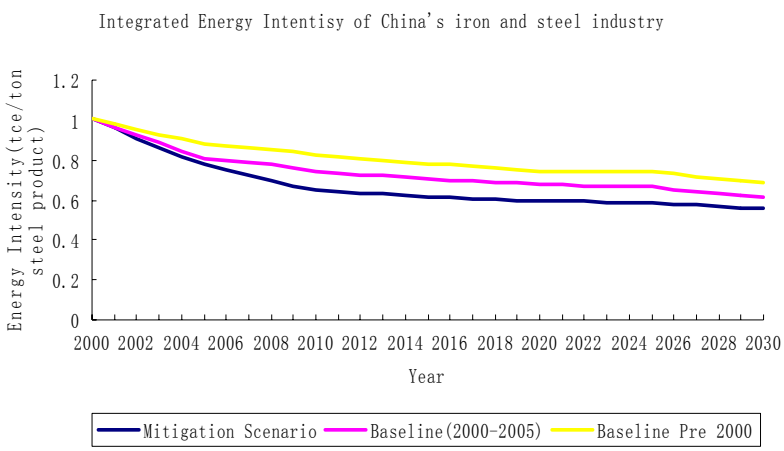

Figure 4-6.Integrated energy intensity of China's iron and steel industry

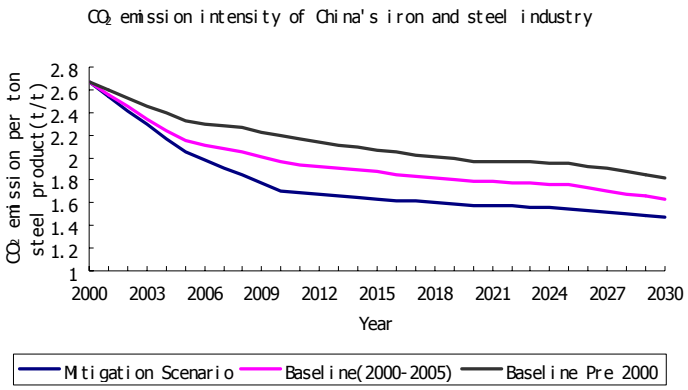

Figure 4-7.CO_2 emission intensity of China's iron and steel industry

The following table shows this trend. Energy intensity of baseline pre 2000 decreases from 29.6 GJ/metric tonne in 2000 to 20.2 GJ/metric tonne in 2030, about 68% of initial level. For baseline (2000-2005), energy intensity level at 2030 is only 60.89% of initial level. From 2000 to 2030, CO2 intensity of baseline pre 2000 declines by 31.7%. For baseline between 2000 and 2005, declining by 39.07%.

Greater degree of decline will occur in the mitigation scenario because of stronger industry restructuring and technological progress. CO2 emission intensity in 2030 will decline by 46% from 2000.

Table 4-16. Energy and CO_2 intensity of two baselines in iron and steel industry

	Baseline (Pre 2000)		Baseline (2000-2005)		Mitigation Scenario	
Year	Energy Intensity (GJ/metric ton)	CO_2 Intensity (tCO_2/t)	Energy Intensity (GJ/metric ton)	CO_2 Intensity (tCO_2/t)	Energy Intensity (GJ/metric ton)	CO_2 Intensity (tCO_2/t)
2000	29.59	2.675	29.59	2.675	29.59	2.675
2005	25.75	2.325	23.75	2.145	22.71	2.052
2010	24.26	2.19	21.74	1.963	18.94	1.712
2015	22.94	2.07	20.72	1.872	18.10	1.638
2020	21.83	1.971	19.86	1.796	17.45	1.581
2025	21.63	1.953	19.49	1.763	17.15	1.554
2030	20.23	1.827	18.02	1.63	16.30	1.447

IV.E Main results of baseline scenarios

For mitigation scenarios, we carry out a deeper analysis with specific mitigation options. The following two tables concluded main results of above two baselines including total production, total fuel consumption and fuel consumption by fuel type, total GHG emission, energy intensity and emission intensity.

Table 4-17. Main results about energy consumption and CO_2 emission for baseline pre 2000

Year	Total Production (million metric tons)	Total Fuel Consumption (PJ)[31]						Total GHG Emissions ($MMTCO_2e$)	Energy Intensity (GJ / metric ton)	Emissions Intensity (MT CO_2e / metric ton output)
		coking coal	power coal	electricity	fuel oil	natural gas	All Fuels			
2000	131.42	1790.92	970.12	1009.39	94.87	22.94	3888.24	351.50	29.59	2.675
2005	210.21	2361.60	1354.07	1551.16	108.84	36.26	5411.92	488.71	25.75	2.325
2010	289.01	2899.15	1712.51	2219.18	124.37	57.50	7012.71	632.78	24.26	2.189
2015	328.00	2946.64	1738.65	2628.57	138.04	71.47	7523.36	678.96	22.94	2.070
2020	364.00	2949.04	1761.98	3065.79	110.37	60.40	7947.57	717.46	21.83	1.971
2025	353.50	2687.81	1645.38	3079.74	181.66	51.23	7645.82	690.32	21.63	1.953
2030	343.00	2311.33	1480.29	2944.62	143.33	60.38	6939.96	626.59	20.23	1.827

Table 4-18. Main results about energy consumption and CO_2 emission for baseline (2000-2005)

Year	Total Production (million metric tons)	Total Fuel Consumption (PJ)[32]						Total GHG Emissions ($MMTCO_2e$)	Energy Intensity (GJ / metric ton)	Emissions Intensity (MT CO_2e / metric ton output)
		coking coal	power coal	electricity	fuel oil	natural gas	All Fuels			
2000	131.42	1790.92	970.12	1009.39	94.87	22.94	3888.24	351.50	29.59	2.675
2005	210.21	2175.92	1249.18	1431.01	103.16	33.45	4992.72	450.91	23.75	2.145
2010	289.01	2590.54	1534.09	1987.97	117.97	51.51	6282.08	567.18	21.74	1.962
2015	328.00	2651.21	1570.27	2374.02	134.74	64.55	6794.80	613.92	20.72	1.872
2020	364.00	2669.26	1602.91	2789.02	113.94	54.95	7230.07	653.92	19.86	1.796
2025	353.50	2406.94	1482.77	2775.39	178.96	46.17	6890.22	623.17	19.49	1.763
2030	343.00	2043.42	1318.68	2623.12	143.23	53.78	6182.25	559.13	18.02	1.630

[31] All of the energy or emissions numbers in the baselines, mitigation measures, or mitigation scenarios include electricity purchased from the local power grid. Share of electricity in total energy consumption in China's iron and steel industry is about 25% in 2000, and this proportion will rise according to the restructure of production process. Emissions factor assumed for electricity is from other similar research (Hu and Jiang, 2001) and the number is 0.1262 tCO_2/GJ

[32] All of the energy or emissions numbers in the baselines, mitigation measures, or mitigation scenarios include electricity purchased from the local power grid. Share of electricity in total energy consumption in China's iron and steel industry is about 25% in 2000, and this proportion will rise according to the restructure of production process. Emissions factor assumed for electricity is from other similar research (Hu and Jiang, 2001) and the number is 0.1262 tCO_2/GJ

Table 4-19. Main results about energy consumption and CO_2 emission for mitigation scenario

Year	Total Production (million metric tons)	Total Fuel Consumption (PJ)						Total GHG Emissions ($MMTCO_2e$)	Energy Intensity (GJ/metric ton)	Emissions Intensity (metric tons CO_2e/metric ton output)
		coking coal	power coal	electricity	fuel oil	natural gas	All Fuels			
2000	131.42	1790.92	970.12	1009.39	94.87	22.94	3888.24	351.5	29.59	2.675
2005	210.21	2059.70	1194.49	1381.83	106.13	31.99	4774.14	431.24	22.71	2.051
2010	289.01	2212.24	1336.85	1766.65	113.77	44.89	5474.39	494.77	18.94	1.712
2015	328.00	2247.21	1372.02	2136.15	125.16	56.40	5936.94	537.15	18.10	1.638
2020	364.00	2252.53	1408.53	2548.73	95.26	48.28	6353.34	575.62	17.45	1.581
2025	353.50	1946.75	1304.70	2711.73	66.83	32.74	6062.75	549.22	17.15	1.554
2030	343.00	1689.30	1192.74	2556.13	105.02	48.65	5591.84	506.49	16.30	1.477

IV.F GHG Mitigation Options and Costs

Mitigation options and costs are the basis of mitigation scenarios analysis. In this section, we will give an overview of each appropriate mitigation option, characteristic of each mitigation option, their costs, their emission reduction potential etc.

IV.F.1 Selection criteria for consideration of mitigation options

When considering the selection of mitigation options in iron and steel industry, several selection criteria need to be followed. They are cost, potential carbon emission, technology feasibility, technology availability, technology application complexity and the linking with current technology level.

Among these criteria, cost and marginal abatement cost of each measure and technology have high priority in the selection of mitigation options.

But cost is not the only factor. In China's iron and steel industry, technology innovation is not without foundation. In some way, different technology measures with different cost will be integrated into one consistent technology innovation plan. So in scenario analysis it will not happen that the applied proportion of A technology is 100% and B technology is 0% if marginal abatement cost of A technology is lower than B.

IV.F.2 Overview of each mitigation option evaluated

In the mitigation scenarios analysis for iron and steel industry, four kinds of measures are considered: energy management, structure adjustment, application of larger scale and more advanced plants and specific energy conservation technology.

Energy management: establishment of energy management center. EMC is a kind of managing mitigation option, but it also covers technologies, gathering information from first time users of technology, and optimizing utilization and allocation of different fuels – one example was the EMC set up in Shanghai. One estimate indicates that establishment of EMC across China will reduce by 5% the energy use for China's iron and steel industry (Huang, 2006; CICRCCU, 2002).

Structure adjustment: share of electric furnace steel, share of smelt reduction iron, proportion of casting, proportion of cool rolling etc.

Application of larger scale and more advanced plants: larger-scale blast furnace (including TRT technology and blast furnace gas recovery technology), larger-scale oxygen blown converter (also including oxygen blown converter gas recovery technology), higher power electric furnace, larger-scale sintering machine etc.

Specific energy conservation technology: dry coke quenching, coal power injection, construction and reconstruction of continuous casting machine.[33]

Energy consumption factor, emission factor and cost information of each measure are based on relevant literature and few of them is from experts interview in this field[34]. Cost information includes fixed cost and variable cost. Fixed cost mainly refers to the cost of facilities (including purchase, installation and maintenance etc. and amortizing to per ton products during their lifetime) .Variable

[33] In China's steel industry, cogeneration such as the recycle of waste gas and heat has been seen as an important mitigation option. In our model, in order to cover all energy consumption and CO_2 emission, recycle of waste gas and heat are included in larger scale and more advanced plants for instance blast furnace and converter. That means more advanced plants are equipped with relevant waste heat recovery equipment, and the energy consumption factor of these plants will be also linked with negative energy consumption factors because they recovery heat.

[34] Hu and Jiang, 2001.Zhang , 2006; Huang, 2006

cost mainly refers to energy cost and sometimes raw material cost. Energy cost information is based on the prices of 2000[35].

All parameters are based on the information of 2000. In order to describe future change, we add a whole technology development ratio that means energy consumption factor of each measure will be lower along with time.[36] Some measure such as energy management only have potential in the near future, and some technology such as smelt reduction iron making process will have potential in medium and long term. At present this kind of technology is too expensive to be applied.

This analysis approach can only consider exiting technologies and cannot cover possible technology innovation in the future.

IV.F.3 Marginal abatement cost of each mitigation option

The following table lists all potential mitigation options in our model and the corresponding marginal abatement cost information. Measure for management capacity increasing such as establishment of energy management center in steel enterprises has higher priority in the early years during scenarios analysis period. But along with the industry development, although the management measure cost will be lower the emission reduction potential will also be slow. So the cost effectiveness will decline. A similar thing occurs to BF coal power injection technology and continuous casting equipment etc.

Table 4-20.Marginal abatement cost of mitigations options

Mitigation Option	Cost Effectiveness of 2010 ($/metric ton CO_2e)	Cost Effectiveness of 2010 ($/metric ton CO_2e)	Cost Effectiveness of 2020 ($/metric ton CO_2e)
Establish energy management center and increase management capacity	-66.20	-14.89	-3.57
Increase coal power injection level	-60.08	-1.24	
More advanced continuous casting machine	-24.30	-22.64	
More advanced blast furnace with TRT	3.28	3.59	5.36
Apply dry coke quenching	4.95	11.35	30.36
More advanced coke oven	6.23	3.79	3.03
Adjust ratio of iron/steel	30.02	15.99	8.19
More advanced sinter machine	43.27	38.16	31.63
More advanced direct steel rolling machine	57.99	51.48	34.88
More advanced oxygen blown converter for steel-making	87.64	75.80	60.96
Apply smelt reduction iron-making process	146.68	82.85	52.67
More advanced electric furnace for steel-making	211.14	165.78	131.39

[35] We add fuel price index in the analysis. They are showed the next footnote. In China, the energy market is not an entirely competitive market. So the international energy market (especially oil market) will not determine the domestic energy market. Moreover, in steel industry, coal and electricity from coal plants are the main fuel types. So the price index will not match the general international oil price assumption.

[36] Some general assumptions in scenario definition.

		2010	2020	2030
Whole energy efficiency improvement ratio annual	Scenario 1	1‰	1.5‰	2‰
	Scenario 2	2‰	2.5‰	3‰
	Scenario 3	3‰	3.5‰	4‰
Fuel price index	Coal	1.1	1.2	1.3
	Electricity	1.2	1.3	1.4
	Natural gas	3	3.5	3.7
	Fuel oil	1.2	1.3	1.5
Exchange rate	1 US. dollar =8.2784 Yuan RMB			
Discount rate	10%			

IV.F.4 Share of different mitigation options in total emission reduction

We have mentioned that emission gap between two baseline scenarios is for the emission reduction potentials through China's current sustainable development policies and measures. The emission gap in the following context is the difference between mitigation scenario and baseline scenario (2000-2005) and it presents further mitigating effort based on current polices. That means more capital and more technology demand. This kind of potential will accord with the following listed mitigation options.

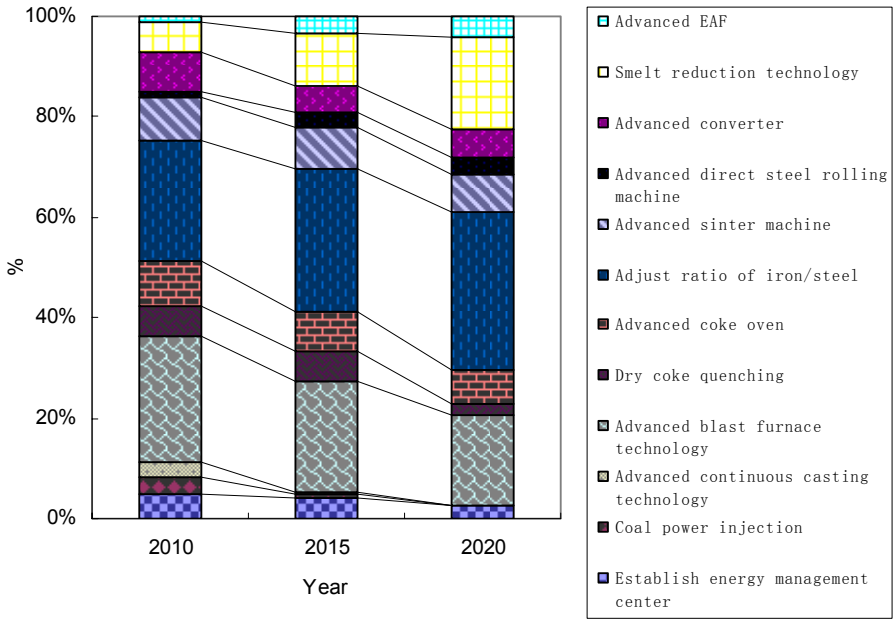

Figure 4-8.Share of different mitigation options in total emission reduction

From Figure 4-8, different mitigation options have different emission reduction potential and the share of each kind of option will change. Share of some negative-cost mitigation options which include energy management center, BF coal power injection and continuous casting will decrease from 2010 to 2020. More specifically, coal power injection and continuous casting technology will not be the candidate mitigation options. In China's steel industry, continuous casting rate is much high and future development scope is small. Similarly, China's steel industry has already made great progress in the application of coal power injection technology. More coal power injection level will be difficult because this technology needs higher standards in the design of blast furnace.

Share of some specific energy conservation technology will also decrease for example advanced blast furnace technology, dry coke quenching etc. On the other hand, with the restructure of production process, share of some measures such as adjustment of the ratio of iron and steel, smelt reduction iron making technology will rise

Nevertheless, abundant coal resources and historical technological characteristics decide the structure of production process that traditional process based on blast furnace and converter will dominate in China's steel industry. So advanced blast furnace technology will always on the technology selection list. In the meantime, adjust ratio of iron and steel and some new technologies such as smelt reduction will also be emphasized.

IV.F.5 Marginal abatement cost curves and tables

Combining marginal abatement cost information and emission reduction potential of each mitigation option and classified these measures according abatement cost, we can get marginal abatement cost curve of each year. The following is the marginal abatement cost curves at 2010, 2015 and 2020.

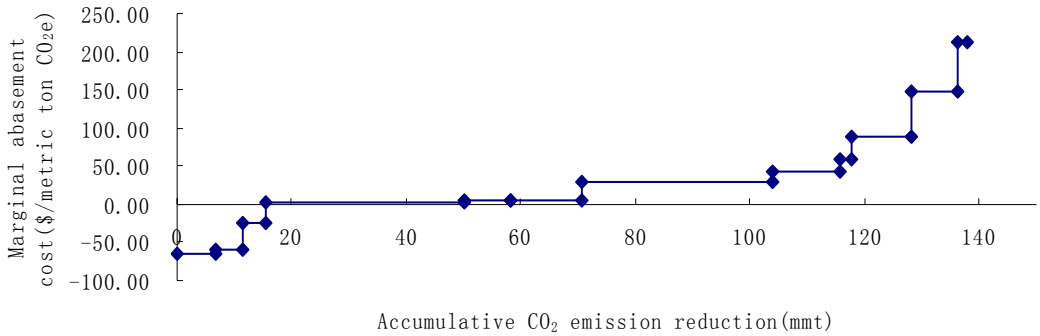

Figure 4-9. Marginal abatement cost curve of iron and steel industry at 2010

Table 4-21 Abatement potential and cost analysis of mitigation measures of 2010

Mitigation Options	Cost Effectiveness ($/ton CO_2)	Total Emission Reduction ($MTTCO_2$)	Total Cost (million $)	Cumulative Emission Reduction ($MTTCO_2$)	Cumulative Net Cost (million $)	Avg. Cumulative Cost Effectiveness ($/ton CO_2)
Establish energy management center	-66.20	6.75	-446.85	6.75	-446.85	-66.20
a-Direct fuel		4.57				
b-Electricity		2.18				
Coal power injection	-60.08	4.67	-280.57	11.42	-727.42	-63.70
a-Direct fuel		3.16				
b-Electricity		1.51				
Advanced continuous casting technology	-24.30	4.14	-100.60	15.56	-828.03	-53.22
a-Direct fuel		2.80				
b-Electricity		1.34				
Advanced blast furnace technology	3.28	34.51	113.19	50.06	-714.83	-14.28
a-Direct fuel		23.36				
b-Electricity		11.15				
Dry coke quenching	4.95	8.28	40.99	58.35	-673.85	-11.55
a-Direct fuel		5.61				
b-Electricity		2.67				
Advanced coke oven	6.23	12.42	77.38	70.77	-596.47	-8.43
a-Direct fuel		8.41				
b-Electricity		4.01				
Adjust ratio of iron/steel	30.02	33.13	994.56	103.90	398.09	3.83
a-Direct fuel		22.43				
b-Electricity		10.70				
Advanced sinter machine	43.27	11.73	507.56	115.63	905.65	7.83
a-Direct fuel		7.94				
b-Electricity		3.79				
Advanced direct steel rolling machine	57.99	1.92	111.34	117.55	1016.99	8.65
a-Direct fuel		1.30				
b-Electricity		0.62				
Advanced converter	87.64	10.72	939.50	128.27	1956.49	15.25
a-Direct fuel		7.26				
b-Electricity		3.46				
Smelt reduction technology	146.68	8.01	1174.91	136.28	3131.40	22.98
a-Direct fuel		5.42				
b-Electricity		2.59				
Advanced EAF	211.14	1.75	369.50	138.03	3500.89	25.36
a-Direct fuel		1.18				
b-Electricity		0.57				

Note: CO2 split as 67.7% fuel and 32.3% electricity from scenario analysis

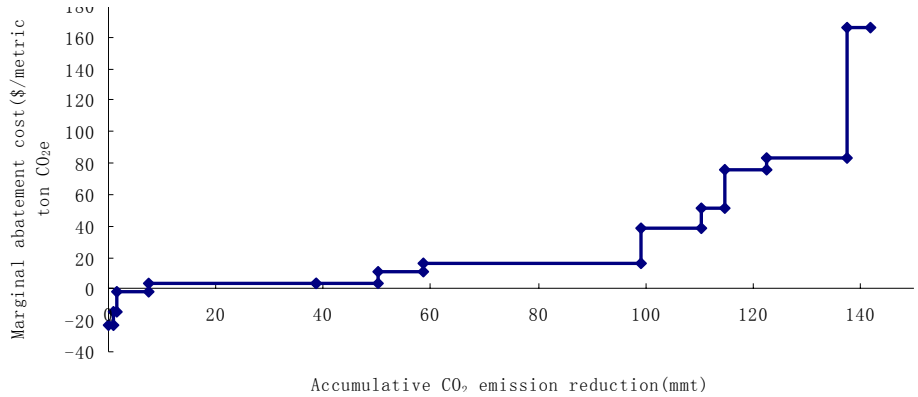

Figure 4-10. Marginal abatement cost curve of iron and steel industry at 2015

Table 4-22. Abatement potential and cost analysis of mitigation measures of 2015

Mitigation Options	Cost Effectiveness ($/ton CO_2)	Total Emission Reduction ($MMTCO_2$)	Total Cost (million $)	Cumulative Emission Reduction (MMT CO_2)	Cumulative Net Cost (million $)	Average Cumulative Cost Effectiveness ($/ton CO_2)
Advanced continuous casting technology	-22.64	0.85	-19.24	0.85	-19.24	-22.64
a-Direct fuel		0.54				
b-Electricity		0.31				
Coal power injection	-14.89	0.71	-10.57	1.56	-29.82	-19.11
a-Direct fuel		0.45				
b-Electricity		0.26				
Establish energy management center	-1.24	5.99	-7.43	7.55	-37.24	-4.93
a-Direct fuel		3.83				
b-Electricity		2.16				
Advanced blast furnace technology	3.59	31.24	112.15	38.79	74.91	1.93
a-Direct fuel		19.99				
b-Electricity		11.25				
Advanced coke oven	3.79	11.36	43.05	50.15	117.96	2.35
a-Direct fuel		7.27				
b-Electricity		4.09				
Dry coke quenching	11.35	8.52	96.70	58.67	214.66	3.66
a-Direct fuel		5.45				
b-Electricity		3.07				
Adjust ratio of iron/steel	15.99	40.46	646.96	99.13	861.62	8.69
a-Direct fuel		25.89				
b-Electricity		3.07				
Advanced sinter machine	38.16	11.40	435.02	110.53	1296.64	11.73
a-Direct fuel		7.30				
b-Electricity		4.10				
Advanced direct steel rolling machine	51.48	4.17	214.67	114.71	1511.32	13.18
a-Direct fuel		2.67				
b-Electricity		1.50				
Advanced converter	75.8	7.71	584.42	122.42	2095.73	17.12
a-Direct fuel		4.93				
b-Electricity		2.78				
Smelt reduction technology	82.85	15.02	1244.41	137.44	3340.14	24.30
a-Direct fuel		9.61				
b-Electricity		5.41				
Advanced EAF	165.78	4.54	752.64	141.98	4092.78	28.83
a-Direct fuel		2.91				
b-Electricity		1.63				

Note: CO2 split as 64% fuel and 36% electricity according to scenario analysis results

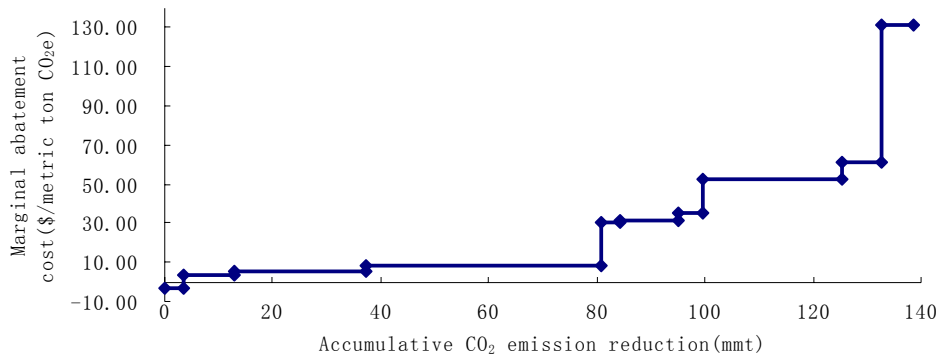

Figure 4-11. Marginal abatement cost curve of iron and steel industry at 2020

Table 4-23. Abatement potential and cost analysis of mitigation measures of 2020

Mitigation Options	Cost Effectiveness ($/ton CO_2)	Total Emission Reduction ($MMTCO_2$)	Total Cost (million $)	Cumulative Emission Reduction ($MMTCO_2$)	Cumulative Net Cost (million $)	Average Cumulative Cost Effectiveness ($/ton CO_2)
Establish energy management center	-3.57	3.64	-12.98	3.64	-12.98	-3.57
a-Direct fuel		2.18				
b-Electricity		1.46				
Advanced coke oven	3.03	9.07	27.44	12.72	14.46	1.14
a-Direct fuel		5.43				
b-Electricity		3.64				
Advanced blast furnace technology	5.36	24.63	131.92	37.35	146.37	3.92
a-Direct fuel		14.75				
b-Electricity		9.88				
Adjust ratio of iron/steel	8.19	43.55	356.57	80.90	502.95	6.22
a-Direct fuel		26.09				
b-Electricity		17.46				
Dry coke quenching	30.36	3.52	106.87	84.42	609.82	7.22
a-Direct fuel		2.11				
b-Electricity		1.41				
Advanced sinter machine	31.63	10.78	340.98	95.19	950.79	9.99
a-Direct fuel		6.46				
b-Electricity		4.32				
Advanced direct steel rolling machine	34.88	4.43	154.50	99.63	1105.30	11.09
a-Direct fuel		2.65				
b-Electricity		1.78				
Smelt reduction technology	52.67	25.63	1349.87	125.25	2455.17	19.60
a-Direct fuel		15.35				
b-Electricity		10.28				
Advanced converter	60.96	7.59	462.70	132.84	2917.87	21.97
a-Direct fuel		4.55				
b-Electricity		3.04				
Advanced EAF	131.39	5.68	746.27	138.52	3664.13	26.45
a-Direct fuel		3.40				
b-Electricity		2.28				

Note: CO2 split as 59.9% fuel and 40.1% electricity according to scenario analysis results

IV.G Analysis of GHG mitigation scenarios

In the analysis of GHG mitigation scenarios, we classify different mitigation scenarios according to the abatement cost.

- Mitigation scenario 1:All zero- or negative cost mitigation options
- Mitigation scenario 2:All mitigation options costing less than $5 per metric ton (including all zero- or negative cost options)
- Mitigation scenario 3:All mitigation options costing less than $10 per metric ton
- Mitigation scenario 4:A scenario that includes all zero- or negative cost mitigation options, plus any other mitigation options that appear likely or feasible based on evaluation of the country's situation and the options' potential co-benefits

IV.G.1 Advanced Options (Mitigation) Scenario #1: All Zero- or Negative Cost Mitigation Options[37]

This mitigation scenario includes establishment of energy management center, BF coal power injection and continuous casting.

IV.G.1.i **Results from the mitigation scenario**

Table 4-24. Annual fuel consumption, emissions and intensity forecast for Iron & Steel sector

Year	Total Production (Mt steel)	Total Fuel Consumption					Electricity (PJ)	Total Energy (PJ, fuel+ electricity)	CO2 emissions (million tones)	Fuel Intensity (GJ/tonne steel)	Energy Intensity (GJ/tonne steel)	Emissions Intensity (tonne CO2 / tonne steel)
		Cooking Coal	Non-Cooking Coal	Fuel Oil	Natural Gas	All Fuels						
2000	131.42	1790.92	970.12	94.87	22.94	2878.85	1009.39	3888.24	351.50	21.91	29.59	2.67
2005	210.21	2218.11	1286.36	114.29	34.45	3653.22	1488.11	5141.32	464.27	17.38	24.46	2.21
2010	289.01	2764.17	1670.38	142.15	56.09	4632.80	2207.41	6840.20	617.21	16.03	23.67	2.14
2015	328.00	2816.08	1719.34	156.84	70.68	4762.94	2676.91	7439.85	671.42	14.52	22.68	2.05
2020	364.00	2803.66	1753.16	118.57	60.09	4735.48	3172.34	7907.83	713.87	13.01	21.72	1.96
2025	353.50	2447.71	1640.44	84.03	41.17	4213.34	3409.54	7622.88	688.25	11.92	21.56	1.95
2030	343.00	2090.28	1475.85	129.95	60.20	3756.28	3162.86	6919.14	624.71	10.95	20.17	1.82

Table 4-25. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)			
	Coal	Oil	Natural Gas	Total All Fuels
2000	242.20	6.13	1.48	249.81
2005	305.62	7.35	2.21	315.18
2010	384.57	9.09	3.59	397.24
2015	391.44	9.98	4.50	405.92
2020	390.30	7.49	3.79	401.59
2025	347.35	5.27	2.58	355.19
2030	303.36	8.16	3.78	315.29

[37] According to marginal abatement cost information of each mitigation option of the year 2015

IV.G.2 Advanced Options Scenario #2: All mitigation options costing less than $5 per metric ton

This mitigation scenario includes 3 additional mitigation options to Advanced Option Scenario #1 "All Zero- of Negative Cost Mitigation Options": advanced blast furnace technology, dry coke quenching and advanced coke oven.

IV.G.2.i **Results from the mitigation scenario**

Table 4-26. Annual fuel consumption, emissions and intensity forecast for iron & steel sector

Year	Total Production (Mt steel)	Total Fuel Consumption					Electricity (PJ)	Total Energy (PJ, fuel+ electricity)	CO2 emissions (million tones)	Fuel Intensity (GJ/tonne steel)	Energy Intensity (GJ/tonne steel)	Emissions Intensity (tonne CO2 / tonne steel)
		Cooking Coal	Non-Cooking Coal	Fuel Oil	Natural Gas	All Fuels						
2000	131.42	1790.92	970.12	94.87	22.94	2878.85	1009.39	3888.24	351.50	21.91	29.59	2.67
2005	210.21	2124.72	1232.20	109.48	33.00	3499.40	1425.45	4924.85	444.73	16.65	23.43	2.12
2010	289.01	2522.16	1524.13	129.71	51.18	4227.18	2014.14	6241.31	563.17	14.63	21.60	1.95
2015	328.00	2591.40	1582.16	144.33	65.04	4382.93	2463.33	6846.26	617.85	13.36	20.87	1.88
2020	364.00	2648.69	1656.25	112.01	56.77	4473.72	2996.98	7470.72	674.41	12.29	20.52	1.85
2025	353.50	2356.87	1579.56	80.91	39.64	4056.98	3283.01	7339.99	662.71	11.48	20.76	1.87
2030	343.00	2033.67	1435.89	126.43	58.57	3654.55	3077.21	6731.76	607.79	10.65	19.63	1.77

Table 4-27. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)			
	Coal	Oil	Natural Gas	Total All Fuels
2000	242.20	6.13	1.48	249.81
2005	292.75	7.04	2.12	301.91
2010	350.90	8.29	3.27	362.46
2015	360.21	9.18	4.14	373.53
2020	368.73	7.07	3.59	379.39
2025	334.46	5.07	2.48	342.01
2030	295.14	7.93	3.68	306.75

IV.G.3 Advanced Options Scenario #3: All mitigation options costing less than $10 per metric ton

This mitigation scenario includes 1 additional mitigation option to Advanced Option Scenario #2 "All Mitigation Options costing less than $5 per metric ton": adjusting the ratio of iron/steel.

IV.G.3.i **Results from the mitigation scenario**

Table 4-28. Annual fuel consumption, emissions and intensity forecast for iron & steel sector

Year	Total Production (Mt steel)	Total Fuel Consumption					Electricity (PJ)	Total Energy (PJ, fuel+ electricity)	CO2 emissions (million tones)	Fuel Intensity (GJ/tonne steel)	Energy Intensity (GJ/tonne steel)	Emissions Intensity (tonne CO2 / tonne steel)
		Cooking Coal	Non-Cooking Coal	Fuel Oil	Natural Gas	All Fuels						
2000	131.42	1790.92	970.12	94.87	22.94	2878.85	1009.39	3888.24	351.50	21.91	29.59	2.67
2005	210.21	2101.37	1218.66	108.28	32.64	3460.94	1409.79	4870.728	439.839	16.46	23.17	2.09
2010	289.01	2369.13	1431.66	121.84	48.07	3970.70	1891.94	5862.6256	529.00408	13.74	20.29	1.83
2015	328.00	2431.93	1484.80	135.45	61.04	4113.21	2311.74	6424.9494	579.83184	12.54	19.59	1.77
2020	364.00	2485.26	1554.06	105.10	53.27	4197.69	2812.06	7009.7567	632.79972	11.53	19.26	1.74
2025	353.50	2111.36	1415.02	72.48	35.51	3634.38	2941.03	6575.4052	593.6752	10.28	18.60	1.68
2030	343.00	1761.12	1243.45	109.48	50.72	3164.77	2664.80	5829.5664	526.3356	9.23	17.00	1.53

Table 4-29. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)			
	Coal	Oil	Natural Gas	Total All Fuels
2000	242.20	6.13	1.48	249.81
2005	289.53	6.96	2.10	298.59
2010	329.61	7.79	3.07	340.47
2015	338.05	8.62	3.88	350.55
2020	345.98	6.64	3.36	355.98
2025	299.62	4.54	2.23	306.38
2030	255.59	6.87	3.18	265.64

IV.G.4 Advanced Options Scenario #4: All feasible mitigation options

This mitigation scenario includes all possible mitigation options.

IV.G.4.i **Results from the mitigation scenario**

Table 4-30. Annual fuel consumption, emissions and intensity forecast for iron & steel sector

Year	Total Production (Mt steel)	Total Fuel Consumption					Electricity (PJ)	Total Energy (PJ, fuel+ electricity)	CO2 emissions (million tones)	Fuel Intensity (GJ/tonne steel)	Energy Intensity (GJ/tonne steel)	Emissions Intensity (tonne CO2 / tonne steel)
		Cooking Coal	Non-Cooking Coal	Fuel Oil	Natural Gas	All Fuels						
2000	131.42	1790.92	970.12	94.87	22.94	2878.85	1009.39	3888.24	351.50	21.91	29.59	2.67
2005	210.21	2059.70	1194.49	106.13	31.99	3392.31	1381.83	4774.14	431.24	16.14	22.71	2.05
2010	289.01	2212.24	1336.85	113.77	44.89	3707.75	1766.65	5474.39	494.77	12.83	18.94	1.71
2015	328.00	2247.21	1372.02	125.16	56.40	3800.79	2136.15	5936.94	537.15	11.59	18.10	1.64
2020	364.00	2252.53	1408.53	95.26	48.28	3804.60	2548.73	6353.34	575.62	10.45	17.45	1.58
2025	353.50	1946.75	1304.70	66.83	32.74	3351.02	2711.73	6062.75	549.22	9.48	17.15	1.55
2030	343.00	1689.30	1192.74	105.02	48.65	3035.71	2556.13	5591.84	506.49	8.85	16.30	1.48

Table 4-31. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)			
	Coal	Oil	Natural Gas	Total All Fuels
2000	242.20	6.13	1.48	249.81
2005	283.79	6.82	2.06	292.67
2010	307.78	7.27	2.87	317.92
2015	312.37	7.96	3.59	323.92
2020	313.58	6.02	3.05	322.64
2025	276.26	4.19	2.05	282.50
2030	245.17	6.59	3.05	254.81

IV.G.5 Co-benefit analysis

All mitigation options will have different co-benefits such as water quality improvement, increased economic productivity and competitiveness, etc.

Because of data limitation, co-benefits analysis will be helped by the following judgment matrix. More in-depth analysis will be carried out at future work.

IV.G.6 Policy Analysis

Twelve kinds of mitigation options are identified and analyzed in this project. For each option, there will be some policies which can promote advanced technology application. Possible polices are listed in the following table.

In this first stage research, main task is to identify possible mitigation options and analysis the emission reduction potential and corresponding cost and give these measures different priorities. Then we can judge which measure has higher priority at different period.

The next question is how to promote the application of specific measures and policies evaluation is very important. It is also the future task for our analysis.

Table 4-32. Possible polices of iron and steel sector

Policy description
Direct government regulation to mandate (or allow) adoption of specific measure, new technology, or product standard
Government-run voluntary assistance program to provide information and training to companies or individuals
Investment tax credit (may be for installation, research and development)
Direct subsidy (investment, research and development, etc.)
Emission standards (usually per unit of output or facility) (possible, in the future)
Energy consumption standards (usually per unit of output)
Local air pollution regulations; energy intensity standard per unit of GDP; emissions intensity standard per unit of GDP; national emission growth limits; emissions cap and trade; carbon tax; energy taxes

Table 4-33. Co-benefits

Mitigation Option	Water quality improvements	Increased economic productivity and competitiveness	Job creation	Technology development and transfer	Infrastructure development	Enhanced energy security and independence	Air quality improvement
Increase coal power injection level	☆☆	☆		☆	☆	☆	☆☆
More advanced continuous casting machine		☆☆		☆	☆	☆	
Establish energy management center and increase management capacity	☆	☆☆	☆	☆		☆☆	☆
More advanced coke oven	☆	☆		☆	☆☆	☆☆	☆☆☆
More advanced blast furnace with TRT		☆☆☆		☆☆	☆☆☆	☆☆☆	☆☆☆
Adjust ratio of iron/steel	☆	☆☆		☆☆	☆	☆☆	☆☆
Apply dry coke quenching	☆☆☆			☆		☆	☆☆☆
More advanced sinter machine	☆	☆		☆		☆	☆☆
More advanced direct steel rolling machine		☆☆		☆	☆	☆	☆
Apply smelt reduction iron-making process	☆	☆☆☆		☆☆	☆	☆☆	☆☆
More advanced oxygen blown converter for steel-making		☆		☆	☆	☆	☆
More advanced electric furnace for steel-making		☆		☆	☆	☆	☆

Note: More☆ means specific mitigation option will produce more co-benefit

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Appendix: Main technical structure change within production process under different scenarios

Process	Plants Classification		Base year	Scenario 1			Scenario 2			Scenario 3		
			2000	2010	2020	2030	2010	2020	2030	2010	2020	2030
Coke Making	Small		8.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Large		41.8	33.0	29.0	23.2	22.0	26.0	23.0	7.0	13.5	19.0
	Domestic advanced		41.4	49.0	52.0	55.0	60.0	55.0	54.0	71.0	61.5	53.0
	International advanced		7.9	18.0	19.0	21.8	18.0	19.0	23.0	22.0	25.0	28.0
Coke quenching	Dry coke quenching		6.0	25.0	42.0	67.0	40.0	65.0	91.0	45.0	80.0	100
Sintering	Small		35.5	23.0	21.0	15.0	19.0	15.0	9.0	11.0	5.0	2.0
	Large		56.5	61.0	59.0	58.0	60.0	57.0	58.0	61.0	56.0	44.0
	International		8.0	16.0	20.0	27.0	21.0	28.0	33.0	28.0	39.0	54.0
Iron making	Blast furnace	Share of total iron/%	100	90	82.7	81.2	90.0	80.0	78.0	90.0	77.0	73.0
		Small	51.9	42.0	35.0	29.0	22.0	19.0	14.0	15.0	11.0	2.0
		Large	18.6	20.0	17.0	13.0	19.0	13.0	9.0	17.0	9.0	5.0
		Advanced	20.9	26.0	30.0	35.0	44.0	45.0	47.0	44.0	46.0	53.0
		International advanced	8.6	12.0	18.0	23.0	15.0	23.0	30.0	24.0	34.0	40.0
	Short process - smelt reduction	Share of total iron/%	0	10.0	17.3	18.8	10.0	20.0	22.0	10.0	23.0	27.0
		DIOS		50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
		COREX		50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Steel making	BOF	Share of total steel/%	84.1	81.0	79.0	77.0	80.0	75.0	71.0	75.0	73.0	67.0
		Normal	13.9	9.0	7.0	5.0	7.0	4.0	2.0	1.0	0.0	0.0
		Large	76.7	68.0	69.0	70.0	75.0	73.0	63.0	72.0	65.0	49.0
		advanced	9.4	23.0	24.0	25.0	18.0	23.0	35.0	27.0	35.0	51.0
	EAF	Share of total steel/%	15.9	19.0	21.0	23.0	20.0	25.0	29.0	25.0	27.0	33.0
		Normal	49.7	29.0	21.0	17.0	25.0	15.0	11.0	11.0	5.0	2.0
		large	41.3	53.0	60.0	62.0	53.0	60.0	57.0	54.0	53.0	47.0
		advanced	9.0	18.0	19.0	21.0	22.0	25.0	32.0	35.0	42.0	51.0
Casting	Normal		17.5	5.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
	Continuous		67.5	72.0	71.0	65.0	74.0	69.0	62.0	71.0	62.0	44.0
	Advanced continuous		15.0	23.0	28.0	35.0	25.0	31.0	38.0	29.0	38.0	56.0
Steel rolling	Normal		7.7	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Large		59.0	45.0	42.0	37.0	46.0	40.0	34.0	36.0	28.0	19.0
	Direct rolling		20.3	33.0	35.0	37.0	33.0	35.0	37.0	27.0	30.0	32.0
	Advanced direct rolling		13.0	19.0	23.0	26.0	21.0	25.0	29.0	37.0	42.0	49.0
Cool rolling	Normal		42.9	37.0	32.0	28.0	35.0	27.0	20.0	29.0	20.0	12.0
	advanced		57.1	63.0	68.0	72.0	65.0	73.0	80.0	71.0	80.0	88.0

		2010	2020	2030
Fuel price index	Coal	1.1	1.2	1.3
	Electricity	1.2	1.3	1.4
	Natural gas	3	3.5	3.7
	Fuel oil	1.2	1.3	1.5
Exchange rate	1 US. dollar =8.2784 Yuan RMB			
Discount rate	10%			

V. Sector Analysis and Results: Cement

V.A Sector Overview

V.A.1 Summary and explanation of economic statistics

V.A.1.i Total output/production, by plant type if available

Table 5-1.China's Cement sector historical output

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	2000
Production(Mt)	210	252.6	308.2	367.9	421	475.6	491.2	511.7	536	718.3

Much of China's remarkable development over the past few decades rests on cement—the primary ingredient in concrete. The country has constructed millions of new houses and buildings, paved thousands of kilometers of new highways, and built hundreds of large power plants, all requiring enormous quantities of cement.

China's cement industry has grown remarkably since economic reforms began in the late 1970s. At the start of reforms in 1978, China ranked fourth in world cement output and produced about 65 million tonnes of cement a year. By 1985, China had become the world's leading producer, and today produces over one-third of total global output.

V.A.1.ii Role of sector in overall economy as source of inputs to other sectors

Forty percent of China's cement is now used for basic infrastructure construction (an area regularly neglected during the period of heavy central planning.), with about one-third of that used in rural areas. Twenty-five percent is used for maintenance activities.

China's transport sector uses cement in road construction rather than asphalt. As China lacks an adequate national highway system and its rail network is so overburdened, investment can be expected in highways over the medium term.

V.A.1.iii Role in exports, international trade

China is the second leading cement exporter in the world, accounting for about 17 percent of total world cement trade. Exports of cement dramatically exceed imports, about 5 million tones v. 200 thousand tonnes, respectively in 2000. Shaft kiln cements of #425 and #525 comprise 60–70 percent of total exports. A share of this is from foreign owned companies or joint ventures, which themselves account for about 25 percent of exported cement. Major exporting regions include Shandong, Jiangsu, Guangdong, Liaoning, Guangxi, and Hebei provinces. The largest exporting companies include Daewoo Shandong Metal and Minerals Import/Export (with sales of about 2 million tonnes); and Taiheiyo Cement (with sales of about 1.8 million tonnes). The United States is the largest market for Chinese cement, accounting for 42 percent of trade in 1998.

V.A.2 Quantitative and qualitative characterization of sector

V.A.2.i <u>Table with breakdown of facilities by type</u>

Table 5-2.Distribution of China's Cement Plants in Clinker Production Process in 2000

		Average Age (Year)*a	No. of plants*a	Share*a	Unit Investment (USD/T)*b
shaft kiln	Mechanical Shaft Kiln	15	7904	83.98%	72.5
	ordinary shaft Kiln	15	347	3.69%	36.2
	Other	15	-	-	
	Subtotal		8251	87.66%	
rotary kiln	dry process plain kiln	15	421	4.47%	72.5
	rotary kiln with waste heat for power generation	15	88	0.93%	72.5
	rotary kiln with cyclone preheater	15	348	3.70%	
	stand-tube preheating kiln	15	-	-	
	kiln operated with off-kiln decomposition	20	86	0.91%	120.8
	Lepol kiln	15	199	2.11%	84.6
	Wet-process Rotary kiln	15	19	0.20%	78.5
	Subtotal		1161	12.34%	
	Total		9412	100%	

Data resource: HU Xiulian, JIANG Kejun, XU Huaqing, et al. Evaluation of Technology and Countermeasure for Greenhouse Gas Mitigation in China[M].Beijing: China Environmental Science Press, 2001. (in Chinese). *a Data in 1995;*b: data in 1995, discounted to 2000 value.

V.A.2.ii Table with breakdown of facilities by range of average CO2 intensity

Table 5-3. Facilities of cement industry

		Energy consumption (Mcal/T)	Coal consumption (kgce/T))*a	Gasoline consumption (kg/T)*a	Electricity consumption (kWh/T)*a	CO2 Intensity (TCO2/T)*b	total CO2 emissions (MTCO2)*c	Share of CO2 emissions*c
shaft kiln	Mechanical Shaft Kiln	1154	144	2.4	141	0.822	257.61	61.84%
	ordinary shaft Kiln	1596	218	3.4	98	0.949	82.84	19.89%
	Subtotal						340.45	81.73%
rotary kiln	dry process plain kiln	1896	249	3.81	133	1.023	6.06	1.45%
	rotary kiln with waste heat for power generation	1229	156	2.43	133	0.842	63.06	15.14%
	rotary kiln with cyclone preheater							
	stand-tube preheating kiln							
	kiln operated with off-kiln decomposition	748	87	1.81	140	0.711	2.29	0.55%
	Lepol kiln	1117	139	2.22	140	0.812	0.85	0.20%
	Wet-process Rotary kiln	1435	184	2.87	140	0.899	3.84	0.92%
	Subtotal						76.1	18.27%
	Total						416.55	100%

*a,*b: HU Xiulian, JIANG Kejun, XU Huaqing, et al. Evaluation of Technology and Countermeasure for Greenhouse Gas Mitigation in China[M].Beijing: China Environmental Science Press, 2001. (in Chinese).data in 1990;*b:emissions from process emissions, fuel combustion and electricity generation;*c: data from LEAPChina model, CO2 emission from fuel combustion and electricity generation

V.A.2.iii Table with breakdown of facilities by range of production capacity

Table 5-4. Distribution of China's cement facilities by production capacity.

		average plant Capacity (MT)*a	Annual Production (MT)*b	Share of Production
shaft kiln	Mechanical Shaft Kiln	0.1	418.0	58.22%
	ordinary shaft Kiln	0.05	116.4	16.21%
	Other	-	64.6	9.00%
	Subtotal		599	83.43%
rotary kiln	dry process plain kiln	0.1	7.9	1.10%
	rotary kiln with waste heat for power generation	0.04	99.9	13.91%
	rotary kiln with cyclone preheater			
	stand-tube preheating kiln			
	kiln operated with off-kiln decomposition	0.5	4.3	0.60%
	Lepol kiln	0.3	1.4	0.19%
	Wet-process Rotary kiln	0.2	5.7	0.79%
	Subtotal		119	16.58%
	Total		718	100%

Data resource:*a:HU Xiulian, JIANG Kejun, XU Huaqing, et al. Evaluation of Technology and Countermeasure for Greenhouse Gas Mitigation in China[M].Beijing: China Environmental Science Press, 2001;*b: assumption in LEAPChina model in 2000 baseline year

V.A.2.iv In-depth discussion and explanation of above breakdowns

The simplified process for cement making can be described as kiln feed preparation, clinker production and finish grinding. Clinker production is the most energy-intensive stage in cement production, accounting for over 90% of total industry energy use, and virtually all of the fuel use. The estimated number of Chinese cement plants ranges from 8,000 to 9,500, although the actual number is uncertain due to the fragmented nature of the industry, the small size of many plants, the fact that some plants exist illegally, and data reliability issues. The cement industry in China is dominated by shaft kilns.

In 2000, about 8500 shaft kilns account for almost 85% of total cement production. These plants account for over 80% of total cement CO2 emissions.

The cement industry is very energy intensive and China relies almost exclusively on coal to produce cement. Energy accounts for roughly 40 percent of the total manufacturing cost of cement in China. Mechanical Shaft Kiln is the largest single source of cement CO2 emissions, accounts for 61.84% of China's total CO2 emissions from cement.

V.A.2.v Ownership patterns of sector

In 2000 and 2001, the Chinese government decentralized its industrial ministries, and the organizational structure of the cement industry remains in a state of flux. The Ministry of Building Materials has been changed, first to a State Administration of Building Materials Industry (SABMI), and earlier in 2001 to a small, quasi-governmental Cement Association. Changes in top officials have occurred and provincial authorities now exert more control over the industry.

A shrinking number of cement companies (now about 24 percent) remain state-owned, while a growing number (about 3 percent) are foreign invested enterprises (FIEs). Collective enterprises account for over 50 percent of companies while 10 percent are privately owned. There also is a trend toward consolidation, as evidenced by the 1999 formation of China United Cement Company, a large state-owned holding company.

V.B Emissions Overview of Sector

Background and discussion of emissions, main sources/causes/drivers, trends
The cement industry is very energy intensive and China relies almost exclusively on coal to produce cement. Energy accounts for roughly 40 percent of the total manufacturing cost of cement in China. Unlike some industrialized countries, China has not yet moved to alternative energy sources in its cement kilns, although that may become an option.

Cement plants are responsible for over 40 percent of total industrial particulate (dust) emissions. Chinese cement plants are also responsible for about 6 to 8 percent of the country's energy consumption. These emissions are produced in roughly equal parts from fuel combustion and the liberation of carbon dioxide from limestone at high temperature. Carbon dioxide emissions from small Chinese plants are two or more times higher than plants in industrialized nations (because of poor efficiencies requiring more fuel use, etc.). Increasing the efficiency of cement kilns is one way to reduce carbon dioxide emissions.

V.B.1 Annual GHG emissions inventory for a recent year

V.B.1.i Percent share of emissions by source (pie chart)

Main sources of CO2 emission from cement sector is fossil fuel combustion, self industrial process and a relative small portion of indirect electrical consumption.

Table 5-5.CO2 emissions in 1990s (MtCO2)

	Energy utilization*	Share of total	industrial process	Share of total	Total
1990	82.4	51.83%	76.5	48.17%	158.9
1991	97.8	51.47%	92.2	48.53%	190.0
1992	116.1	50.78%	112.5	49.22%	228.5
1993	146.8	52.59%	132.3	47.41%	279.1
1994	156.8	50.48%	153.7	49.52%	310.5
1995	174.6	50.13%	173.7	49.87%	348.4
1996	183.1	50.48%	179.6	49.52%	362.7
1997	188.2	50.13%	187.1	49.86%	375.3

Data resource: Chinese energy statistics year book 1998.
* emission include fuel combustion and electricity generation

V.B.2 Historical annual fuel consumption and GHG emissions trends over time by fuel type

Table 5-6.China's cement sector historical annual fuel consumption

	Coal (Mt)	Electric (Twh)	Oil (Mt)	Total (MTce)	Unit consumption (kgce/T)
1990	32.08	21.37	0.15	40.71	194.13
1991	38.1	24.63	-	48.05	190.21
1992	45.21	30.57	-	57.57	186.79
1993	57.19	36.2	-	67.11	185.18
1994	61.07	42.1	-	78.09	185.40
1995	68.05	47.6	-	87.28	183.38
1996	71.34	49.2	-	91.21	185.34
1997	73.32	49.3	-	93.21	181.78

Data resource: HU Xiulian, JIANG Kejun, XU Huaqing, et al. Evaluation of Technology and Countermeasure for Greenhouse Gas Mitigation in China[M].Beijing: China Environmental Science Press, 2001

V.B.3 Relative contribution of each sector in 2000

V.B.3.i <u>total national energy consumption and emissions</u>

Table 5-7. Sector's share of total energy consumption

Target Sectors	Electricity	Iron &Steel	Cement	Pulp &Paper
Share of China's total energy consumption (2000)	8.56%*	9.95%	7.86%	1.67%
CO2 Emission (MtCO2)(2000)	256.65*/1199	351.53	678.4	62.67

Asterisk implies emissions from electricity that is consumed at the same site or plant where it is generated, and not transmitted across the local grid.

V.B.3.ii <u>total world sector emissions</u>

Table 5-8.Share of China in cement and limestone

Cement & Limestone			
Countries	$MtCO_2$	% of Developing Country	% of World
China	678.4	56%	36%

V.C Background Assumptions for Sector Analysis

V.C.1 Baseline with policies adopted before 2000

V.C.1.i <u>Policies under Consideration</u>

- Elimination of small illegal cement plants

In 1999 and 2000, and continuing into 2001, China reportedly closed hundreds of small, illegal cement plants. In 1999, cement plants with a total production capacity of 42 million tonnes were closed. The measures where taken to reduce pollution and to remove excessive production capacity. In June 2000, the Beijing Municipal Environmental Protection Bureau closed several cement factories in the Beijing area for violating environmental standards.
Implementation of technical retrofit

Since the middle of the 1980s, the government has made extensive efforts to technical retrofit plants in the cement industry and introduced New Suspension Heater (NSP) kiln technology for the first time with government budgets, public bonds, bank loans. The distinct characteristics of this technical retrofit are "wet process to dry process" and "large-scale options". The government also made guidelines of technical retrofit and outlines of technical development, and shut down small-scale cement plants in order to encourage the development and adoption of energy conservation technologies. All the following points are confirmed in "Policy Outlines of Energy Conservation Technologies", enacted in 1984 and revised in 1996.

- Declaration of energy conservation

According to the "Policies Outlines of Energy Conservation Technologies", the principle of recovering and utilizing the heat from kilns is to use the waste heat firstly for pre-warming the inputs of kilns such as air, fuel and raw materials.

In the August of 1995, an agreement was signed to demonstrate the operation of using low temperature heat for power generation among NEDO (New Energy and Industrial Technology Development Organization of Japan), SDPC (State Development and Planning Commission of P. R. China) and State Construction Material Bureau. Japan side donated a whole set of power generation

system that was installed at a cement plant in China. The government will promote active adoption of using low temperature heat for power generation at cement industry according to "The China Medium and Long Term Energy Conservation Plan".

It should indicate in the new version of "Energy Conservation of People's Republic of China" or correlative regulations to be implemented that public utilities must be prescribed unconditionally to allow the power plants using waste heat and exhaust energy to connect to the power grid. There should be some discounts in the tariff in order to encourage using power generated by waste heat and exhaust energy.

V.C.1.ii Assumptions about the Effectiveness of Policies

The micro-policies mainly direct the way how China's cement industry take its renovation. Big issues China emphasized before 2000 focused on technical retrofit and energy conservation, which can be realized through technology advancement. A number of effective measures can be taken through cement production process, which can be classified as raw materials preparation, clinker production, finish grinding, products change and some general measures such as energy management control.

The recent baseline scenario employed here is a conservative projection of China's cement industry future that closely tracks previous Chinese forecasts. The scenario assumes that sector's relative policies will not change radically, although some technologies are projected to improve gradually.

V.C.2 Baseline with policies adopted between 2000 and 2005

V.C.2.i Policies under Consideration

- *Improvement of both production capacity and product quality*

Chinese planners project that cement output will increase by 3.4 percent annually during the Tenth Five-Year Plan (2001–2005) and by 2.9 percent during the Eleventh Five-Year Plan. They anticipate producing 660 million tonnes by 2005, 750 million tonnes by 2010, and 800 million tonnes by 2015. In peer review, it is said the actual data indicates that cement production in 2005 was 1064 Mt, and projects it to rise to 1250 in 2010.[38] So the outputs projection has the same problem as electricity sector. We make modest assumptions between the above two opinions.

- *Management organization reformation*

In 2000 and 2001, the Chinese government decentralized its industrial ministries, and the organizational structure of the cement industry remains in a state of flux. The Ministry of Building Materials has been changed, first to a State Administration of Building Materials Industry (SABMI), and earlier in 2001 to a small, quasi-governmental Cement Association. Changes in top officials have occurred and provincial authorities now exert more control over the industry.

- *Energy efficiency enhancement*

Provinces and cities given priority investment during the Tenth Five-Year Plan include Xinjiang, Ningxia, Qinghai, Shaanxi (including Xian), Gansu, Sichuan, Tibet (Xizang), Chongqing, Guizhou, and Yunnan (including Kunming). Eastern provinces should not expect new plants but will receive technology upgrades.

- *Market system renovation*

[38] Prof Cui Yuan-sheng, VP of Institute of Technical Information for Building Materials Industry of China, CBMIA, *Status Quo of the Chinese Cement Industry in 2005 and Future Prospect*. Presentation, MidEast & North Africa Cement Conference, Dubai, United Arab Emirates, March 20-21, 2006.

Foreign investment is expected to play a key role in growth in the cement industry during the 10th Five-Year Plan (2001–2005).[16] These financing sources are expected to be guided toward large cement production lines in central and western China and other less economically developed areas.

- *Environmental protection issues*

In many relatively wealthy urban areas, public pressure plays an important role in government planning and environmental enforcement. Enforcement of existing environmental regulations will become stricter in major urban areas, especially Beijing.

Chinese Government strengthens to supervise and inspect environmental protection. With the standard further improvement of environmental protection increasingly, increasing the investment in environmental protection is inevitable. Because of the constant rise of prices of oil, coal, natural gas, electricity, etc., it impels the enterprises to carry on the technological innovation transformation, take energy-conserving and environmental protection as the center and meet present development situation. According to experts' estimation, energy shortage and energy rising price will continue in the Chinese economy for a long time, and have especially caused the enormous existent pressure for cement enterprises. Therefore saving-energy and reducing consumption are the important rules for cement enterprise to reduce operation cost, to raise productivity effect and to be on the way of sustainable development.

V.C.2.ii Assumptions about the Effectiveness of Policies

Here we can tell the policies adopted through 2000~2005 still pay great attention to technical development. China strive for making market system renovation and policies to introduce investment to promote technology upgrades. Compared to the policies adopted before 2000, environmental protection issues become more and more perspective.

In this scenario, we will evaluate projected emissions using combination of measures in place before the end of 2005. Taking regards of Report of 16th Party Congress, Tenth Five-Year Plan as well as relative industrial long term development policies and plans. The policy takes more consideration for environmental protection and sustainable development.

V.D Baseline (business-as-usual) Forecasts for sectors

V.D.1 Production/output forecast

It is said China's GDP in 2020 will quadruple above 2000 levels in the Considering the Report of 16th Party Congress. We refer to series of literatures on Chinese energy and carbon scenarios[39] and assume China's GDP will keep the fast growth in 1990s, the annual growth rate is set to be 7.5% during 2000 to 2010. Then the growth speed will slow down, and the annual growth rate is set to be 6.5% from 2010 to 2020, and 5.5% after 2020. And cement sectoral production is projected consistent with economy development, see Table 5-9. The projection trend is shown in Fig 5-1.

Table 5-9. China's GDP and Cement Production Assumptions in the Analysis

year	2000	2005	2010	2015	2020	2025	2030
Annual growth ratio	7.50%			6.50%		5.50%	
GDP（billion dollar）	1081	1552	2227	3096	4181	5465	7142
Sectoral production (MT)	718.3	881.5	1045	1132	1220	1324	1427

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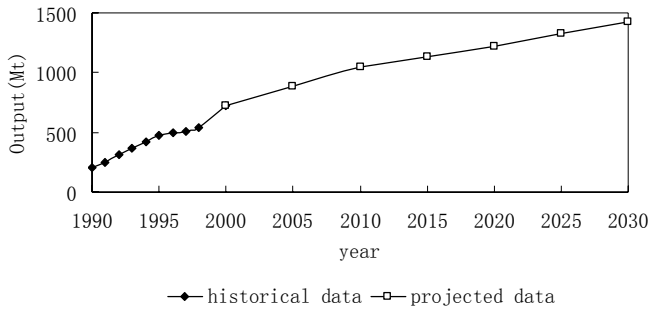

Fig 5-1 Output projection for cement sector in the analysis

V.D.2 Energy and fossil fuel consumption (by type) forecast

Table5-10 Energy consumption under 2000 baseline scenario(Unit:PJ)

Year	Total Fuel Consumption (PJ)				Energy Intensity (GJ / metric ton)
	Coal	Electricity	Gasoline	All Fuels	
2000	3285.8	338.5	87.7	3712.0	5.17
2005	4070.3	413.0	110.3	4593.6	5.21
2010	4868.7	486.7	133.8	5489.2	5.25
2015	5254.3	525.0	144.3	5923.7	5.23
2020	5636.5	563.1	154.7	6354.3	5.21
2025	6090.3	608.0	167.1	6865.4	5.19
2030	6540.1	652.4	179.3	7371.8	5.16

Table 5-11 Energy consumption under 2005 baseline scenario(Unit:PJ)

Year	Total Fuel Consumption (PJ)				Energy Intensity (GJ / metric ton)
	Coal	Electricity	Gasoline	All Fuels	
2000	3285.8	338.5	87.7	3712.0	5.17
2005	3862.4	420.5	106.3	4389.2	4.98
2010	4375.8	504.5	124.3	5004.6	4.79
2015	4571.1	546.6	131.2	5249.0	4.64
2020	4740.0	588.7	137.6	5466.3	4.48
2025	5012.3	639.7	146.8	5798.8	4.38
2030	5264.1	690.9	155.6	6110.6	4.28

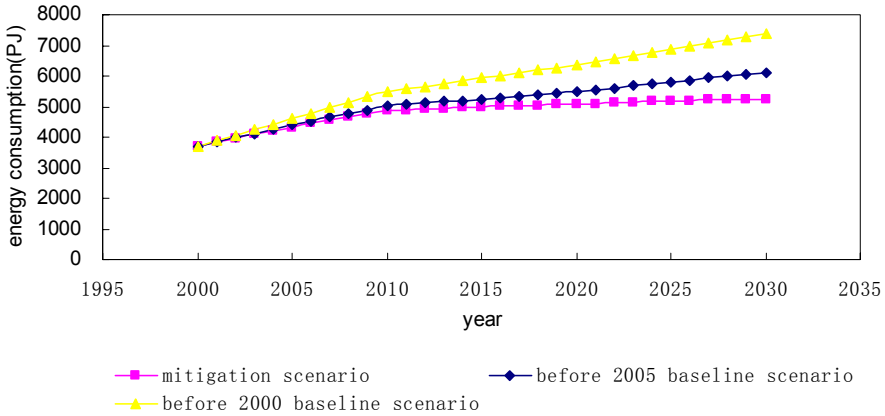

Fig 5-2 energy consumption for cement sector under three scenarios

V.D.3 Annual GHG forecast

V.D.3.i Total GHG emissions

The corresponding CO2 emissions related to fuel combustion are calculated, see table.

Table 5-12. CO2 emission for China's cement sector by fuel type under 2000 baseline scenario (MMtCO2)

	2000	2005	2010	2015	2020	2025	2030
Gasoline	4.3	5.4	6.6	7.1	7.6	8.3	8.9
Electricity	35.9	43.9	51.7	55.8	59.8	64.6	69.3
Coal	299.9	371.5	444.4	479.6	514.5	555.9	596.9
Total	340.2	420.8	502.7	542.5	581.9	628.7	675.1
Process	338.2	418.5	497.6	532.7	576.3	624.5	660.1
Total	678.4	839.3	1000.3	1075.2	1158.2	1253.2	1335.2
Emission intensity* (kgCO2/kg)	0.944	0.952	0.957	0.950	0.949	0.947	0.936

* emission from energy utilization and industrial process

Table 5-13. CO2 emission for China's cement sector by fuel type under 2005 baseline scenario (MMtCO2)

	2000	2005	2010	2015	2020	2025	2030
Gasoline	4.3	5.2	6.1	6.5	6.8	7.2	7.7
Electricity	35.9	44.7	53.6	58.1	62.5	67.9	73.4
Coal	299.9	352.5	399.4	417.2	432.6	457.5	480.5
Total	340.2	402.4	459.1	481.8	502.0	532.7	561.5
Process	338.2	398.5	447.4	478.2	497.3	525.6	554.5
Total	678.4	800.9	906.5	960.0	999.3	1058.3	1116
Emission intensity*(kgCO2/kg)	0.944	0.909	0.867	0.848	0.819	0.799	0.782

* emission from energy utilization and industrial process

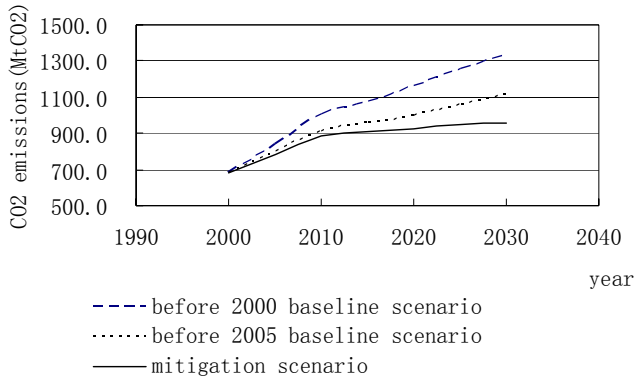

Fig 5-3 Emissions projection for cement sector under three scenarios

V.E GHG Mitigation Options and Costs

V.E.1 Selection criteria for consideration of mitigation options

First of all, technologies and measures listed in this section have been tested by many developed countries. They can virtually reduce the energy intensity (i.e. the electricity or fuel consumption per unit of output) of the various process stages of cement production. Second, implementation of such

technologies and measures are compatible with China's cement industry policies focus on energy efficiency improvement and sustainable development.

V.E.2 Overview of each mitigation option evaluated

V.E.2.i Description, including technologies required

Measures generally fall into 4 classes:

Technology structure Adjustment and process management
Wide variation exists in equipment used to produce cement in China. The gap between proportions of modern rotary kilns vs. inefficient mechanical shaft kilns, new dry process rotary kilns vs. old rotary kilns is great. There is obvious energy efficiency contrast between large scale and small scale companies. China has less efficiency than the developed countries' even as the same production process. Table 5-16.

Table 5-14. China's cement production heat consumption comparison with international advanced level

	Internal average level		External advanced level		Internal/External
Kiln	Heat consumption (kJ/kg)	Thermal efficiency (%)	Heat consumption (kJ/kg)	Thermal efficiency (%)	(%)
kiln operated with off-kiln decomposition	3553	49.4	2888	60.9	123.0
rotary kiln with cyclone preheater	4182	42	3056	57.8	136.9
stand-tube preheating kiln	4700	37.3	3600	48.8	130.6
Lepol kiln	4605	38.2	3349	52.5	137.5
rotary kiln with waste heat for power generation	6100	28.8	5232	33.6	116.6
Wet-process Rotary kiln	6145	30.0	5232	33.6	117.5
Mechanical Shaft Kiln	4887	36.5	2990	60	163.4

Data resource: Hu Xiulian, Comparison of national and international production unit energy consumption. 1997.(in Chinese)

Active improvement of technology structure and enhancement of industrial monitoring and management are the key elements for CO2 emission reductions through energy utilization in this sector. Some detailed measures are as follows:

Process management and Control: Heat from the kiln may be lost through non-optimal process conditions or process management. Improved process control will also help to improve the product quality, e.g. reactivity and hardness of the produced clinker, which may lead to more efficient clinker grinding. Process control systems also include the use of on-line analyzers that permit operators to instantaneously determine the chemical composition of raw materials being processed in the plant, thereby allowed for immediate changes in the blend of raw materials. A uniform feed allows for more steady kiln operation, thereby saving ultimately on fuel requirements. Energy savings from such process control systems may vary between 2.5% and 10%, and the typical savings are estimated at 2.5-5%.

High-Efficiency Motors and Drives: Motors and drives are used throughout the cement plant to drive fans (preheater, cooler, alkali bypass), rotate the kiln, transport materials and, most importantly, for grinding.

Preventative Maintenance: Preventative maintenance involves training personnel to be attentive to energy consumption and efficiency. Successful programs have been launched in many industries.

Raw Material Preparation

Efficient transport systems: Transport systems are required to transport powdered materials such as raw meal, kiln dust, and cement throughout the plant. These materials are usually transported by means of either pneumatic or mechanical conveyors. While mechanical conveyors use less power than pneumatic they can have higher capital costs than pneumatic.

High-efficiency roller mills: Traditional ball mills used for grinding certain raw materials (mainly hard limestone) can be replaced by high-efficiency roller mills, by ball mills combined with high pressure roller presses, or by horizontal roller mills. The use of these advanced mills saves energy without compromising product quality.

High-efficiency Powder Classifiers: A recent development in efficient grinding technologies is the use of high-efficiency classifiers or separators. Classifiers separate the finely ground particles from the coarse particles. The large particles are then recycled back to the mill. Standard classifiers may have a low separation efficiency, which leads to the recycling of fine particles, leading to extra power use in the grinding mill.

Introduction for advanced clinker making technology
Theoretical heat consumption of raw material is 1759kJ/kg. Pre-decomposition invented in 1970s together with pre-heating system improvement make it down to 2929kJ/kg, with the thermal efficiency of 60%, which is very close to theoretical value. To improve the cement clinker making efficiency, some substantial measures are described as follows:

Combustion System Improvement: Fuel combustion systems in kilns can be contributors to kiln inefficiencies with such problems as poorly adjusted firing, incomplete fuel burn-out with high CO formation, and combustion with excess air.

Kiln Shell Heat Loss Reduction: There can be considerable heat losses through the shell of a cement kiln, especially in the burning zone. The use of better insulating refractories can reduce heat losses.

Use of Waste Derived Fuels: Waste fuels can be substituted for traditional commercial fuels in the kiln. Waste derived fuels may replace the use of commercial fuels, and are hence accounted as energy savings. The carbon dioxide emission reduction depends on the carbon content of the waste derived fuel, as well as the alternative use of the waste and efficiency of use (e.g. incineration with or without heat recovery).

Conversion to Multi-stage pre-heater kiln: Installing multi-stage suspension preheating (i.e. four- or five-stage) may reduce the heat losses and thus increase efficiency. By installing new preheaters, the productivity of the kiln will also increase, due to a higher degree of pre-calcination (up to 30-40%) as the feed enters the kiln.

Development for Finish Grinding technology, exploitation of additives
Active Additives. 1 ton cement contains 620 kg calces, and 750 kg raw materials are needed when producing 1 ton cement in China. Increasing the output of raw material is essential for cement production. Blending additives as fly ash, pozzolans, blast furnace slag, silica fume, volcanic ash with various proportions in to inter-grinding of clinker will increase the output of cement greatly. The use of blended cements is a particular attractive efficiency option since the inter-grinding of clinker with other additives not only allows for a reduction in the energy used (and carbon emissions) in clinker production, but also corresponds to a reduction in carbon dioxide emissions in calcination as well.

Composite Cement: Chinese national standard GB12958-91 defines composite cement as being made of silicate cement raw material, two or more than two appointed mixtures, some hydraulic cementitious materials from gypsum grinding. Composite cement is fast developed new product for it's quite compatible with our nation's status, and composite cement can be produced from whatever kind of kilns or processes.

V.F Analysis of GHG mitigation scenarios

V.F.1 Marginal abatement cost curve

Theoretically, the marginal cost for each measure should be calculated through its mitigation effect compared to its situation in 2000 baseline year. Actually, there is no such systemic data strictly complied with options classification in our mitigation scenario. So we find the marginal cost for similar measures in America[40]. Also, we do adjustments by checking the Chinese cement sector related literature of disperse marginal abatement cost data for mitigation measures[41,42].

V.F.1.i 2010

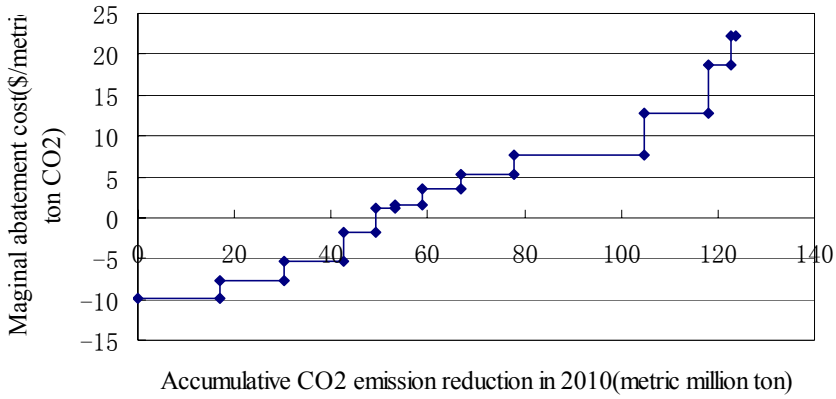

Figure 5-4.Marginal abatement cost curve of China's cement sector in 2010

Table 5-15. Cost of mitigation options and relevant emission reduction in 2010

No.	Measures	Marginal mitigation cost (U.S.Dollar/ tCO2)	Total Emission Reduction (MMt CO2)	Total Cost (million $)	Cumulative Emission Reduction* (MMT CO_2e)	Cumulative Net Cost (million $)	Average Cumulative Cost Effectiveness ($/metric ton CO_2e)
1	Preventative Maintenance	-9.8	16.8	-164.6	16.8	-164.6	-9.8
2	Process management and Control	-7.72	13.5	-104.2	30.3	-268.9	-8.9
3	Use of Waste Derived Fuels	-5.28	12.3	-64.9	42.6	-333.8	-7.8
4	Kiln Shell Heat Loss Reduction	-1.76	6.71	-11.8	49.31	-345.6	-7.0
5	High-Efficiency Motors and Drives	1.07	3.9	4.2	53.2	-341.4	-6.4
6	Active Additives	1.6	5.61	9	58.8	-332	-5.7
7	Composite Cement	3.55	7.87	27.9	66.7	-305	-4.6
8	Combustion System Improvement	5.34	11.2	59.8	77.9	-245	-3.1
9	Conversion to Multi-stage pre-heater kiln	7.6	26.9	204.4	104.8	-40	-0.4
10	High-efficiency roller mills	12.7	13.1	166.4	117.9	126	1.1
11	High-efficiency Powder Classifiers	18.6	4.93	91.7	122.8	218	1.8
12	Efficient transport systems	22.2	1.03	22.9	123.9	241	1.9

* emission from energy utilization and industrial process

[40] Nathan Martin, Ernst Worrell, and Lynn Price. Energy Efficiency and Carbon Dioxide Emissions Reduction Opportunities in the U.S. Cement Industry. 1999.
[41] Mason H. Soule, Jeffrey S. Logan, and Todd A. Stewart.Trends, Challenges and opportunities in China's Cement Industry. 2002.
[42] HU Xiulian, JIANG Kejun, XU Huaqing, et al. Evaluation of Technology and Countermeasure for Greenhouse Gas Mitigation in China[M].Beijing: China Environmental Science Press, 2001.

V.F.1.ii **<u>2015</u>**

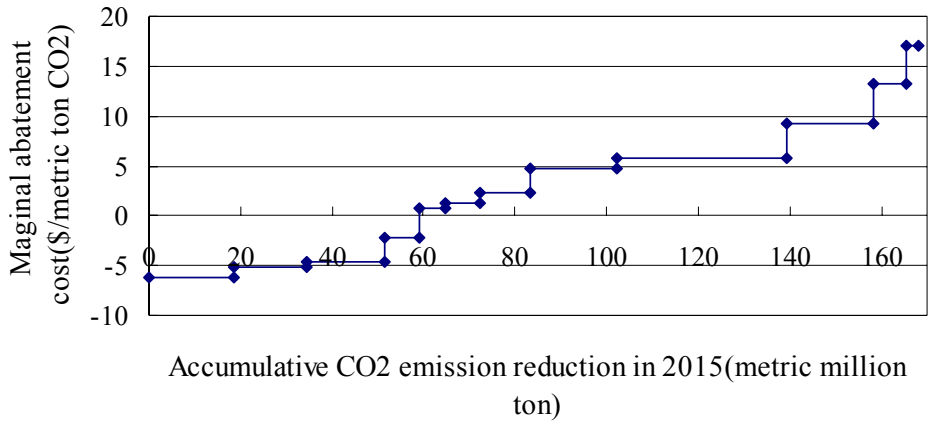

Figure 5-4.Marginal abatement cost curve of China's cement sector in 2015

Table 5-16. Cost of mitigation options and relevant emission reduction in 2015

No.	Measures	Marginal mitigation cost (U.S.Dollar/tCO2)	Total Emission Reduction (MMtCO2)	Total Cost (million $)	Cumulative Emission Reduction* (million metric tons CO_2e)	Cumulative Net Cost (million $)	Average Cumulative Cost Effectiveness ($/metric ton CO_2e)
1	Preventative Maintenance	-6.12	18.7	-114.4	18.7	-114.4	-6.1
2	Process management and Control	-5.23	15.6	-81.6	34.3	-196.0	-5.7
3	Use of Waste Derived Fuels	-4.58	17.1	-78.3	51.4	-274.4	-5.3
4	Kiln Shell Heat Loss Reduction	-2.24	7.79	-17.4	59.19	-291.8	-4.9
5	High-Efficiency Motors and Drives	0.75	5.46	4.1	64.7	-287.7	-4.5
6	Active Additives	1.24	7.79	10	72.4	-278	-3.8
7	Composite Cement	2.39	10.9	26.1	83.3	-252	-3.0
8	Combustion System Improvement	4.78	18.7	89.4	102.0	-163	-1.6
9	Conversion to Multi-stage pre-heater kiln	5.72	37.4	213.9	139.4	51	0.4
10	High-efficiency roller mills	9.23	18.7	172.6	158.1	224	1.4
11	High-efficiency Powder Classifiers	13.3	7.47	99.4	165.6	323	2.0
12	Efficient transport systems	17.1	2.33	39.8	167.9	363	2.2

* emission from energy utilization and industrial process

V.F.1.iii 2020

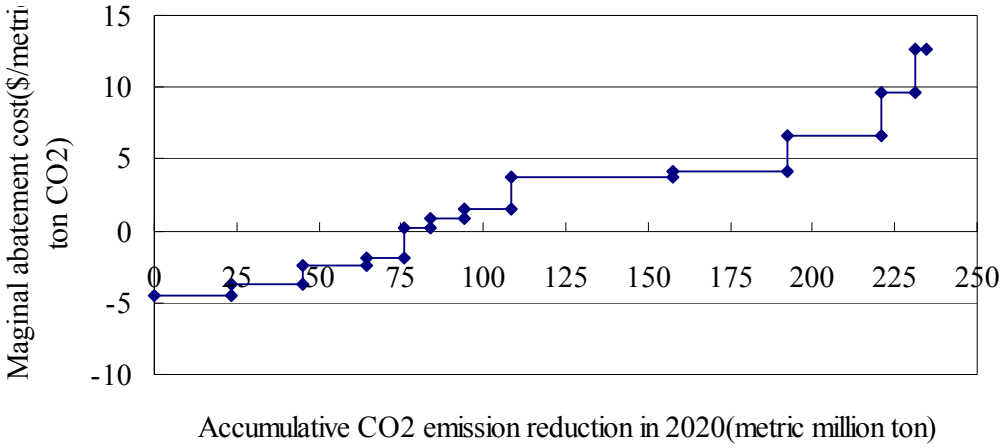

Figure 5-4.Marginal abatement cost curve of China's cement sector in 2020

Table 5-17. Cost of mitigation options and relevant emission reduction in 2020

No.	Measures	Marginal mitigation cost (U.S.Dollar/tCO2)	Total Emission Reduction (MMt CO2)	Total Cost (million $)	Cumulative Emission Reduction* (million metric tons CO_2e)	Cumulative Net Cost (million $)	Average Cumulative Cost Effectiveness ($/metric ton CO_2e)
1	Preventative Maintenance	-4.53	23.5	-106.5	23.5	-106.5	-4.5
2	Use of Waste Derived Fuels	-3.75	21.5	-80.6	45	-187.1	-4.2
3	Process management and Control	-2.44	19.5	-47.6	64.5	-234.7	-3.6
4	Kiln Shell Heat Loss Reduction	-1.89	11.3	-21.4	75.8	-256.0	-3.4
5	High-Efficiency Motors and Drives	0.22	8.17	1.8	84.0	-254.2	-3.0
6	Active Additives	0.87	10.2	9	94.2	-245	-2.6
7	Composite Cement	1.54	14.3	22.0	108.5	-223	-2.1
8	Conversion to Multi-stage pre-heater kiln	3.79	49.1	186.1	157.6	-37	-0.2
9	Combustion System Improvement	4.14	34.8	144.1	192.4	107	0.6
10	High-efficiency roller mills	6.59	28.6	188.5	221.0	295	1.3
11	High-efficiency Powder Classifiers	9.67	10.2	98.6	231.2	394	1.7
12	Efficient transport systems	12.69	3.67	46.6	234.8	441	1.9

* emission from energy utilization and industrial process

V.G Analysis of GHG mitigation scenarios

V.G.1 Advanced Options (Mitigation) Scenario #1: All Zero- or Negative Cost Mitigation Options

This mitigation scenario includes Preventative Maintenance, Use of Waste Derived Fuels, Process management and Control, and Kiln Shell Heat Loss Reduction.

V.G.1.i Results from the mitigation scenario

Table 5-18. Annual fuel consumption, emissions and intensity forecast for cement sector

Year	Total Production (Mt cement)	Total Fuel Consumption					Total Energy (PJ, fuel+ electricity)	CO2 emissions (million tones)	Fuel Intensity (GJ/tonne cement)	Energy Intensity (GJ/tonne cement)	Emissions Intensity (tonne CO2 / tonne cement)
		Coal	Gasoline	Natural Gas	All Fuels	Electricity (PJ)					
2000	718.3	3286	87.7		3374	338	3712	678.4	4.70	5.17	0.94
2005	881.5	3967	106.9		4074	415	4489	814.6	4.62	5.09	0.92
2010	1044.8	4623	125.7		4749	492	5241	950.7	4.55	5.02	0.91
2015	1132.3	4887	133.7		5021	530	5551	1008	4.43	4.90	0.89
2020	1219.8	5132	141.3		5273	568	5841	1064	4.32	4.79	0.87
2025	1323.6	5423	150.5		5573	618	6191	1129	4.21	4.68	0.85
2030	1427.4	5691	159.1		5850	668	6518	1181	4.10	4.57	0.83

Table 5-19. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)			
	Coal	Oil	Electricity	Process
2000	299.9	4.30	35.9	338.2
2005	362.1	5.03	41.4	406.1
2010	422.0	6.02	49.5	473.2
2015	446.1	6.52	55.0	500.5
2020	468.4	6.90	59.1	529.9
2025	495.0	7.39	63.7	562.5
2030	519.4	7.83	69.0	585.1

V.G.2 Advanced Options Scenario #2: All Mitigation Options costing less than $5 per metric ton

This mitigation scenario includes 3 additional mitigation options to Advanced Options Scenario #1 "All Zero- and Negative-cost Mitigation Options": High-Efficiency Motors and Drives, Active Additives, and Composite Cement.

V.G.2.i **Results from the mitigation scenario**

Table 5-20. Annual fuel consumption, emissions and intensity forecast for cement sector

Year	Total Production (Mt cement)	Total Fuel Consumption					Total Energy (PJ, fuel+ electricity)	CO2 emissions (million tones)	Fuel Intensity (GJ/tonne cement)	Energy Intensity (GJ/tonne cement)	Emissions Intensity (tonne CO2 / tonne cement)
		Coal	Gasoline	Natural Gas	All Fuels	Electricity (PJ)					
2000	718.3	3286	87.7		3374	338.5	3712	678.3	4.70	5.17	0.94
2005	881.5	3928	105.6		4034	415.9	4450	805.3	4.58	5.05	0.91
2010	1044.8	4531	122.6		4654	493.6	5148	932.1	4.45	4.93	0.89
2015	1132.3	4749	129.7		4879	532.2	5411	982.9	4.31	4.78	0.87
2020	1219.8	4942	136.3		5079	570.5	5649	1029.0	4.16	4.63	0.84
2025	1323.6	5172	144.2		5317	621.7	5938	1081.7	4.02	4.49	0.82
2030	1427.4	5373	151.5		5524	673.4	6198	1123.5	3.87	4.34	0.79

Table 5-21. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)			
	Coal	Oil	Electricity	Process
2000	299.9	4.30	35.9	338.2
2005	358.5	4.89	40.5	401.5
2010	413.6	5.80	48.6	464.1
2015	433.5	6.30	54.7	488.4
2020	451.1	6.64	58.8	512.4
2025	472.1	7.05	63.4	539.2
2030	490.4	7.43	68.8	556.9

V.G.3 Advanced Options Scenario #3: All Mitigation Options costing less than $10 per metric ton

This mitigation scenario includes 1 additional mitigation option to Advanced Options Scenario #2 "All Mitigation Options costing less than $5 per metric ton": Conversion to Multi-stage pre-heater kiln

V.G.3.i **Results from the mitigation scenario**

Table 5-22. Annual fuel consumption, emissions and intensity forecast for cement sector

Year	Total Production (Mt cement)	Total Fuel Consumption					Total Energy (PJ, fuel+ electricity)	CO2 emissions (million tones)	Fuel Intensity (GJ/tonne cement)	Energy Intensity (GJ/tonne cement)	Emissions Intensity (tonne CO2 / tonne cement)
		Coal	Gasoline	Natural Gas	All Fuels	Electricity (PJ)					
2000	718.3	3286	87.7		3374	338.5	3712	678.3	4.70	5.17	0.94
2005	881.5	3850	103.0		3953	417.5	4371	786.8	4.48	4.96	0.89
2010	1044.8	4348	116.5		4464	497.4	4961	895.0	4.27	4.75	0.86
2015	1132.3	4474	121.7		4596	536.1	5132	932.6	4.06	4.53	0.82
2020	1219.8	4564	126.2		4690	574.5	5264	958.6	3.84	4.32	0.79
2025	1323.6	4672	131.7		4804	629.2	5433	988.2	3.63	4.10	0.75
2030	1427.4	4736	136.4		4872	684.9	5557	1008.1	3.41	3.89	0.71

Table 5-23. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)			
	Coal	Oil	Electricity	Process
2000	299.9	4.3	35.9	338.2
2005	351.4	4.6	38.6	392.2
2010	396.8	5.4	47.0	445.8
2015	408.4	5.9	54.1	464.2
2020	416.6	6.1	58.2	477.6
2025	426.4	6.4	62.7	492.7
2030	432.3	6.6	68.6	500.6

V.G.4 Advanced Options Scenario #4: All feasible mitigation options

V.G.4.i **Results from the mitigation scenario**

Table 5-24 Annual fuel consumption, emissions and intensity forecast for cement sector

Year	Total Production (Mt cement)	Total Fuel Consumption					Total Energy (PJ, fuel+ electricity)	CO2 emissions (million tones)	Fuel Intensity (GJ/tonne cement)	Energy Intensity (GJ/tonne cement)	Emissions Intensity (tonne CO2 / tonne cement)
		Coal	Gasoline	Natural Gas	All Fuels	Electricity (PJ)					
2000	718.3	3285.8	87.7		3712	338.5	4050.5	678.3	5.17	5.64	0.94
2005	881.5	3811.7	101.7		4331.7	418.3	4750.0	777.5	4.91	5.39	0.88
2010	1044.8	4255.6	113.5		4868.3	499.3	5367.6	876.4	4.66	5.14	0.84
2015	1132.3	4336.3	117.7		4992.2	538.1	5530.3	907.4	4.41	4.88	0.80
2020	1219.8	4374.4	121.2		5072.1	576.5	5648.6	923.3	4.16	4.63	0.76
2025	1323.6	4421.5	125.5		5179.9	633.0	5812.9	941.5	3.91	4.39	0.71
2030	1427.4	4417.5	128.8		5236.9	690.6	5927.5	950.4	3.67	4.15	0.67

Table 5-25. CO2 Emissions and Intensity by fuel type

Year	CO_2 Emissions ($MMTCO_2e$)			
	Coal	Oil	Electricity	Process
2000	299.9	4.30	35.9	338.2
2005	347.9	4.48	37.6	387.5
2010	388.4	5.15	46.1	436.7
2015	395.8	5.65	53.9	452.1
2020	399.3	5.85	58.0	460.2
2025	403.6	6.03	62.4	469.4
2030	403.2	6.23	68.4	472.5

V.G.5 Co-Benefits

Mitigation Option	Water quality improvements	Increased economic productivity and competitiveness	Job creation	Technology development and transfer	Infrastructure development	Enhanced energy security and independence	Air quality improvement
Preventative Maintenance		☆☆☆☆		☆	☆☆☆		
Process management and Control	☆	☆☆☆		☆	☆☆	☆	☆☆
Use of Waste Derived Fuels	☆☆	☆☆☆		☆☆	☆☆	☆	
Kiln Shell Heat Loss Reduction		☆☆		☆	☆☆	☆	☆
High-Efficiency Motors and Drives		☆☆		☆	☆		
Active Additives	☆	☆		☆			
Composite Cement	☆	☆					
Combustion System Improvement	☆☆	☆		☆☆	☆	☆☆	☆☆
Conversion to Multi-stage pre-heater kiln	☆	☆☆		☆☆☆	☆	☆☆	☆☆☆
High-efficiency roller mills	☆	☆		☆☆	☆	☆	
High-efficiency Powder Classifiers		☆		☆	☆	☆	
Efficient transport systems		☆		☆	☆☆	☆	

VI. Sector Analysis and Results: Pulp and Paper

VI.A Sector Overview

Total annual output and consumption of paper in China has kept rising starting from 1990. Over the past 20 years, the annual paper production capacity in the China has increased significantly, from 5.56 million tonnes in 1980 to 27.44 million tonnes in 1997, representing an average increase of 1.21 million tonnes or 10.1% per year, higher than the 6.7% global growth rate during the period. 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 tonnes. In 2000, China was the world's third largest paper producer, after the United States and Japan (Now, China is the second largest paper producer only after USA).

There is about 5 million metric tons gap between consumption and production. Paper consumption in China represented approximately 10% of the world's total consumption in 2000. In 2000, China surpassed Japan as the world's second largest and Asia's largest paper consumer. However, per capita paper products consumption in China was only approximately 28 kilograms per year in 2000 whereas per capita consumption in most developed countries such as the United States and Japan was more than 200 kilograms per year.

It is obvious that total consumption of paper products in China will increase further due to continuing development of China's economy following the increase of the country's living standard.

Table 6-1. Annual output and consumption of China's paper industry

Year	Paper pulp output(10000 metric tons)	Paper and paperboard(1000 metric tons)				Consumption per capital(kilogram per capita per year)
		Total output	Import	Export (1000 metric tons)	Total consumption	
1990	834.96	1391.87	96.20	25.20	1462.87	2.79
1991	860.59	1498.69	133.90	23.30	1609.29	13.89
1992	1031.81	1745.10	251.60	23.00	1973.70	16.86
1993	823.28	1820.00	245.00	22.20	2042.80	17.24
1994	1006.69	2136.00	318.00	27.00	2427.00	20.25
1995	1143.69	2400.00	302.90	53.00	2649.90	21.70
1996	1211.79	2600.00	449.00	22.00	3027.00	24.70
1997	1147.79	2733.00	552.00	27.00	3258.00	26.40
1998		2800.00	577.00	30.00	3347.00	26.80
1999	918.43	2900.00	652.30	13.80	3525.00	27.80
2000	1048.72	3050.00	597.10	71.80	3575.00	28.00

At present, according to industrial experts, the Chinese paper industry's major problems revolve around the fact that many Chinese factories are poorly equipped in regard to both facilities and technology. Chinese paper mills are either equipped with facilities produced 40 or 50 years ago or those very advanced imported ones. Due to poor equipment, most Chinese paper factories are continuing to produce paper out of non-wood fibre, such as straw fibre. Foreign countries now mainly produce high value-added paper out of wood fibre. Last year, China imported a large amount of this type of paper.

The industry structure, including enterprise scale and use of raw materials, leads to higher energy consumption and more pollutants in China's pulp and paper industry.

The following table show energy efficiency in China's pulp and paper industry comparing with Japan. The data is out of date and the energy efficiency gap between China and Japan at present already shortened. But the general technology level of China's pulp and paper has been at low level.

Table 6-2.Energy efficiency in China's pulp and paper industry comparing with Japan

	Units	China,19995	Japan,1993	Comparing with Japan
Paper and paperboard output	million metric tons	27.80	27.67	100.4%
Energy consumption	Million metric tce	21.38	17.81	119%
Energy consumption per unit production	Metric tce/t	1.57	0.65	241%
thereinto:				
Sulphate pulp bleaching	Metric tce/t	0.714	0.391	210%
Mechanical pulp	Metric tce/t	0.278	0.166	167%
Printing paper	Metric tce/t	0.36	0.363	174%

In order to produce higher quality paper and paperboard and to reduce pollution, China's paper manufacturers are turning away from traditional fibres such as wheat straw, bamboo and bagasse and now use increasing amounts of wood pulp and recycled wood fibres in the manufacture of paper products. In 2002, Non-wood pulp accounts for 32% of total pulp and only 30% in 2003.

Table 6-3.China's paper grade fiber consumption

	2002	Share of total %	2003	Share of total %	Change %
Total	34700.00	100	39100.00	100	12.68
Wood pulp	7400.00	21	8200.00	21	10.81
Waste paper	16200.00	47	19200.00	49	18.52
Non-wood pulp	11100.00	32	11700.00	30	5.41

Data source: China Paper Association

Total employee in China's pulp and paper industry is 806.7 thousand and physical labor productivity keeps rising.

Table 6-4.Work force and physical labor productivity of pulp and paper industry

Year	Work force(10000 people)		Physical labor productivity(metric ton per capita per year
	Total employee	technician	
1990	80.73	3.17	17.07
1991	83.29	3.37	18.06
1992	84.32	3.45	19.62
1993	78.74	3.71	20.68
1994	79.28	3.63	21.89
1995	81.66	3.99	21.04
1996	80.03	4.00	21.40
1997	76.35	4.05	22.05
1998	52.20		23.52
1999	86.42		25.00
2000	80.67		30.83

Most paper production facilities in China are state-owned enterprises. Many of these facilities have yet to meet international standards, in terms of quality and product variety, and are of a scale much smaller than international operators. In order to compete more effectively with foreign paper imports, China is actively undergoing restructuring with a view to expedite the development of its paper industry. These restructuring measures include encouraging plant automation of state-owned enterprises with a view to improve product quality and diversity, promoting merger and acquisition activities within the industry, encouraging foreign investments in forming equity or cooperative joint venture in pulp and paper production in China and suspending the production of smaller producers, particularly those that cause severe pollution.

According to China Paper Association, there were approximately 4,000 paper factories in China in 2001. Of this number, 2,620 paper factories had an annual sales of RMB 5 million and their combined production accounted for approximately 82% of the country's total.

In 2003, the number of the companies whose individual sales over RMB 5 million per year rose to 2766, 14.06% were owned or majority held by the state, down 3.74% from 2002, 9.04% were under Sino-foreign JV or 100% foreign ownership, up 0.94% and 76.90% were collectively or privately owned, up 2.8% from 2002.

By revenue, 29.23% came from state-owned or state-held companies, down 2.17% from 2002, 31.18% from joint venture or 100% foreign owned operations, up 0.88% from 2002 and 39.59% from collectively or privately owned companies, up 1.29% from 2002.

This confirmed the changes in equity structure in the industry. Although JV and foreign owned companies only accounted for 9.04% in number, they took up more than 30% of industry sales, earnings before interest and tax and net earnings respectively. Their progress in production, product development and market shares enabled them remarkable economic returns.

China Government regulates those industries that produce waste water such as the pulp and paper industry. Under the "People's Republic of China Environmental Protection Law", the environmental protection administration departments under the State Council are responsible for the overall regulation and management of environmental protection in China, whereas the various provincial environmental protection administration departments are delegated the powers to regulate and manage environmental protection of the relevant provinces. Waste water is produced in pulp and paper production and the quality of waste water produced by such manufacturers is subject to the monitoring of environmental protection bureau in their respective provinces and must meet the waste water effluent standard in terms of chemicals discharged set by China Government for the paper industry. Along with water pollution abatement, there will also co-benefits from energy conservation. In pulp and paper industry the scale of facilities is the main factor influencing energy efficiency and environmental performance.

VI.B Emissions Overview of Sector

VI.B.1 Background and discussion of emissions, main sources/causes/drivers, trends

Greenhouse gas emissions in pulp and paper sector are primarily the result of burning fossil fuels during the production. In 2000, pulp and paper industry accounts for 1.67% of country's total energy consumption. The following table is the historical annual fuel consumption and GHG emission. During all fuel consumption of pulp and paper industry, share of coal is more than 90%.

Table 6-5.Historical annual fuel consumption and GHG emissions

Year	Total Annual Fuel Consumption, all Fuels (PJ)	Annual GHG Emissions ($MMTCO_2e$)
1990	496.48	45.31
1991	508.49	46.41
1992.	555.39	50.69
1993	566.23	51.68
.1994	580.59	52.99
1995	626.61	57.19
1996	644.78	58.85
1997	645.36	58.90
1998.	561.54	51.25
1999	569.45	51.98
2000	679.34	62.67

VI.C Background Assumptions for Sector Analysis

Prevention and control of water pollution is the focus of pulp and paper industry, rather than energy conservation.

There are many difficulties in the evaluation of mitigation option's cost and reduction potential in pulp and paper industry. Because the industry structure rather than some one specific technology is the most important in energy conservation.

In order to simplify our analysis and gain some results, we establish three kinds of scenarios named baseline pre 2000, baseline between 2000 and 20005, mitigation scenario.

In the scenario analysis of pulp and paper, differences between these three scenarios is the output proportion of enterprises with different scale.

The following figure shows the analytical framework and data structure for pulp and paper industry.

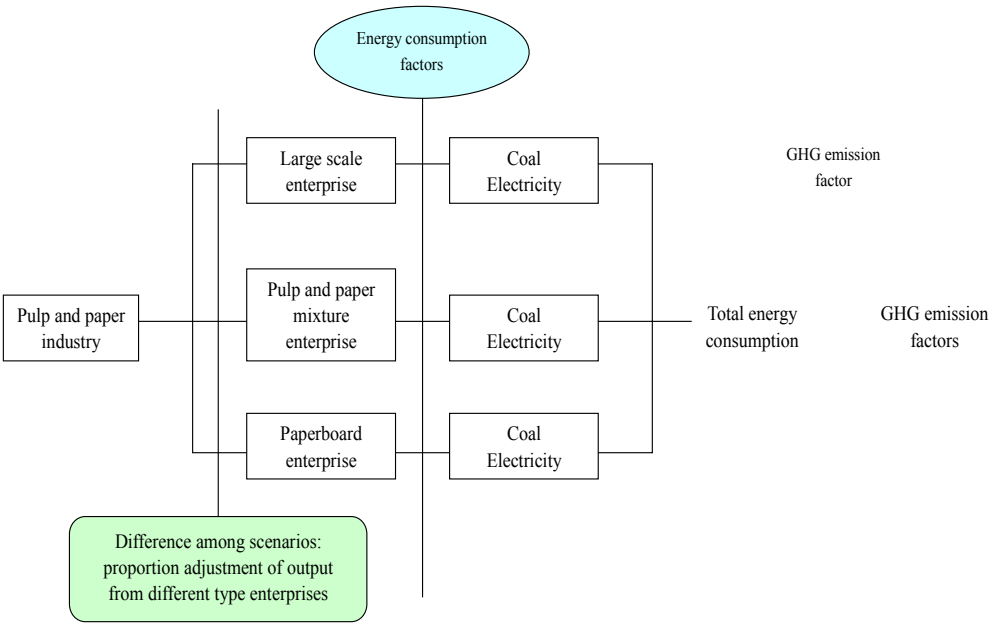

Figure 6-1. Analytical framework and data structure for pulp and paper industry

VI.D Baseline (Business-As-Usual) Forecasts for Sectors

VI.D.1 Production/output forecast

In China, per capita paper products consumption is at lower level and obviously in the future following the increase of people's living standard, per capita paper products consumption will rise and total consumption then will increase further.

The following figure is the output forecast of paper and paperboard in China's pulp and paper industry from 2000 to 2003.

Output of paper products will keep rising and reach 48.28 million tonnes at 2010,76.42 million tonnes at 2020 and 120.98 million tonnes at 2030.

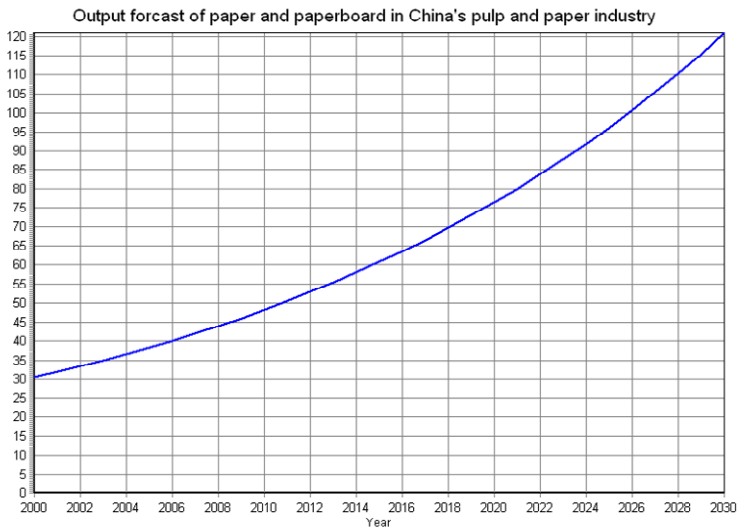

Figure 6-2. Output forecast of paper and paperboard in China's pulp and paper industry

VI.D.2 Energy and fossil fuel consumption (by type) forecast

Along with the increasing of output of paper products, energy consumption and GHG emission will also keep rising, just as the following figure shows.

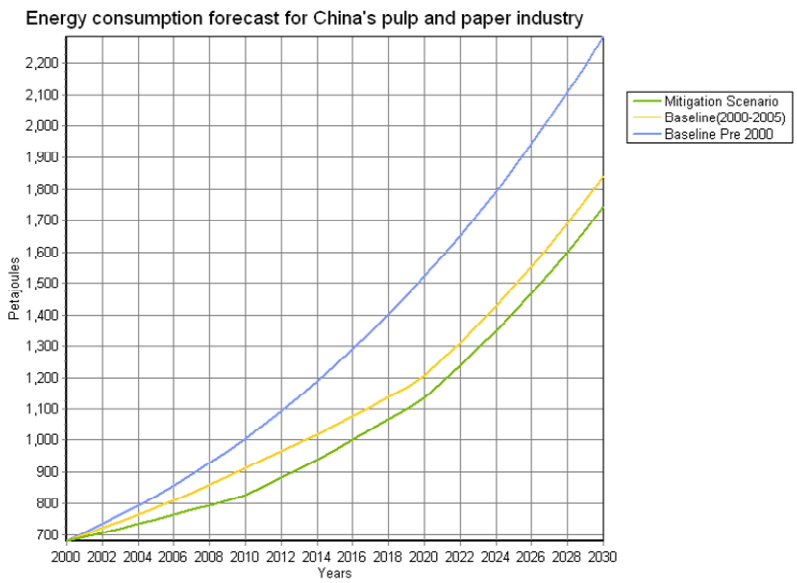

Figure 6-3. Energy consumption forecast for China's pulp and paper industry

VI.D.3 Annual GHG forecast

CO2 emission has the similar trend with energy consumption forecast. Compared with two baseline scenarios, mitigation scenario will have much emission reduction potential. In the mitigation scenario, more paper products are produced by larger scale enterprises. These enterprises will have wood resource owned by themselves and then produce wood pulp, produce paper and different paperboard.

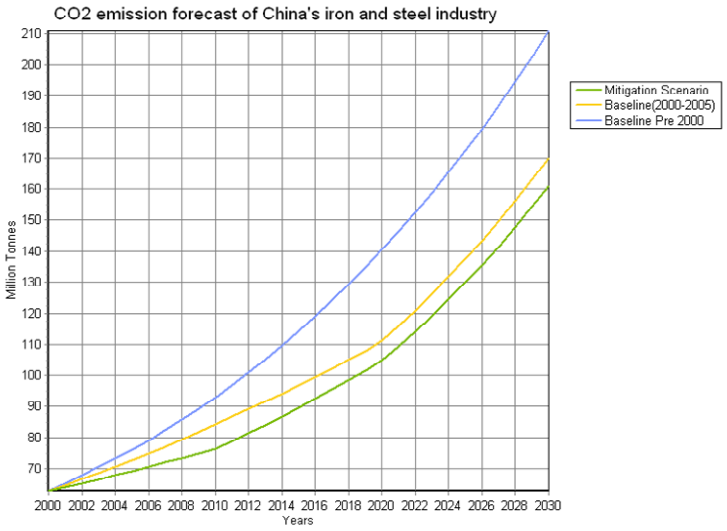

Figure 6-4. CO2 emission forecast for China's pulp and paper industry

Compared with baseline pre 2000, other two scenarios have emission reduction potential. The accumulative emission reduction between two baselines is 41.77 million metric tons at 2010,233.19 million metric tons at 2020 and 588.69 million metric tons at 2030.

The accumulative emission reduction between mitigation scenario and baselines pre 2000 is 82.11 million metric tons at 2010,343.27 million metric tons at 2020 and 776.06 million metric tons at 2030. Finally, the accumulative emission reduction between mitigation scenario and baselines 2000-2005 is 40.34 million metric tons at 2010,110.07 million metric tons at 2020 and 187.37 million metric tons at 2030.

Taking into account the exiting rapid technology advancement in China's pulp and paper industry, which has be boosted by some new industry policies promulgated between 2000 and 2005, emission reduction potential between mitigation scenario and baseline 2000-2005 will have more significance for mitigation policy in this industry.

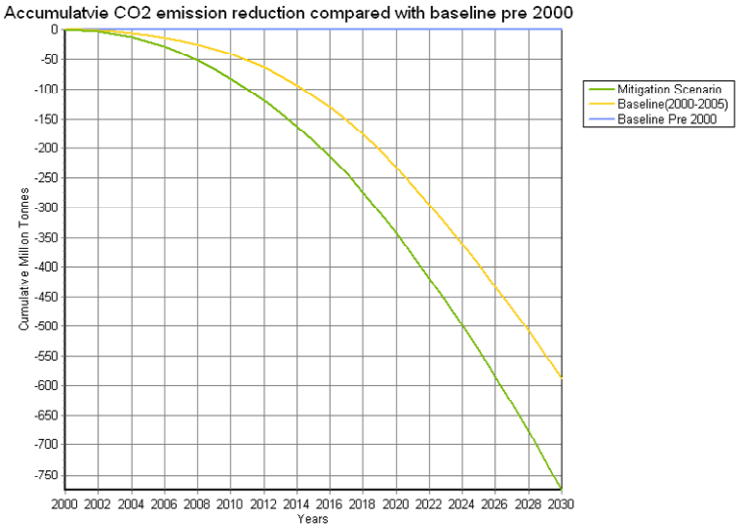

Figure 6-5. Accumulative CO2 emission reduction compared with baseline pre 2000

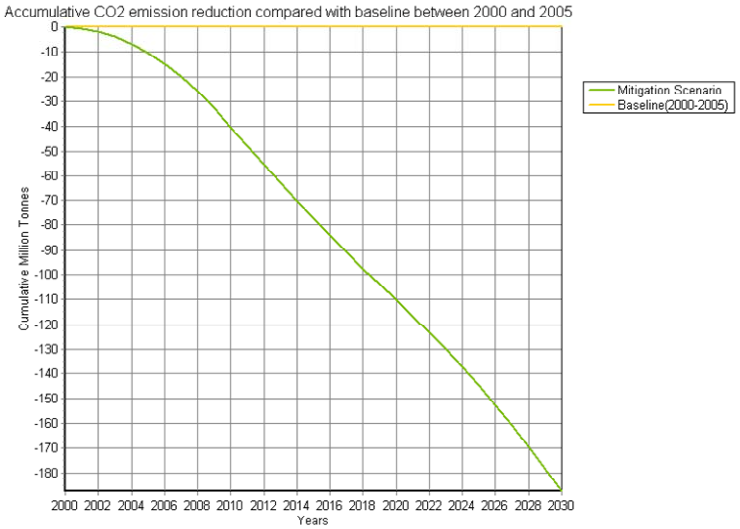

Figure 6-6. Accumulative CO2 emission reduction compared with baseline between 2000 and 2005

The following tables show the consolidated results of this sector's scenario analysis.

From these results, several conclusions can be gained.

The first, along with the rising of total production, total fuel consumption and total GHG emissions keep on rising in all scenarios.

The second, because of the industry's restructure and technology advancement, energy intensity and emission intensity, in all scenarios, keep on descending.

The third, because of stronger structure adjustment and technology advancement, the energy and emission intensities' descending will be fastest and then the increase of total fuel consumption and total GHG emission will be slower than the other two baseline scenarios.

Finally, difference of total energy consumption and GHG emission between mitigation scenario and baseline 2000-2005 will be smaller than the difference between two baselines.

VI.D.4 Energy intensity and CO2 intensity forecast (per unit of output)

Table 6-6. Annual Fuel Consumption, Emissions and Intensity Forecast (Baseline Pre 2000)

Year	Total Production (million metric tons)	Total Fuel Consumption (PJ)			Total GHG Emissions (MMTCO2e)	Energy Intensity (GJ/metric ton)	Emissions Intensity (metric tons CO2e/metric ton output)
		electricity	coal	All fuels			
2000	30.50	44.30	635.04	679.34	62.67	22.27	2.05
2005	38.37	53.79	771.11	824.90	76.09	21.50	1.98
2010	48.28	65.51	938.96	1004.47	92.66	20.81	1.92
2015	60.74	80.72	1156.99	1237.71	114.18	20.38	1.88
2020	76.42	99.42	1425.02	1524.44	140.63	19.95	1.84
2025	96.15	121.80	1745.69	1867.49	172.27	19.42	1.79
2030	120.98	149.11	2136.96	2286.07	210.88	18.90	1.74

Table 6-7 Annual Fuel Consumption, Emissions and Intensity Forecast (Baseline 2000 to 2005)

Year	Total Production (million metric tons)	Total Fuel Consumption (PJ)			Total GHG Emissions (MMTCO2e)	Energy Intensity (GJ /metric ton)	Emissions Intensity (metric tons CO2e/metric ton output)
		electricity	coal	All fuels			
2000	30.50	44.30	635.04	679.34	62.67	22.27	2.05
2005	38.37	51.35	736.04	787.39	72.63	20.52	1.89
2010	48.28	59.50	852.86	912.37	84.16	18.90	1.74
2015	60.74	68.27	978.48	1046.75	96.56	17.23	1.59
2020	76.42	78.53	1125.37	1203.90	111.06	15.75	1.45
2025	96.15	97.17	1392.48	1489.65	137.42	15.49	1.43
2030	120.98	120.21	1722.51	1842.72	169.99	15.23	1.41

Table 6-8. Annual Fuel Consumption, Emissions and Intensity Forecast (Advanced Options/Mitigation Scenario)

Year	Total Production (million metric tons)	Total Fuel Consumption (PJ)			Total GHG Emissions (MMTCO2e)	Energy Intensity (GJ /metric ton)	Emissions Intensity (metric tons CO2e/metric ton output)
		electricity	coal	All fuels			
2000	30.50	44.30	635.04	679.34	62.67	22.27	2.05
2005	38.37	48.82	699.76	748.59	69.05	19.51	1.80
2010	48.28	54.03	774.37	828.40	76.42	17.16	1.58
2015	60.74	63.27	906.64	969.91	89.47	15.97	1.47
2020	76.42	74.18	1062.82	1137.00	104.89	14.88	1.37
2025	96.15	91.87	1316.15	1408.02	129.89	14.64	1.35
2030	120.98	113.76	1629.44	1743.20	160.81	14.41	1.33

VII. Sector Analysis and Results: Transportation

VII.A Sector Overview

VII.A.1 Summary and explanation of economic statistics

Transport sector is one of the fundamental sectors in national economy and plays the role of transferring freight and passengers. Along with the booming economy and the improving living condition in China, transport sector has also been experiencing a rapid development.

VII.A.1.i Total output/production

Table 7-1 shows the development of passenger and freight traffic in China from 1990 to 2000. The volume of passenger traffic had almost doubled, and the freight traffic volume in 2000 was 1.4 times of the 1990 level.

Table 7-1 Statistics of Passenger Traffic and Freight Traffic in China, 1990-2000

Year	Passenger Traffic (million people-trips)	Freight Traffic (million tons)	Activity Level of Passenger Traffic (billion persons-km)	Activity Level of Freight Traffic (billion tons-km)
1990	7727	9706	562.9	2621
1991	8061	9858	617.8	2799
1992	8609	10459	694.9	2922
1993	9966	11159	785.8	3053
1994	10929	11804	859.1	3328
1995	11726	12349	900.2	3591
1996	12447	12984	914.3	3659
1997	13261	12782	1006	3839
1998	13787	12674	1064	3809
1999	13944	12930	1130	4057
2000	14786	13587	1226	4432

Data source: China Statistic Yearbook
Note: Passenger traffic data includes national railways, local railways, highways, marine transport and civil aviation. Freight traffic data includes national railways, local railways, highways, marine transport, civil aviation and petroleum and gas pipelines.

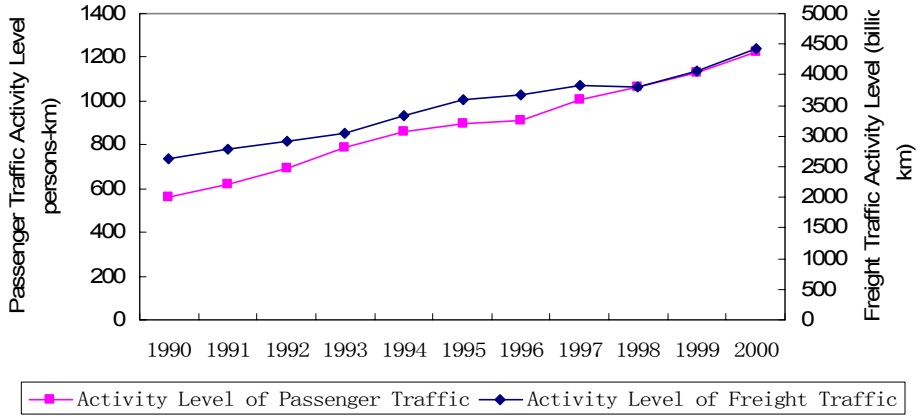

Figure 7-1 Activity level of passenger and freight traffic in China from 1990-2000

Figure 7-1 displays a steadily growing activity level of passenger and freight traffic in China from 1990-2000. It is a normal reflection of China's booming economy and people's higher demand for travel and freight delivery.

VII.A.1.ii Employment

Table 7-2 shows that the number of staff and workers engaged in transport sector from 1996 to 2002 had been declining all the time. And it remained for all these years along that around 60% of staff worked in railway and highway transport.

Table 7-2 Number of Staff and Workers Engaged in Transport Sector 1996-2002 (thousand persons)

Year	Railway Transport	Highway Transport	Pipeline Transport	Marine Transport
1996	2214	2063	36.0	757.0
1997	2238	2000	26.0	723.0
1998	1934	1395	33.0	513.0
1999	1852	1290	29.0	443.0
2000	1811	1200	22.0	388.0
2001	1789	1090	17.9	326.2
2002	1758	1016	50.9	281.5
Year	Air Transport	Transport Subsidiary Trades	Other Transports	Total
1996	108.0	1516	46.0	6740
1997	116.0	1521	40.0	6664
1998	112.0	1478	20.0	5485
1999	125.0	1512	25.0	5276
2000	117.0	1477	19.0	5034
2001	121.5	1457	21.5	4824
2002	120.5	1409	18.7	4655

Data Source: China Statistic Yearbook

Besides, in 2003, people worked in auto industry (only people working at vehicle manufacturing plants, components and auto-related industries excluded) reached 33 million, which was 1/7 of the urban employees. This data didn't include those people working in component supply industries and auto-related industries. (Miao. 2004)

VII.A.1.iii Revenues, share of GDP

We can tell from Table 7-3 that from 1990 to 2000, the revenues of transport sector had quadrupled, while its share of GDP remained almost the same during this period.

Table 7-3 Revenue of Transport, Storage, Postal & Telecommunications Services and its share of GDP

	Revenue (billion US$)[a]	GDP (billion US$)[a]	Share of GDP
1990	13.9	224.3	6.20%
1991	17.0	261.4	6.52%
1992	20.3	322.1	6.31%
1993	25.6	418.7	6.12%
1994	32.5	565.4	5.75%
1995	37.0	707.1	5.23%
1996	42.2	820.9	5.14%
1997	45.9	884.4	5.20%
1998	49.8	930.7	5.35%
1999	53.9	974.4	5.53%
2000	65.4	1067	6.13%

Data source: China Statistic Yearbook

[a] in year 2000 US$ Exchange rate of USD: RMB=1:8.27

It should be noted that due to statistical caliber in China, revenue of transport sector is not available. Here we use revenue of transport, storage, postal & telecommunications services for reference.

VII.A.1.iv Role of transport sector in overall economy as source of inputs to other sectors

Transport has always played a supportive role for other sectors' development. According to a research, the annual new job opportunities directly created by transport sector from 2001 to 2004 reached 10 million, and the number is rising by 1.7 million per year. And the induced job opportunities by transport investment had reached about 25 million, which was 13% of the new job opportunities national-wide for the same period. (Cen, 2004) The development in transport sector would bring market demand for manufacturing, marketing, maintenance, financial service, storage sector, environmental protection and etc. Besides, a well-designed transport system would increase the efficiency of other sectors' material purchase and merchandise selling, which indirectly increases the sectors' net income. For the auto industry especially, according to the experience in developed countries, each dollar added by the auto industry would bring in 0.65 dollar to the upper industries (such as component manufacturing industries) and 2.63 dollars to the subsequent industries (such as carwash industries) (Zhao. 2003).

VII.A.2 Quantitative and qualitative characterization of sector

Patterns of the development of total fuel consumption and fuel economy vary significantly among different transport facilities, such as railway, road, waterway, air, and pipeline. Here, we focus on the fuel consumption of road transport for the following reasons: 1) road transport took up over 50% of the total gasoline and diesel consumption in the whole transport sector and is experiencing a rapid consumption growth rate—nearly 12.6% per year, which is higher than all the other transport ways except air transport (Zhou et al. 2003); 2) the mitigation potential of road transport is larger than that of other transport modes; 3) the data and research in road transport are much more available than the others. Taking all these factors into consideration, we focus all the following characters and analysis on road transport.

VII.A.2.i Breakdown of vehicles in Analysis

In road transport, facilities could be divided into truck, bus, car and motorcycle. Truck refers to freight carrier or towing vehicle. Bus refers to vehicle which can carry more than 9 people, with rectangular carriage, mainly for passengers and their taken-with baggage. Car refers to small passenger vehicle which can carry 2 to 8 people, with four wheels, including taxi. Motorcycle refers to 2-wheel or 3-wheel vehicle. Each type contains vehicles for both commercial and personal use. Furthermore, truck could still be categorized into heavy (HT), medium(MT), light(LT) and mini(MiniT) by gross vehicle weight, and bus into the similar categories (HB, MB, LB and MiniB) by total vehicle length[43].

Table 7-4 shows the number of different types of vehicles in China in 2000. The total vehicle ownership (excluding motorcycle) in 2000 had reached 15.72 million, in which truck, bus and car took up 46%, 26% and 28% respectively. The total motorcycle ownership in 2000 was 37.7 million. The most recent data shows that in 2004, the vehicle ownership in China reached 27.42 million (motorcycle excluded) (NSB, 2005). And from 1990-2003, the average annual growth rate of vehicle ownership was 12%. And the average annual growth rate of private vehicle ownership reached 31% in the same period (Shen, 2005), which aligned with the encouragement policy in China for vehicles' private ownership.

43 Heavy truck (HT): 14.0 tons<gross vehicle weight (GVW)
Medium truck (MT): 6.0 tons <GVW<14.0 tons
Light truck (LT): 1.8 tons<GVW<6.0 tons
Mini truck (MiniT): GVW<1.8tons
Heavy bus (HB): 10.0 meters<total vehicle length (TVL)
Medium bus (MB): 7.0 meters<TVL<10.0 meters
Light bus (LB): 3.5 meters<TVL<7.0 meters
Mini bus (MiniB): TVL<3.5 meters

Table 7-4 Number of entire fleet of vehicles by type in China (million units), data in 2000

Truck	Bus	Car	Motorcycle
7.18	4.14	4.40	37.7

Data Source: Huo Hong (2002)

Table 7-5 and 7-6 show the composition of new trucks and buses sold in China in 2000. In 2000, new light truck took up more than 50% of the total new truck sales and new mini bus took up nearly 60% of the total new bus sales.

Table 7-5 Percentage of HT, MT, LT and MiniT in total new trucks in China, data in 2000

HT	MT	LT	MiniT
10.7%	21.1%	51.2%	17.0%

Data Source: Huo Hong (2002)

Table 7-6 Percentage of HB, MB, LB and MiniB in total new buses in China, data in 2000

HB	MB	LB	MiniB
1.3%	5.0%	35.0%	58.7%

Data Source: Huo Hong (2002)

Gasoline and diesel are the main vehicle fuels in China. And most light vehicles are using gasoline. Table 7-7 shows the percentage of gasoline vehicle in different types of fleet-wide vehicles in China in 2000.

Table 7-7 Percentage of gasoline vehicle in different types of vehicles in China, data in 2000

HT	MT	LT	MiniT	Car
2.00%	35.00%	40.00%	99.50%	100.00%
HB	MB	LB	MiniB	
8.00%	45.00%	67.00%	100.00%	

Data Source: China Automotive Industry Yearbook (2001)

Table 7-8 shows the annual average traveled kilometers of each class of vehicle in China in 2000.

Table 7-8 Annual vehicle kilometers traveled (VKT) of each type of vehicle in China (thousand kilometers), data in 2000

HT	MT	LT	MiniT	Car
67.4	25	20.9	43.2	26.4
HB	MB	LB	MiniB	MC
52	52	34	35	9

Data source: Huo Hong (2002)

By 2000, there has been no officially published fuel economy statistics of each class of vehicles in China. However, in 1998, Department of Mechanics and Industry had released a New Vehicle Technology Handbook, which demarcated the tested fuel economy of vehicles at that time. European NEDC test cycle is used to measure tested fuel economy. See Table 7-9.

Table 7-9 Tested fuel economy of new vehicles (km/L) in 1998 in China

HT		MT		LT		MiniT		Car	
Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel
3	4.42	3.98	5.71	7.87	8.7	15.38	18	14.71	20
HB		MB		LB		MiniB		MC	
Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel		
2.94	4.03	3.57	4.21	10.03	11.76	15.87	19	49.02	

Data Source: New Vehicle Technology Handbook (1998)

Up till 2000, there has been no fuel efficiency data or limits published. Therefore, we intend to use the above 1998 data to reflect the situation in 2000. Furthermore, an adjustment factor is introduced here to transform the tested fuel economy to the on-road fuel economy. This factor takes other important factors influencing fuel economy into consideration, such as the kilometers the vehicle had traveled, average travel speed, driver's personal habits, fuel quality and road conditions etc. We set this adjustment factor 75% in the research (Huo Hong, 2002). Take heavy truck for example. The fuel economy of new heavy truck in 1998 was 3 km/L, so that the real fuel economy of new heavy truck was 3×75%, that was 2.25 km/L. Table 7-10 shows the on-road fuel economy of new vehicles (km/L) in 2000 in China. It should be noted that for the fuel economy of cars, we choose to refer to a research on regulations and policies on Chinese vehicles' fuel economy (CATARC, 2003), which mentioned the cars' fuel economy reality in 2000 (it says phase I of the newly published Maximum Limits of Fuel Economy for Passenger Cars would help cars and LDVs to increase their fuel economy by 5% to 10% in the 10th five-year period, so we use the limits to educe the fuel economy reality. We also assume there is no fuel economy difference between gasoline and diesel cars.).

Table 7-10 On-road fuel economy of new vehicles (km/L) in 2000 in China

HT		MT		LT		MiniT		Car	
Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel
2.25	3.32	2.99	4.28	5.90	6.53	11.5	13.5	6.17	6.17
HB		MB		LB		MiniB		MC	
Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel		
2.21	3.02	2.68	3.16	7.52	8.82	11.90	14.25	36.77	

VII.A.2.ii Brief and general comparisons with rest of the world

Figure 7-2 shows the comparison of fuel economy of Chinese vehicle models (red dots) and the European models (black triangles) in 2004. Obviously, Chinese vehicles models are lighter but less efficient.

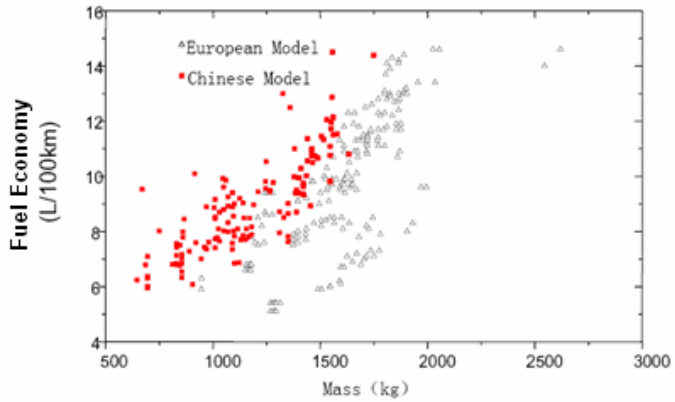

Figure 7-2 Comparison of fuel economy of Chinese and European vehicle models in 2004
Source: Feng An (2004)

VII.A.2.iii Ownership patterns of sector

Car ownership in China in 2005 is very low. The total number is about 9 cars per 1000 people, as compared to over 700 per 1000 people in US. However, it is growing at impressive rates as China's urban middle class embraces the automobile just as Americans did in the 1930s (Wei. 2005).

VII.B Emissions Overview of Sector

VII.B.1 Background and discussion of emissions

Road transport emissions keep growing these years. Although the current advanced technology has greatly improved fuel efficiency, the booming vehicle ownership, the more and more severe traffic congestion, and people's higher desire for comfort have resulted in the higher emission share of road transport in total national emissions.

VII.B.2 Annual GHG emissions inventory for a recent year

VII.B.2.i Total emissions by source

In 2000, the CO2 emission of road transport sector in China reached 213 million tons. Table 7-11 shows the CO2 emission by vehicle type in road transport sector.

Table 7-11 CO2 emission of road transport sector in China, data in 2000 (million tons)

HT		MT		LT		MiniT		Car	
Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel
1.45	22.70	14.34	22.62	9.98	17.96	11.94	0.012	43.2	0
HB		MB		LB		MiniB		MC	Total
Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel		
0.16	2.21	5.62	7.03	13.55	5.86	13.22	0	21.19	213.0

Data source: Huo Hong (2002)

VII.B.2.ii Percent share of emissions by source

From Figure 7-3, it is obvious that in China in 2000, emission from truck took up nearly half of the total road transport emissions, followed by bus (22%), car (20%) and motorcycle(10%).

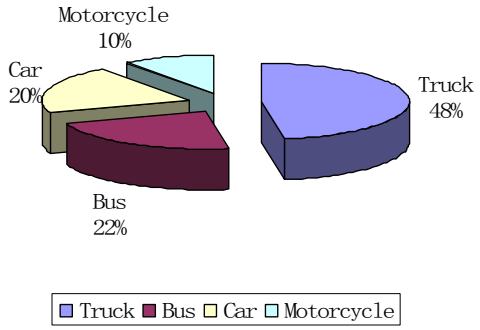

Figure 7-3 Percent share of emission by vehicle type, data in 2000

VII.B.3 Historical annual fuel consumption and GHG emissions trends by fuel type (1990--2000)

Due to statistical restrictions, we could only use energy consumption in transport, storage, postal & telecommunications Services to roughly show the trends and share of road transport sector. See Table 7-12 and Figure 7-4.

Table 7-12 Energy consumption of Transport, Storage, Postal & Telecommunications Services and its share in total energy consumption

	1995	1996	1997[b]	1998	1999	2000	2001	2002	2003
Energy Consumption of Transport, Storage, Postal&Telecommunications Services(billion GJ)[a]	1.59	1.63	1.84	2.05	2.51	2.70	2.79	3.02	3.47
Total Energy Consumption (billion GJ)	35.7	37.8	37.7	37.6	35.4	35.4	36.7	40.3	46.5
Share	4.47%	4.31%	4.89%	5.46%	7.10%	7.61%	7.60%	7.48%	7.45%

Data: China Statistic Yearbook

[a]1 tce=27.2 GJ (ZBEPB(Zibo Environmental Protection Bureau))

[b]The 1997 data is not available from China Statistic Yearbook. The data here is the average of value in 1996 and 1998.

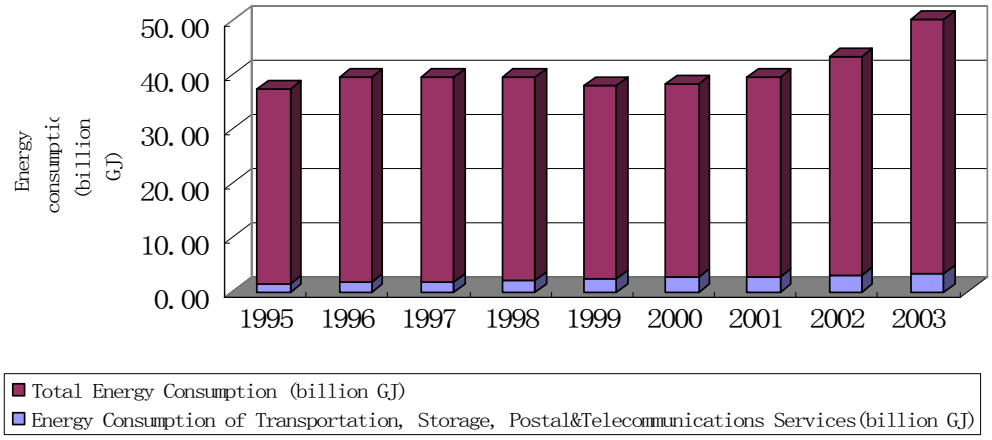

Figure 7-4 Energy consumption of Transport, Storage, Postal & Telecommunications Services (billion GJ) and its share in total energy consumption

The sector had experienced a continuous growth in energy consumption from 1996 to 2003; with its share gradually increase in total energy consumption. This aligns with the global trend that transport would become one of the main sectors that consume most of the energy.

VII.B.4 Relative contribution of each sector in 2000

VII.B.4.i <u>to total national energy consumption and emissions</u>

As we can see from the tables above, transport sector takes up about 7% of the national energy consumption. As road transport sector takes up 50% (Zhou et al, 2003) of the energy consumption in transport sector, then the relative contribution of road transport would be roughly 3.5-4%.

VII.C Background Assumptions for Sector Analysis

VII.C.1 Baseline with policies adopted before 2000

VII.C.1.i <u>Policies under Consideration</u>

Policies related to road transport sector adopted before 2000 include:

In 1986 <Law on Fuel Saving Management in Transport Sector> focused on ways to improve management structure and enhance management efficiency.

In April 1986, <The seventh five-year plan of national economy and social development in the People's Republic of China> listed auto-manufacturing industry as one of the key industries in China, and since that time there has been a booming automobile industry.

In 1994 <Policies on Auto Industry> mentioned that the government would gradually adjust the current public-owned consumption mode in auto industry and greatly encourage individuals auto buyers. Meanwhile, it was referred that the government would enhance the reformation and investment centralization in auto industry.

In 1997, the government renewed the 1986 < Standards for the Scrapping of Motor Vehicles >and since then, two major adjustments had been made to it in 1998 and 2000. The most updated scrapping standards mainly are: Commercial-use vehicles (including taxis) have a legally required scrapping time – 8 years. Among non-commercial-use vehicles, passenger vehicles (including cars and SUVs) with no more than 9 seats have a suggested scrapping time – 15 years. Passenger vehicles with more than 9 seats have a suggested scrapping time – 10 years. Yet they do not need to pass any inspection to get the permission to extend their life-span, however they need to have two inspections each year (compared to only one inspection for normal vehicles). Heavy buses have a suggested scrapping time of 10 years and needs to pass inspection to get the permission to extend the life-span. Mini trucks have a legally required scrapping time of 8 years. Light truck, medium truck and heavy truck can drive for 10 years and needs to apply and pass the inspection if wanting to extend the life-span, yet the maximum life-span extension should not be longer than 10 years. Motorcycles have a suggested scrapping time of 9 years yet the maximum life-span extension should not be longer than 3 years. No inspection is needed for motorcycles to extend its life-span.

<Measurement method of fuel saving technology for automobiles> was published in 1994, and <Rules for the Publication of Energy Conservation Products of Automobiles and Vessels> in 1995, and <Decision on modifying highway law> in 1999.

And before 2000, another important technology handbook should be referred here. It was the < New Vehicle Technology Handbook> published by Department of Mechanics and Industrial. In the following sector analysis, we refer most of the fuel efficiency data in this handbook as the real fuel economy of new vehicles of vehicles in China in 2000.
Almost no policies directly related to reducing automobile fuel consumption and GHG emissions had been adopted before 2000.

VII.C.2 Baseline with policies adopted between 2000 and 2005

VII.C.2.i <u>Policies under Consideration</u>

In 2000, <Detailed Rules on the Implementation of Energy Conservation Law in the Transport Industries> implemented Energy Conservation Law from managerial perspective. And it encouraged adjusting vehicle structure and road planning and carrying out research on aspects such as fuel consumption limits, new fuel substitutes and lower friction.

In Mar. 2001 <Summary of the tenth five-year plan of national economy and social development> referred in official documents for the first time that ordinary families were encouraged to own autos. However, this policy has always been accompanied by fierce debate on its effects to urban transport and energy consumption.

In 2004, new <Policies on Auto Industry> was published to align with WTO regulations and added more market-oriented factors into the management system. Besides the policies that aimed at improving the market competency of home auto companies, companies were also induced and encouraged to develop energy-saving and environmental friendly automobiles, some with new types of fuel as well. The new policy had emphasized the harmony between auto industry development and the environment.

Also in 2004, the government had set up limits of fuel consumption level for two periods, for cars with different complete mass -- <Maximum Limits of Fuel Consumption (L/100-km) for Passenger Cars >.

The limits are applicable to vehicles which 1) are equipped with ignition engine or compression ignition engine; 2) have the maximum designed vehicle speed no less than 50km/h; 3) have the maximum designed mass no more than 3500 kg; 4) are passenger vehicles that have no more than 9 seats (including the driver seat). Obviously these limits are only applicable to cars in this research.

European NEDC test cycle is used to measure the fuel economy. These limits are tested fuel economy and are weight based. Standards for gasoline and diesel vehicles are identical. There are two separate sets of standard, one for passenger cars with manual transmission, and another for those with automatic transmission, SUVs and MPVs (Multi-Purpose Vehicles – vehicles with functions of cars, wagons, vans) with 3+ rows (all transmission types). Moreover, there are differences between the standard implementation timeline between the new registered vehicles and in-production vehicles. For new registered vehicles, phase I to implement these limits start from July 2005 and phase II starts from Jan 2008; for in-production vehicles, the corresponding two dates to start implementation are both one year behind the new registered vehicles. The limits in phase I could ensure the realization of goal in the 10th five-year plan (the oil consumption per 100 kilometers of cars and light duty vehicles could decrease 5% to 10% compared to the current oil consumption level) and the limits in phase II could ensure the realization of goal in the 11th five-year plan (a 15% decrease compared to current oil consumption level)

One fact is that most vehicles in China are manual. To simplify the following calculation and analysis, here we neglect the limits for auto/SUV and those in-production vehicles. The detailed limits information is shown in table below.

Table 7-13 Maximum Limits of Fuel Consumption for Passenger Car (L/100km)

Complete Mass (CM) (kg)	Stage I	Stage II
CM≤750	7.2	6.2
750 < CM≤865	7.2	6.5
865 < CM≤980	7.7	7
980 < CM≤1090	8.3	7.5
1090 < CM≤1205	8.9	8.1
1205 < CM≤1320	9.5	8.6
1320 < CM≤1430	10.1	9.2
1430 < CM≤1540	10.7	9.7
1540 < CM≤1660	11.3	10.2
1660 < CM≤1770	11.9	10.7
1770 < CM≤1880	12.4	11.1
1880 < CM≤2000	12.8	11.5
2000 < CM≤2110	13.2	11.9
2110 < CM≤2280	13.7	12.3
2280 < CM≤2510	14.6	13.1
2510 < CM	15.5	13.9

Data Source: Limits of Fuel Consumption for Passenger Car (GB19578-2004), 2005

In Nov 2004, <Mid- and Long-term Specific Plan on Energy Conservation> encouraged developing diesel vehicles and public transport. For passenger cars, the average on-road fuel economy should reach 8.2~6.7 liters per 100 km in 2010, compared 9.5 liters per 100 km in 2000. This plan greatly promoted the energy conservation action for all society.

VII.D Baseline (business-as-usual) Forecasts

The GHG emission in road transport sector is dependent on three factors: 1) vehicle fleet mix; 2) VKT of each type of vehicle; 3) fuel economy of each type of vehicle. This research only tracks tailpipe CO2 emissions from vehicles but does not account for non-CO2 tailpipe (such as e.g., CH4, N2O) and direct GHG emissions from air-conditioning coolant leaks.

VII.D.1 Production/output forecast

Projections on vehicle fleet mix and VKT are identical for both baseline scenarios (the 2000 policies and the 2005 policies).

VII.D.1.i Vehicle fleet mix

Since the late 1970s, the vehicle ownership in China has grown extremely rapidly, increasing about 10-fold during the past two decades. By the end of 2000, the total number of vehicles had reached nearly 16 million (motorcycles excluded). The following table shows the vehicle ownership by class in China from 1997 to 2000.

Table 7-14 Vehicle ownership in China from 1997 to 2000 (million units)

	Truck	Bus	Car	Total (Motorcycle excluded)	Motorcycle
1997	6.01	2.42	3.38	11.8	20.2
1998	6.28	2.88	3.67	12.8	25.2
1999	6.77	3.29	4.11	14.2	26.2
2000	7.18	4.14	4.4	15.7	37.7

Data source: Huo Hong (2003)

Elasticity factor method is used here to estimate the future vehicle ownership in China. According to Huo 2002, it is assumed that the growth rate of GDP in China is 8.0% from 2000 to 2010, 7% from 2010 to 2020, and 6.0% from 2020 to 2030, and the elasticity factor of vehicle ownership to GDP growth is 1.2 from 2000 to 2010, 1.15 from 2010 to 2020 and 1.1 from 2020 to 2030. The elasticity factor of motorcycle ownership to GDP growth is assumed to gradually decrease. In 2000-2006, it is stable at 2.5 and starts to decrease by 0.5 every year since 2006. It is stable at 0.5 in 2010-2015, and starts to decrease 0.1 every year since 2015. And since 2020, it is assumed that the elasticity factor turns down to 0. In 2030, China will have about 160 million vehicles, among which 60% are cars. Here we assume that the average scrapping time is 15 years.

In 1999, the proportion of trucks, buses, and cars in the total vehicle ownership was 48.9%, 20.3%, and 30.8% (motorcycle excluded) (Huo. 2002). As mentioned in the policies before year 2000, we see an industrial policy which was to encourage the development of cars and the improvement of people's quality of life. Therefore, this report assumes that the proportion of cars will increase greatly in the future 30 years. Although the number of buses and truck will also increase greatly, but their growth rate is much slower than that of cars. Therefore, their proportion in the total vehicle ownership will decrease gradually, as shown in Table 7-15.

Table 7-15 Projection of proportion of new trucks, buses, and cars in the total ownership, till 2030

Year	Truck	Bus	Car
2000	46%	23%	31%
2005	30%	28%	42%
2010	24%	30%	46%
2015	20%	30%	50%
2020	15%	30%	55%
2025	10%	30%	60%
2030	10%	30%	60%

It is projected that in 2020, there will be 85.1 million vehicles and an extra 175.6 million motorcycles in China, as is shown in Table 7-16. Figure 7-5 shows the growth trend of vehicle ownership in China, from 2000 to 2030, from which we find a comparatively more rapid growth of cars. It should be noted that this projection result is based on the 2000 baseline and is developed upon our own assumptions.

That is why the data in Table 7-16 has some differences with the reality of vehicle population described in the paragraph preceding Table 7-4.

Table 7-16 Vehicle ownership and motorcycle ownership forecast in China, 2000-2030 (million units)

Year	Truck	Bus	Car	Total (Motorcycle excluded)	Motorcycle
2000	7.18	4.14	4.40	15.7	37.7
2005	6.98	7.36	10.3	24.6	89.6
2010	8.93	12.1	17.9	38.9	133.3
2015	11.0	17.6	28.6	57.3	158.1
2020	13.0	25.8	46.3	85.1	175.6
2025	12.0	35.3	69.6	116.8	169.3
2030	16.3	48.4	95.8	160.5	173.9

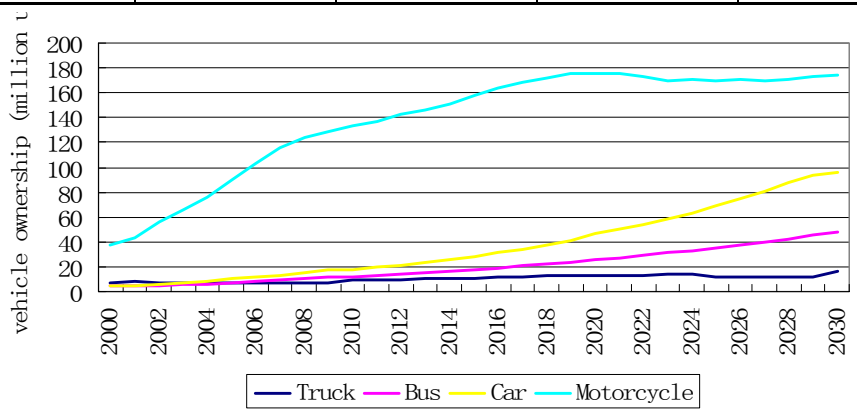

Figure 7-5 Vehicle ownership and motorcycle ownership forecast in China, 2000-2030 (million units)

The CHINA AUTOMOTIVE INDUSTRY YEARBOOK displayed the proportion of each vehicle type in new vehicles fleet during 1989 and 1999. The future structure of new fleet is projected based on these historical data, the Chinese policy to promote light duty vehicles and related research (Huo, 2002), as shown in Table 7-17.

Table 7-17 Projection of structure of new fleet till 2030

Year	HT	MT	LT	MiniT	HB	MB	LB	MiniB
2000	10.7%	21.1%	51.2%	17.0%	1.3%	5.0%	35.0%	58.7%
2005	25.0%	10.0%	50.0%	15.0%	1.3%	5.5%	32.5%	60.7%
2010	26.5%	7.5%	52.0%	14.0%	1.3%	6.0%	30.0%	62.7%
2015	28.0%	5.0%	55.0%	12.0%	1.2%	7.0%	30.0%	61.9%
2020	30.0%	4.0%	58.0%	8.0%	1.0%	8.0%	30.0%	61.0%
2025	30.0%	4.0%	62.0%	4.0%	1.0%	8.0%	30.0%	61.0%
2030	30.0%	4.0%	65.0%	1.0%	1.0%	8.0%	30.0%	61.0%

The China Automobile Industry Yearbook had included the proportion of the vehicles fueled with gasoline and diesel in each vehicle type during 1995 and 1999. At present, most of the light duty vehicles are fueled with gasoline. Given the recent policy to encourage diesel vehicles and related research (Huo, 2002), we assume that the proportion of diesel vehicles in light vehicles will increase a little during the future 30 years. For the heavy duty vehicles, the proportion of gasoline vehicles is very large at present. Considering the high efficiency of diesel vehicles and the policy direction of Chinese government, we assume that the proportion of diesel vehicles in large duty vehicles will growth greatly and will be 100% in 2030, as shown in Table 7-18.

Table 7-18 Projection of the proportion of gasoline in each vehicle type, till 2030

Year	HT	MT	LT	MiniT	HB	MB	LB	MiniB	Car	MC
2000	2.0%	35.0%	40.0%	99.5%	8.0%	45.0%	67.0%	100.0%	100.0%	0.0%
2005	1.5%	32.5%	37.5%	97.3%	6.5%	42.5%	66.0%	97.5%	97.5%	0.0%
2010	1.0%	30.0%	35.0%	95.0%	5.0%	40.0%	65.0%	95.0%	95.0%	0.0%
2015	0.5%	25.0%	32.5%	92.5%	2.5%	37.5%	62.5%	92.5%	92.5%	0.0%
2020	0.0%	20.0%	30.0%	90.0%	0.0%	35.0%	60.0%	90.0%	90.0%	0.0%
2025	0.0%	15.0%	25.0%	90.0%	0.0%	32.5%	60.0%	90.0%	90.0%	0.0%
2030	0.0%	10.0%	20.0%	90.0%	0.0%	30.0%	60.0%	90.0%	90.0%	0.0%

Table 7-19 and 7-20 show the projection of vehicle ownership of vehicles with different fuels.

Table 7-19 Total vehicle ownership for gasoline vehicle of each type (million units) till 2030

Year	HT	MT	LT	MiniT	HB	MB	LB	MiniB	Car	MC
2000	0.02	0.75	1.23	1.39	0.00	0.13	1.31	1.96	4.40	0
2005	0.02	0.46	1.22	1.15	0.01	0.20	1.94	3.97	10.1	0
2010	0.02	0.34	1.60	1.39	0.01	0.29	2.63	7.12	17.0	0
2015	0.03	0.28	1.97	1.42	0.01	0.43	3.54	10.4	26.5	0
2020	0.02	0.21	2.34	1.50	0.01	0.67	4.88	14.8	41.7	0
2025	0.01	0.14	2.09	1.11	0.00	0.94	6.46	19.7	62.6	0
2030	0.00	0.10	2.47	0.69	0.00	1.26	8.74	26.6	86.2	0

Table 7-20 Total vehicle ownership for diesel vehicle of each type (million units) till 2030

Year	HT	MT	LT	MiniT	HB	MB	LB	MiniB	Car	MC
2000	0.40	1.39	2.01	0.00	0.05	0.15	0.55	0.00	0.00	37.7
2005	0.87	1.32	1.91	0.01	0.09	0.25	0.86	0.04	0.26	89.6
2010	1.87	0.89	2.79	0.03	0.15	0.41	1.34	0.19	0.89	133.3
2015	2.89	0.66	3.72	0.07	0.21	0.64	1.93	0.52	2.15	158.1
2020	3.62	0.55	4.67	0.10	0.29	1.11	2.90	1.14	4.63	175.6
2025	3.42	0.45	4.66	0.09	0.37	1.73	4.12	1.93	6.96	169.3
2030	4.85	0.56	7.60	0.07	0.49	2.57	5.77	2.89	9.58	173.9

VII.D.1.ii VKT

There has been no publicized vehicle kilometer traveled (VKT) data in China. Thus researchers usually turn to field surveys or models to estimate the VKT. See Table 7-21. There have been few changes in annual average traveled kilometers from 1997 to 2000.

Table 7-21 Annual VKT per vehicle (thousand km), from 1997 to 2000

Year	HT	MT	LT	MiniT	HB	MB	LB	MiniB	Car	MC
1997	73.6	25.0	24.5	36.3	68.9	68.0	35.2	35.0	27.2	10.0
1998	75.6	25.0	23.3	39.5	67.3	66.5	34.9	35.0	27.3	10.0
1999	72.0	25.0	22.0	44.8	58.6	57.8	36.0	35.0	26.4	10.0
2000	67.4	25.0	20.9	43.2	52.0	52.0	34.0	35.0	26.4	9.0

Data Source: Huo Hong (2002)

Projected VMT in the future 30 years is estimated based on Huo's research in 2002, as shown in Table 7-22. Here we assume new vehicles have the same VKT as older vehicles.

Table 7-22 Projection of annual average traveled mileage, till 2030 (Th. Km)

Year	HT	MT	LT	MiniT	HB	MB	LB	MiniB	Car	MC
2000	67.4	25.0	20.9	43.2	52.0	52.0	34.0	35.0	26.4	9.0
2005	50.0	24.0	19.5	35.6	51.1	46.8	32.1	32.1	24.0	9.0
2010	50.0	24.0	18.3	30.4	52.4	42.9	29.7	29.7	21.0	9.0
2015	50.0	24.0	16.5	25.2	53.7	38.9	27.4	27.4	18.0	9.0
2020	50.0	24.0	15.3	21.0	54.7	35.0	25.5	25.5	15.0	9.0
2025	50.0	24.0	15.3	21.0	54.7	35.0	25.5	25.5	15.0	9.0
2030	50.0	24.0	15.3	21.0	54.7	35.0	25.5	25.5	15.0	9.0

Data Source: Huo Hong (2002); Note: It is assumed that in one class of vehicles, there is no difference in the annual average traveled mileages between gasoline and diesel.

As the growth rate of vehicle ownership outpaces the growth rate of passenger and freight traffic and people's travel demand, the VKT in China generally has a decline tendency. Because most of the medium and heavy trucks and buses are commercial-used and the need for commercial use traffic would not vary too much, the decline of VKT is comparatively slow. Along with the rapid development of private-owned and non-commercial-use LDV, those vehicles are taking up a larger and larger percentage in the total fleet wide. The VKT of these LDVs is projected to have a faster decline speed. (Huo Hong, 2002)

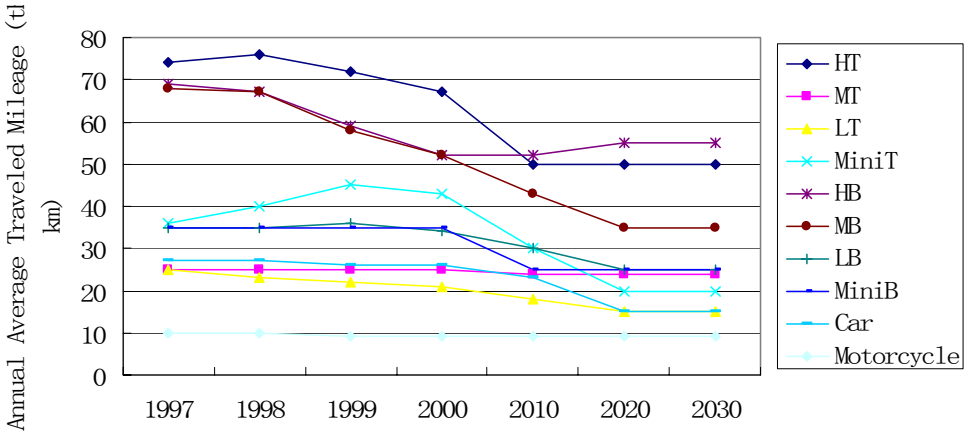

Figure 7-6 Projection of annual average traveled mileage, till 2030 (Th. Km)

VII.D.2 Energy and fossil fuel consumption (by type) forecast

VII.D.2.i <u>Fuel Economy</u>

The fuel economy differs between the scenarios of year 2000 policies and the year 2005 policies. For year 2000 policies, we assume that almost no policies would be published to affect the fuel economy of fleet wide. Therefore, the future fuel economy from 2000-2020 is assumed to remain as the year 2000 level. The on-road fuel economy of new vehicles under 2000 policies is shown as Table 7-10.

For year 2005 polices, we mainly take into account the Mid- and Long-term Plan on Energy Conservation. This plan has pointed out the average on-road fuel economy goal for passenger cars to reach in 2010. We assume that this plan will be fully implemented. And for the other types of vehicles, as there is no fuel economy improvement policy for them, we assume that their fuel economy would remain as the year 2000 level. It should be noted that Maximum Limits of Fuel Consumption (L/100-km) for Passenger Cars, compared to the Mid- and Long-term Plan, has a more detailed fuel economy goals for each category of passenger cars. However, as we are lack of car ownership data of each category of passenger cars, we cannot deduce the average fuel economy from it. Therefore, we mainly utilize the Mid- and Long-term Plan on Energy Conservation.

For the fuel economy of cars in 2010, we simply take the average value of goal range (8.2-6.7 L/100km)– 7.45 L/100km, which is 13.4 km/L, as the average of on-road fuel economy of cars. For years between 2000 and 2010, we assume that the fuel economy of cars will increase by a certain absolute amount each year. For years between 2010 and 2020, although the Mid- and Long-term Plan on Energy Conservation mentioned that fuel conservation will continue in auto industry, there is no text showing to what exact extent the fuel economy would improve, thus we simply assume that the fuel economy of cars would remain at the 2010 level. We also assume there is no difference of fuel economy between gasoline cars and diesel cars.

Table 7-23 shows the actual average fuel economy of fleet wide under 2005 policies. Except for cars, the adjustment factor is introduced to adjust the demarcated fuel economy to the on-road fuel economy of other vehicles. Moreover, the average fuel economy of all vehicles excluding cars is derived from the weighted average of real fuel economy of new vehicles of last 15 years (we assume in this research that the average scrapping time for vehicles in China is 15 years).

Table 7-23 Actual average fuel economy of fleet wide (km/L) under 2005 policies

	HT		MT		LT		MiniT		Car	
	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel
2000	2.25	3.32	2.99	4.28	5.90	6.53	11.54	13.50	10.5	10.5
2005	2.25	3.32	2.99	4.28	5.90	6.53	11.54	13.50	11.95	11.95
2010	2.25	3.32	2.99	4.28	5.90	6.53	11.54	13.50	13.4	13.4
2015	2.25	3.32	2.99	4.28	5.90	6.53	11.54	13.50	13.4	13.4
2020	2.25	3.32	2.99	4.28	5.90	6.53	11.54	13.50	13.4	13.4
2025	2.25	3.32	2.99	4.28	5.90	6.53	11.54	13.50	13.4	13.4
2030	2.25	3.32	2.99	4.28	5.90	6.53	11.54	13.50	13.4	13.4
	HB		MB		LB		MiniB		MC	
	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel		
2000	2.21	3.02	2.68	3.16	7.52	8.82	11.90	14.25	36.77	
2005	2.21	3.02	2.68	3.16	7.52	8.82	11.90	14.25	36.77	
2010	2.21	3.02	2.68	3.16	7.52	8.82	11.90	14.25	36.77	
2015	2.21	3.02	2.68	3.16	7.52	8.82	11.90	14.25	36.77	
2020	2.21	3.02	2.68	3.16	7.52	8.82	11.90	14.25	36.77	
2025	2.21	3.02	2.68	3.16	7.52	8.82	11.90	14.25	36.77	
2030	2.21	3.02	2.68	3.16	7.52	8.82	11.90	14.25	36.77	

VII.D.2.ii Energy Consumption

Functions to calculate fuel consumption and CO2 emissions in transport sector are shown below.

$$\mathrm{GasolineCon_i} = \sum_{j^G} \left(\mathrm{Tr_{i,j^G}} \times \mathrm{VP_{i,j^G}} / \mathrm{FE_{i,j^G}} \right) \times \mathrm{Den_i^G}$$

$$\mathrm{DieselCon_i} = \sum_{j^D} \left(\mathrm{Tr_{i,j^D}} \times \mathrm{VP_{i,j^D}} / \mathrm{FE_{i,j^D}} \right) \times \mathrm{Den_i^D}$$

$$CO_{2i} = \left(GasolineCon_i \times Carbon_i^G + DieselCon_i \times Carbon_i^D \right) \times 44/12$$

Note:
In this function,
i – year
j^G -- vehicle type that uses gasoline
j^D—vehicle type that uses diesel
$GasolineCon_i$—the vehicle gasoline consumption in year *i* (million tons)
$DieselCon_i$—vehicle diesel consumption in year *i* (million tons)
FE_{i,j^G} -- the aveage fuel econmy of j^Gin year *i* (km/L)
FE_{i,j^D} -- the average fuel economy of j^Din year *i* (km/L)
Tr_{i,j^G} -- average vehicle traveled kilometer of j^G in year *i* (thousand kilometers)
Tr_{i,j^D} -- average vehicle traveled kilometer of j^D in year *i* (thousand kilometers)
VP_{i,j^G} -- total vehicle ownership of j^G in year *i* (million units)
VP_{i,j^D} -- total vehicle ownership of j^D in year *i* (million units)
Den_i^G—density of vehicle gasoline in year *i* (kg/L)

Den_i^D—density of vehicle diesel in year *i* (kg/L)
$Carbon_i^G$—the percent of carbon in vehicle gasoline in year *i*
$Carbon_i^D$ – the percent of carbon in vehicle diesel in year *i*
CO_{2i}—the total vehicle CO2 emission in year *i* (million tons)

Assumption:
Density and the percent of carbon in fuel is constant. The density of vehicle gasoline is 0.732 kg/L, and the percent of carbon in it is 85.5%; the density of vehicle diesel is 0.875 kg/L, and the percent of carbon in it is 87%.

Projection of total oil consumption by year 2000 policies and year 2005 policies is shown in Table 7-24, Table 7-25 and Figure 7-7. After comparing the projected oil consumption of 2000 policies and 2005 policies, the implementation of 2005 policies has produced a total oil saving of 10.7 million tons in 2020. And the cumulative oil savings through 2020 would reach 108.5 million tons, of which 99.6 are gasoline and 8.88 are diesel.

Table 7-24 Total oil consumption by year 2000 policies and year 2005 policies (million tons)

	Gasoline consumption - Year 2000 Policies	Diesel consumption - Year 2000 Policies	Total fuel consumption - Year 2000 Policies	Gasoline consumption - Year 2005 Policies	Diesel consumption - Year 2005 Policies	Total fuel consumption - Year 2005 Policies
2000	37.3	24.6	61.8	37.3	24.6	61.8
2005	58.1	30.9	89.0	56.0	30.9	86.9
2010	81.6	48.7	130.3	76.2	48.4	124.6
2015	101.6	69.3	170.9	94.4	68.6	163.0
2020	124.1	90.1	214.2	114.6	88.9	203.5
2025	157.2	101.4	258.6	143.1	99.5	242.6
2030	201.7	145.6	347.3	182.2	143.0	325.2

Table 7-25 Gasoline and diesel consumption by year 2000 policies and year 2005 policies (billon liters)

	Gasoline consumption -Year 2000 Policies	Diesel consumption - Year 2000 Policies	Gasoline consumption - Year 2005 Policies	Diesel consumption - Year 2005 Policies
2000	50.9	28.1	50.9	28.1
2005	79.4	35.3	76.6	35.3
2010	111.5	55.7	104.1	55.3
2015	138.8	79.2	129.0	78.4
2020	169.5	103.0	156.6	101.5
2025	214.8	115.9	195.5	113.7
2030	275.6	166.4	248.9	163.4

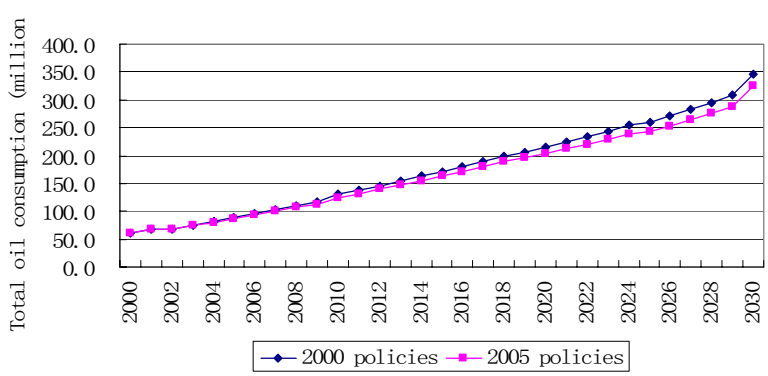

Figure 7-7 Total oil consumption of 2000 policies and 2005 policies

VII.D.3 Annual GHG forecast

In 2020, under year 2000 and year 2005 policies, the CO2 emission in road transport sector in China would reach respectively 674.4 and 642.9 million tons.

Table 7-26 Annual CO2 emission forecast (million tons), till 2030

Vehicular CO2 emission	Year 2000 Policies			Year 2005 Policies		
	By Gasoline	By Diesel	Total	By Gasoline	By Diesel	Total
2000	116.8	78.4	195.2	116.8	78.4	195.2
2001	126.7	89.9	216.5	125.9	89.9	215.8
2002	135.4	81.9	217.4	133.6	81.9	215.5
2003	147.6	89.5	237.1	144.6	89.4	234.0
2004	161.1	97.6	258.7	156.7	97.5	254.2
2005	182.1	98.7	280.8	175.7	98.5	274.2
2006	198.4	105.3	303.7	190.1	105.0	295.1
2007	215.0	112.3	327.4	204.7	111.9	316.6
2008	230.5	118.9	349.3	217.8	118.2	336.0
2009	244.7	124.7	369.4	229.5	123.8	353.3
2010	255.8	155.4	411.2	238.9	154.3	393.3
2011	266.9	167.9	434.8	249.0	166.7	415.6
2012	279.1	180.9	460.1	260.2	179.5	439.7
2013	290.6	194.8	485.4	270.6	193.1	463.7
2014	304.1	209.9	514.0	283.0	208.0	490.9
2015	318.6	221.0	539.6	296.1	218.8	514.9
2016	332.6	236.4	569.0	308.9	233.9	542.8
2017	346.2	250.4	596.6	321.2	247.6	568.9
2018	359.7	264.9	624.6	333.5	261.7	595.3
2019	373.5	279.6	653.1	346.0	276.1	622.1
2020	389.0	287.4	676.4	359.4	283.4	642.9
2021	407.5	299.4	707.0	375.6	295.1	670.7
2022	425.9	311.4	737.3	391.4	306.8	698.2
2023	444.8	323.4	768.2	407.6	318.3	726.0
2024	467.8	335.1	802.9	427.7	329.7	757.3
2025	493.0	323.5	816.4	448.5	317.5	766.0
2026	519.3	334.6	853.9	471.4	328.2	799.5
2027	546.4	345.3	891.7	494.7	338.4	833.1
2028	576.6	355.6	932.2	520.9	348.1	868.9
2029	609.4	365.5	974.8	549.3	357.4	906.7
2030	632.4	464.4	1096.7	571.2	456.1	1027.3

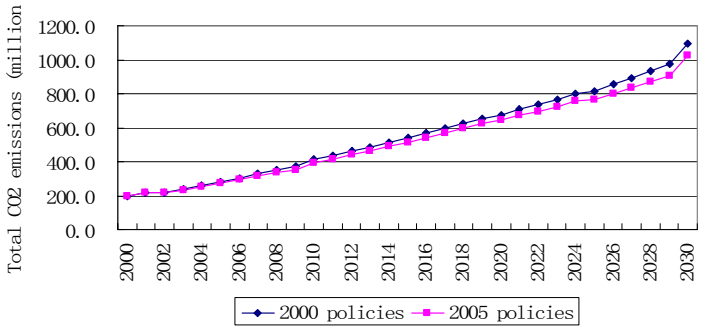

Figure 7-8 Total CO2 emissions of 2000 policies and 2005 policies

After comparing the projected oil consumption and CO2 emission of 2000 policies and 2005 policies, the implementation of 2005 policies has produced CO2 emission reduction of 33.5 million tons in 2020. And the cumulative CO2 emission reduction through 2020 could reach 340.5 million tons, in which 312.2 are from reduced gasoline consumption and 28.3 are reduced diesel consumption.

VII.E GHG Mitigation Options and Costs

Mitigation options and costs are the basis of mitigation scenarios analysis. In this section, we will give an overview of each appropriate mitigation option, characteristic of each mitigation option, their costs, their emission reduction potential etc.

VII.E.1 Selection criteria for consideration of mitigation options

There are many options for reaching GHG mitigation goals in transport sector, such as improve transport conditions, adjust vehicle structure and improve its components, utilize substitute fuels, encourage public transport, enhance transport management system, etc.
Selection criteria for consideration of mitigation options include capital costs, operating costs, carbon dioxide emissions abatement performance, traffic noise, traffic congestion, quality of life, public acceptability, practicality and etc.

VII.E.2 Overview of each mitigation option evaluated

VII.E.2.i Description, including technologies required

Fuel economy of vehicles is mainly a function of three factors, which are vehicle, fuel and travel demand. Vehicle related options include improving engine technologies, transmission technologies, vehicle technologies (rear to front) and engine-transmission-vehicle technologies. The following table will imply more details. Fuel related factors include renewable fuels and more clean fuels substitution, such as switching from gasoline and diesel to liquefied petrol gas (LPG) and compressed natural gas (CNG), etc. Travel demand factors include urban planning, Bus Rapid Transit (BRT), improve road conditions, etc.

In vehicle related options, among all possible technologies, hybrid electric engines[44], direct injection gasoline/diesel engines and variable valve lift and timing have the most remarkable fuel efficiency improvement effect[45] (Gallagher, 2006).
Commercially available hybrid-electric vehicles contain both a conventional gasoline engine and a battery-driven electric motor. The electric motor and the internal combustion engine work together during acceleration – the engine is downsized from the engine in a normal vehicle, so the electric motor provides additional power when needed. The fuel savings are mostly derived from utilizing more efficient electric motors in stop-and-go urban driving, capturing wasted energy from braking, converting it into electricity, and storing it for later use by the electric-drive motor in a battery. Hybrid-electric vehicles vary in the degree to which they actually utilize the electric motor, but all hybrids take advantage of the main innovation – the combined use of electric and gasoline motors together to power the automobile (Gallagher, 2006).

In traditional gasoline or diesel engines, fuel is injected into a port before it enters the combustion chamber. The use of a port gives the fuel time to evaporate and mix uniformly with the air that it will be burnt with. However, this is not ideal because it provides little control over the air and fuel mixture. Direct Injection gasoline/diesel engines do not inject fuel into a port. These engines inject the fuel directly into the combustion chamber instead. This approach gives control over the air/fuel mixture and reduces fuel evaporation to enhance the fuel efficiency.

Poppet valves are used in gasoline and diesel engines to control the intake and exhaust of air passing through the engine. When the intake valves open, fuel and air are both drawn into the engine cylinder. After the fuel has been burnt, the exhaust valves then open to let it leave. In conventional engines, the

[44] According to previous researches, the technology of hybrid electric engines had been classified as engine-related technology in some cases and fuel-related option in others. In this research, we define hybrid electric engines as engine-related technology.
[45] Gallagher (2006) indicated that China's Ministry of Science and Technology (MOST), believe that the technologies that China should consider adopting are hybrid-electric or fuel-cell vehicles. However, FCVs are still in the research and development stage, and are not yet available commercially.

poppet valves open and close at a constant speed. Their timings do not depend on how fast the engine is running. At high engine speeds [e.g. when overtaking a slower vehicle], this starts to become a problem. Large amounts of air are required by the engine at higher speeds. However, the intake valves may close before all the air has been given a chance to flow in. On the other hand, if the valves were calibrated to remain open for longer periods of time, problems start to occur at the lower engine speeds. In these situations, un-burnt fuel may exit from the engine since the valves are still open. This leads to lower engine performance and increased emissions. Around the early 1990s, Variable Valve Lift and Timing started to become popular on gasoline passenger cars. Using this technique, engine manufacturers are able to control the extent and duration for which the poppet valves are open. In addition, the opening and closing of the valves can also be varied depending on the crank angle. With variable valve lift and timing, a sensor is used to detect the engine's speed. An electronic system then uses this information to adjust the valve opening and closing timings accordingly. This avoids the problems mentioned earlier and allows for maximum torque at all engine speeds (Bong, 2002).

Bus Rapid Transit (BRT) can be broadly defined as "a permanent system of facilities, services and amenities that collectively improve the speed, reliability and identity of bus transit" (Levinson et.al., 2002). BRT systems provide a roadway-based rapid transit alternative that combines high levels of service, intelligent transport systems (ITS) and low emission vehicle technologies. For example, as a full BRT system, TransMilenio of Bogota provides several different sources of emission reductions, including the following (Wright and Fulton, 2005):

- Increasing the share of public transport ridership by dramatically improving the quality of service (in terms of travel time, comfort, security, cleanliness, etc.).
- Constructing segregated busways that permit uninhibited bus movements without delays from mixed traffic.
- Using pre-board fare-collection systems that reduce dwell times.
- Replacing four to five smaller buses with a larger articulated vehicle.
- Requiring the destruction of four to eight older buses for every new articulated vehicle introduced into the system.
- Managing the fleet through global positioning satellite (GPS) technology and thus allowing the optimization of demand and supply during peak and nonpeak periods.
- Encouraging transit-oriented development around stations and along corridors.
- Requiring minimum-emission standards for vehicles (currently Euro II vehicles are employed with a future schedule requiring eventual Euro III/IV compliance).

Currently, the possible fuel switch options for fossil fuels include LPG, CNG, hydrogen fuel-cell and electric motors, etc, of which LPG and CNG are comparatively market-ready.

VII.E.2.ii <u>Background on use of option in country to date, future potential of option</u>

Vehicle related option packages can be summarized to those improving engine technologies, improving transmission technologies, vehicle (rear-to-front) technologies and engine-transmission-vehicle technologies, and some options in those packages have been used widely in China, especially those that have comparatively lower costs and comparatively better efficiency. China already has some small-scale BRT systems in Beijing, Kunming, Shenyang, Shijiazhuang and Taipei (Xu, 2003). In Kunming for instance, the first modern bus-only road had been built in April 1999 and in their city planning, it is referred that a BRT system with 63 km network size would be finally built in Kunming (KIUT, 2004). It is expected to have a promising future in China's transport system (Xu, 2003). For fuel transition from diesel/gasoline to LPG and CNG, it had been widely implemented in some big cities in China, such as Beijing. LPG is much more popular in mass and public transport sector (and a forecast (Jiang, 2003) shows that Beijing will have clean fuel occupy 90% of the public transport market), however, in private transport part, gasoline still takes the leading role.

In China, a notice about the clean vehicles actions mentioned that the major technology option to reduce vehicle emissions and pollution near term is to promote the clean fossil fuel vehicles and

promote the gas vehicles (MOST & SEPA, 1999). LPG and CNG vehicles are experiencing a rapid development in China. Take Beijing for Example. Till the end of 2001, there had been 86 gas stations all around Beijing, among which 62 are LPG gas stations and 24 are CNG gas stations. Number of Gasoline-LPG bi-fuel taxis reached 32 thousand, and the number of CNG and LPG bus reached 5 thousand. In 2003, Beijing had newly imported 600 single-fuel (LPG) taxis (CSDTP, 2004). Similar tendency is happening in other cities in China, although which one is more preferred, LPG or CNG, depends mainly on its resource. Although hydrogen fuel-cell, methanol and ethanol are in hot discussion these days, they still have a long way to go for commercial use.

VII.E.3 Marginal abatement cost curve

Here are some explanation on how marginal abatement cost curves are developed here and what those assumptions in the development process are.

Vehicle related options

, light duty vehicles (LDVs) have long been considered the pivot of fuel consumption control. In this research, LDV refer specifically to cars, light bus and mini bus. In China, those LDVs take up large proportion in road transport fuel consumption (29.87% in 2000 (Huo, 2002)). Huo (2003) has summarized the current possible technologies to utilize in vehicles. They vary in their costs, fuel economy improvement rates, and also the expansion potential. Benefits and cost of those technologies are shown in Table 7-28.

Table 7-28 Benefit and cost of the efficiency technologies

Technologies	FE improvement (%)	Cost (Year 2000 US$)
1 Engine technology		
1.1 Improve the mechanical efficiency		
1.1.1 better optimize engine operations		
Multi-valve, overhead camshaft	5	135.4
Variable valve timing	5	135.4
Variable valve lift and timing	10	203.1
Intake valve throttling	6	399.0
Camless valve actuation	10	544.1
1.1.2 reduce the friction of engine		
Low-friction lubricants	1	10.9
Reduce the friction of components (such as bearing, oil seal)	3	72.6
Roller cylinder (rocker)	2	72.6
1.1.3 reduce friction of accessory		
Improve engine accessory by increasing the technical skills of suppliers	2	108.8
1.2 Improve the work process of engine		
Improve compression ratio +0.5	1.5	12.1
Cylinder deactivation	6	241.8
Variable compression ratio engine	6	483.7
1.3 Other engine technologies		
Engine downsizing and supercharging	7	544.1
Direct injection gasoline engine	20	556.2
Direct injection diesel engine	35	725.5
Hybrid Electric Vehicles	30*	2418.4*
2 Transmission technologies		
4 and 5 speed manual transmission	3	48.4
Automatic Transm. with aggressive shift logic	3	67.7
4 and 5 speed automatic transmission	3	145.1
Automatic Shift Manual Transmission	5	278.1
Continuously variable transmission	8	362.8
5 and 6speed automatic transmission	2	362.8
Advanced Continuously variable transmission	2	822.2
Automatic transm replace manual transm.	-7	1813.8
3 Vehicle technologies (rear to front)		
Aerodynamic improvement	2	145.1
Low-resistance tires	1.5	54.4
42 volt electricity system	2	278.1
Integrated starter-generator	7	362.8
Electric power steering system	2.5	145.1
Safety enhancing weight reductions	4	338.6
4 Engine-Transmission-Vehicle technologies		
Engine-Transmission-Vehicle matching technologies	1.5	120.9

Data source: Huo Hong (2002)

It should be noted here that:

*Huo does not include Hybrid Electric Vehicles in the technology list. However, after analyzing from related governmental attitudes towards HEV, we think it is necessary to add it into the list. And the FE improvement and cost information of HEV is from http://www.qyev.com/chinesenew/jsmt/index.htm.

Ccst information in Table 7-28 all refers to cost per vehicle.

All the cost data in this form reflects only the operational data of those technologies. The cost for R&D, technology trade, managerial cost and etc are not included, because there is little research on this area and it is far too complex to estimate.

In Hong's paper, she designed three schemes (high, medium and low). High scheme implies the best of factory's managerial level, employees' skills and the fuel efficiency improvement effects when utilizing one technology. And in our research, we assume that it is under the high scheme background. And the table above just presents the detailed data of the high scheme.

Table 7-29 shows the possible starting period of each technology (Huo, 2003). Technology with * means it will start utilizing in China since a certain period. Some technologies which have never been involved in any term of technology package (such as 4 and 5 speed manual transmission) have been omitted in this table.

In Huo (2003), she explains near-term, mid-term and long-term as follows:

- Near term technologies are those which have been widely used internationally, and could be totally commercialized in the near 5 years;
- Mid term technologies are those which have begun to be used internationally and could possibly be totally commercialized in the near 10 years;
- Long term technologies are those in the process of commercialization and would possibly be completely commercialized in 20 years.

In this research, we simply assume that the near term technologies represent the period from 2006-2010, the mid term technologies represent the period from 2011-2015, and the long-term technologies represent the period from 2016-2020. We also make an assumption that once a technology is starting to be used, it is used by all corresponding vehicles. For example, we see from Table 7-29 that hybrid electric vehicles are going to be utilized in cars since 2016. In the research, we assume that there is not any hybrid electric vehicle in 2015; however from 2016, all the new and old cars will become hybrid electric vehicles.

In Table 7-29, it should also be noted that in Huo's paper that some vehicles are installed with variable valve timing and variable compression ratio engine. However, as variable valve lift and timing and improve compression ratio +0.5 are incompatible with them and are both more widely used, we assume that no vehicles will use variable valve timing and variable compression ratio engine.

From Table 7-29, we could get the costs and fuel saving rates for engine technologies, transmission technologies, vehicle technologies, engine-transmission-vehicle matching technologies, in different periods, for cars and for LB and MiniB respectively, as is shown in Table 7-30(a) and 7-30(b)(c).

It should be noted that the fuel saving rate is different from FE improvement rate. The fuel efficiency improvement rate x% is changed into the fuel saving rate y by y=x/(100+x). For example, if an option has a 100% fuel efficiency improvement rate, then its corresponding fuel saving rate is 100/(100+100)=50%; and multi-valve, overhead camshaft has a 5% fuel efficiency improvement rate, then its corresponding fuel saving rate is 5/(100+5)=4.76%. And when calculating the fuel saving rate of a technology package (such as engine technologies package), we accumulate the fuel saving rate of each option one by one. If one option has been utilized in one vehicle and has an x fuel saving rate, when another option with y fuel saving rate is added into the same vehicle, then the cumulative fuel saving rate is z=1-(1-x)*(1-y); if another option with k fuel saving rate is added, then the new cumulative fuel saving rate is 1-(1-z)*(1-k). This process keeps going until all options are included in the package they should belong to. The cost of the package is the cumulative cost of each option included.

Table 7-29 Starting period of each technology

		Engine Technologies															
Mitigation Option		Low-friction lubricants	Improve compression ratio +0.5	Reduce the friction of components	Roller cylinder (rocker)	Improve engine accessory by increasing the technical skills of suppliers	Multi-valve, overhead camshaft	Variable valve lift and timing	Engine downsizing and supercharging	Direct injection gasoline engine	Hybrid Electric Vehicles	Cylinder deactivation	Intake valve throttling	Camless valve actuation	Direct injection diesel engine	Variable compression ratio engine	Variable valve timing
For Cars	Near term	*	*	*	*	*	*	*									
	Mid term	*	*	*	*	*	*	*	*								
	Long term	*	*	*	*	*	*	*	*	*	*						
For LB and Mini Bus	Near term	*	*	*	*	*	*										
	Mid term	*	*	*	*	*	*	*	*								
	Long term	*	*	*	*	*	*	*	*	*	*						

		Transmission Technologies		Vehicle Technologies						Engine-Transmission-Vehicle matching technologies
Mitigation Option		Automatic Transm. with aggressive shift logic	continuously variable transmission	Low-resistance tires	Aerodynamic improvement	Electric power steering system	42 volt electricity system	Safety enhancing weight reductions	Integrated starter-generator	Engine-Transmission-Vehicle matching technologies
For Cars	Near term			*	*			*		*
	Mid term			*	*		*	*		*
	Long term		*	*	*	*	*	*	*	*
For LB and Mini Bus	Near term			*	*					*
	Mid term			*	*		*	*		*
	Long term		*	*	*	*	*	*	*	*

Table 7-30(a) Fuel Saving Rate of different terms and different technology packages

			Engine Technologies Fuel Saving Rate	Transmission Technologies Fuel Saving Rate	Vehicle Technologies Fuel Saving Rate	Engine-Transmission-Vehicle matching technologies Fuel Saving Rate	Total Fuel Saving Rate
For Cars	2006－2010	near term	21.19%	0%	7.12%	1.48%	29.79%
	2011－2015	mid term	26.34%	0%	8.95%	1.48%	36.77%
	2016－2020	long term	52.78%	7.41%	16.98%	1.48%	78.65%
For LB and MiniB	2005－2010	near term	13.31%	0%	3.41%	1.48%	18.19%
	2011－2015	mid term	26.34%	0%	8.95%	1.48%	36.77%
	2016－2020	long term	52.78%	7.41%	16.98%	1.48%	78.65%

Table 7-30(b) Cost per vehicle (US$) in different terms

			Engine Technologies	Transmission Technologies	Vehicle Technologies	Engine-Transmission-Vehicle matching technologies
For Cars	2006－2010	near term	615.5	0	538.1	120.9
	2011－2015	mid term	1159.6	0	816.2	120.9
	2016－2020	long term	4134.2	362.8	1324.1	120.9
For LB and MiniB	2005－2010	near term	412.4	0	199.5	120.9
	2011－2015	mid term	1159.6	0	816.2	120.9
	2016－2020	long term	4134.2	362.8	1324.1	120.9

Table 7-30(b) displays the cost per vehicle in different terms; however, Table 7-30(c) displays the cost per vehicle per year in US$ in 2000. Cost of implementing vehicle related technologies has been distributed to a 15-year lifetime. So the cost per vehicle per year is the corresponding cost per vehicle divided by 15, then the result has been discounted back to the value in year 2000, by a discount rate of 10%. Costs in different years per vehicle are the same, however, when discounted, the costs may vary according to how far it is to year 2000.Table 7-30(c) only lists costs in 2010, 2015 and 2020. So the cost per vehicle per year in 2010 using engine technologies, after discounted back to year 2000, is (615.5/15)*((1-10%)^10)=14.3.

Table 7-30(c) Cost per vehicle per year (US$ in 2000) in 2010, 2015 and 2020

		Engine Technologies	Transmission Technologies	Vehicle Technologies	Engine-Transmission-Vehicle matching technologies
For Cars	2010	14.3	0	12.5	2.81
	2015	15.9	0	11.2	1.65
	2020	33.5	2.94	10.7	0.98
For LB and MiniB	2010	9.59	0	4.64	2.81
	2015	15.9	0	11.2	1.65
	2020	33.5	2.94	10.7	0.98

Multiplying the cost per vehicle in US$ 2000 by vehicle population in a certain year could get the total cost in US$ 2000 in that year. Multiplying the fuel saving rates by the original oil consumption could get the oil savings and the corresponding oil saving benefits in that year. After the discount rate is taken into consideration, we could get the oil saving value in US$ 2000. The net cost is the total cost minus the oil saving benefits. And the cost effectiveness is the net cost divided by CO2 emission reduction in that year.

BRT

In this section, we intend to tell the amount of CO2 emission reduction by the construction of all BRT systems in China and the corresponding CO2 emission reduction cost.

The evaluation of CO2 emission reduction effects of constructing BRT systems in China is based on the analysis of difference BRT cases. We assume that there will only be three types of network size in BRT in China – 100 km, 200 km and BRT package (BRT package is characterized by its pedestrian upgrades and cycleway investment). We assume that the BRT package in China contains a 200 km BRT (costing $2,500,000 per km), a 400 km footpath (costing $150,000 per km), a 500 km cycleway (costing $100,000 per km) and a promotional campaign (costing $10,000,000)(Costing information is from Wright and Fulton, 2005). The main difference between the three types of BRT systems is the change in travel mode share. Based on the current development situation of BRT in China, we assume that before the end of 2010, all BRT programs will be under construction and since 2011, there will be twelve 100 km BRT, six 200 km BRT and two BRT packages becoming effective in twenty large cities in China, which means the emission reduction effects from BRT only comes into being since 2011. The total emission reduction achieved by BRT is a simple sum of the emission reduction from these 20 BRT systems. Costs will mainly come from infrastructures; however, BRT systems could also bring in oil saving benefits due to the travel mode change introduced in the city by BRT. Infrastructures costs have been evenly split into year 2011-2020, the duration where also oil saving benefits is.

IMI Consumer Behavior and Living Conditions Yearbooks (from 1995-2005) had summarized the travel mode share of several important cities in China from late 1990s to the early 2000s; however, the current travel mode share national-wide is developed in a simplified manner with no assumed difference between the several important cities and the whole country, and no assumed change between the current mode share and the mode share in 2010. Clearly, this static assumption will not be the case. We can tell from the IMI yearbook that along with the quick economic development in China, taxi, buses and automobiles are taking more and more shares and the shares of bicycles and walking are quickly shrinking. However, this assumption makes the result more conservative since any baseline growth in private vehicle emissions will make the reductions even greater. For the 100 km BRT, 200 km BRT and BRT package case, we have changed the mode share according to the characteristics of each case and some previous research (Wright, 2005). Table 7-31 shows the settings of mode share in different cases.

The emission reduction effect of each BRT system is educed from the comparison of reference case and the BRT system. We assume the current mode shares and total number of trips per day (10 million) (according to Wright 2005) are appropriate for a common city in China in 2000. The known travel mode share will tell us trips per day for each kind of travel mode. However, different years will have different total trips due to the change in vehicle population, VKT, and fuel efficiency. The total trips are in direct ratio with the oil consumption in pre-2000 baseline. In year 2015, for example, after comparing oil consumption in 2000 and in 2015 in the pre-2000 baseline, we deduce the total trips in 2015 to input into the cases. From the total trips data and the mode share data, we could tell the trips per day for each mode. For the passenger/vehicle-km data, we refer to Wright 2005 and then educed the distance traveled per day for each mode (Distance traveled per day is equal to trips/day divided by passengers/vehicle-km). By entering the projected fuel economy data in 2010, we could educe the oil consumption per year and then the CO2 emission per year (we have also adjusted the CO2 emission per liter of fuel according to the reality in China). By comparing the CO2 emission between the reference case and different BRT cases, the emission reduction effect of BRT system is gained. See Table 7-32 and Table 7-33. The CO2 emission reduction for implementing a 50 km BRT system in a city in 2015 is (1887.2-1845.5)×1000=41700 tonnes. As we know there are twelve 100km BRT, six 200km BRT and 2 BRT packages in China in 2015, and we can tell the amount of CO2 emission reduction of each type of BRT system, we could add them up to the total emission reduction effect of BRT systems in 2015.

As said above, the cost of BRT systems will mainly come from the infrastructure. We can tell the total cost of infrastructure by adding up the cost for each BRT system. The cost has been split evenly into year 2011-2020, to compare with the oil saving income. In 3), by comparing the reference case to the BRT case, we can tell the amount of oil savings in a specific year. By multiplying the price of oil in

that year (in this research, we assume that oil price in China would be constant at a price of $0.55 per liter), we can tell the monetary value oil savings. All the costs and incomes have been discounted back to year 2000 by a discount rate of 10%. The net cost is the infrastructure cost in that year minus the oil saving income.

Net cost divided by total CO2 emission reduction in a specific year will tell us the cost per ton of CO2 emission reduction in that year.

It should be noted that the CO2 emission factor of gasoline in China is assumed to be 3172 kg CO2/ton gasoline; the CO2 emission factor of diesel in China is assumed to be 3188 kg CO2/ton diesel (Zhu, 2004). As the density of gasoline and diesel is assumed to be 0.732kg/L and 0.875kg/L, the CO2 emissions for each liter of gasoline and diesel are respectively 2.32kg and 2.79kg.

As the vehicle category mini-bus in Wright and Fulton refers to all non-BRT buses, so the fuel consumption used for mini-bus is the weighted average of HB, MB, LB and MiniB on-road fuel economy in 2000. We assume no change would happen to the fuel consumption for mini-bus during 2000-2020. The on-road fuel economy (km/L) of HB-Gasoline, HB-Diesel, MB-Gasoline, MB-Diesel, LB-Gasoline, LB-Diesel, MiniB-Gasoline, MiniB-Diesel is 2.21, 3.02, 2.68, 3.16, 7.52, 8.82, 11.9 and 14.25. And the vehicle ownership (million) for the corresponding types of vehicles is 0.003, 0.046, 0.126, 0.153, 1.306, 0.545, 1.959, and 0.000. So the fuel consumption for 'mini-bus' in BRT is 9.40 km/L, which is 10.64 liters/100km.

Table 7-31 Transport mode share in different cases

Mode Share (%)	Automobile	Motorcycle	Taxi	Mini-bus	BRT	Walking	Bicycle
Reference Case	5	7	3	40	0	15	30
100 km BRT	4	7	3	36	5	15	30
200 km BRT	3	7	2	33	10	15	30
BRT Package	3	6	2	24	10	20	35

Note: Reference case refers to the projected mode share in 2010 in China. And the other cases reflect the refreshed mode share when different size of BRT network is utilized.

Table 7-32 Reference case (city with no BRT system)

Mode	Mode Share (%)	Trips/day (000s)	Passengers / vehicle-km	Distance travelled / day (km, 000s)	Fuel Consumption (litres / 100km)	litres/yr (000s)	CO2 (kg) / litre	CO2 / yr (tonnes, 000s)
Automobile	5	1382	0.15	9,213	7.46	214,426	2.32	497.5
Motorcycle	7	1935	0.105	18,425	2.72	156,364	2.79	436.3
Taxi	3	829	0.15	5,528	7.46	128,656	2.32	298.5
Mini-bus	40	11055	1.3	8,504	10.64	282,305	2.32	654.9
BRT	0	0	5.2	0	64.1	0	2.32	0
Walking	15	4146	1	150	0	0	0	0
Bicycle	30	8291	1	8,291	0	0	0	0
Sum	100	27638						1887.2

Table 7- 33 100 km BRT case (city with a 100 km BRT system)

Mode	Mode Share (%)	Trips/day (000s)	Passengers / vehicle-km	Distance travelled / day (km, 000s)	Fuel Consumption (litres / 100km)	litres/yr (000s)	CO2 (kg) / litre	CO2 / day (tonnes, 000s)
Automobile	4	1106	0.15	7,370	7.46	171,541	2.32	398.0
Motorcycle	7	1935	0.105	18,425	2.72	156,364	2.79	436.3
Taxi	3	829	0.15	5,528	7.46	128,656	2.32	298.5
Mini-bus	36	9950	1.3	7,654	10.64	254,075	2.32	589.5
BRT	5	1382	5.2	266	64.1	53,148	2.32	123.3
Walking	15	4146	1	150	0	0	0	0
Bicycle	30	8291	1	8,291	0	0	0	0
Sum	100	27638						1845.5

As the BRT systems in China become effective since 2011, there will be a corresponding cost effectiveness value since that year too. The cost effectiveness of BRT systems in 2015 and 2020 are respectively 17.9 US$/per tonne and 2.64 US$/per tonne.

For Fuel Switch

Fuel switch in this research includes both gasoline and diesel to both LPG and CNG, for buses only. There has been few research related to the cost of fuel switch in China. Wright (2005) indicated that fuel switch from a EURO II diesel bus with a ten-year, 750,000 mile lifetime would educe an estimated cost of 442 US$/ tonne CO2. As in research, China has a similar emission criteria and VKT, and the biggest difference is the emission reduction rate – 25% (as mentioned in Jiang, 2003), we roughly estimate that the cost in China would be 442/(25%/10%), about 176.8 US$/tonne CO2 in 2000. We also assume the fuel switch from gasoline and diesel into LPG and CNG in China would cost the same. When we are estimating the CO2 emission per vehicle, we take the VKT and FE data from mini Bus because its share in all buses is the biggest. Considering that Beijing plans to have 90% buses use clean energy in 2020 (CSDTP, 2004), we assume that China will start fuel switch in 2010, and in 2010, 10% of buses would use CNG or LPG, in 2015, 30% of buses would use CNG or LPG, and in 2020 in China, the percentage for buses to use CNG or LPG would reach 50%.

The 25% emission reduction rate would tell us the amount of emission reduction for each bus per year. Take year 2010 for example. By multiplying the emission reduction amount per year by the bus population, we could deduce the total emission reduction in 2010. And the fuel switch cost in 2010 is 176.8, however, when discounted back to year 2000 with a discount rate 10%, the value changed to 61.6 US$ per tonne CO2.

After these researches and assumptions, we generated the marginal abatement cost curve of road transport in China in 2010, 2015 and 2020. The corresponding graphs and tables are listed below.

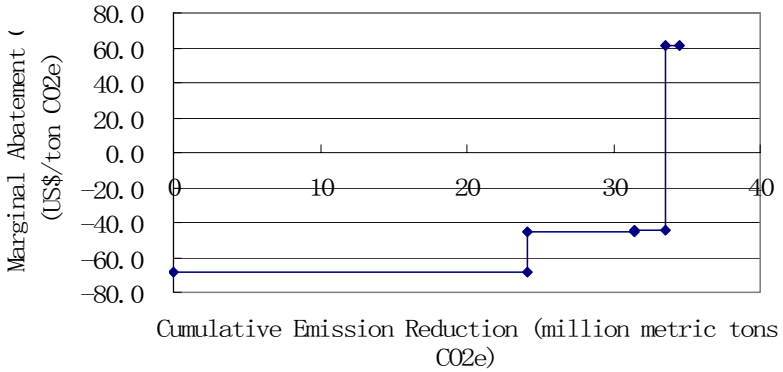

Figure 7-9 Marginal abatement cost curve of transport sector at 2010

Table 7-34 Cost of mitigation options and relevant emission reduction in 2010

Mitigation Option	Cost Effectiveness ($/metric ton CO_2e)	Total Emission Reduction (million metric tons CO_2e)	Total Cost (million $)	Cumulative Emission Reduction (million metric tons CO_2e)	Cumulative Net Cost (million $)	Average Cumulative Cost Effectiveness ($/metric ton CO_2e)
Engine Technologies	-68.5	24.1	-1654	24.1	-1654	-68.5
Vehicle Technologies	-45.7	7.3	-333.1	31.4	-1987	-63.2
Engine-Transmission-Vehicle Technologies	-44.8	2.1	-94.7	33.5	-2082	-62.1
Fuel Switch	61.6	0.9	58.4	34.5	-2023	-58.7

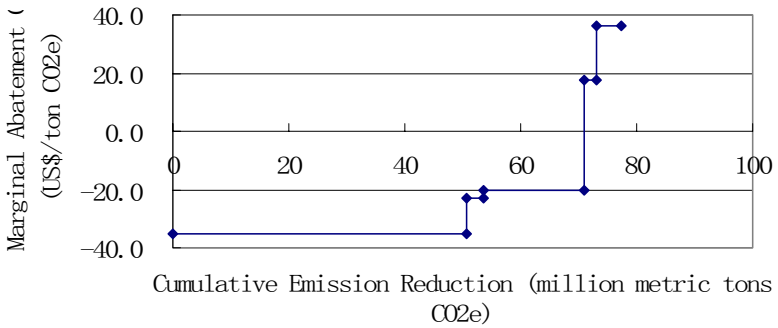

Figure 7-10 Marginal abatement cost curve of transport sector at 2015

Table 7-35 Cost of mitigation options and relevant emission reduction in 2015

Mitigation Option	Cost Effectiveness ($/metric ton CO_2e)	Total Emission Reduction (million metric tons CO_2e)	Total Cost (million $)	Cumulative Emission Reduction (million metric tons CO_2e)	Cumulative Net Cost (million $)	Average Cumulative Cost Effectiveness ($/metric ton CO_2e)
Engine Technologies	-35.3	50.8	-1791	50.8	-1791	-35.3
Engine-Transmission-Vehicle Technologies	-23.2	2.8	-66.0	53.6	-1857	-34.6
Vehicle Technologies	-20.2	17.2	-347.6	70.9	-2205	-31.1
BRT	17.9	2.3	40.2	73.1	-2165	-29.6
Fuel Switch	36.4	4.2	152.3	77.3	-2012	-26.0

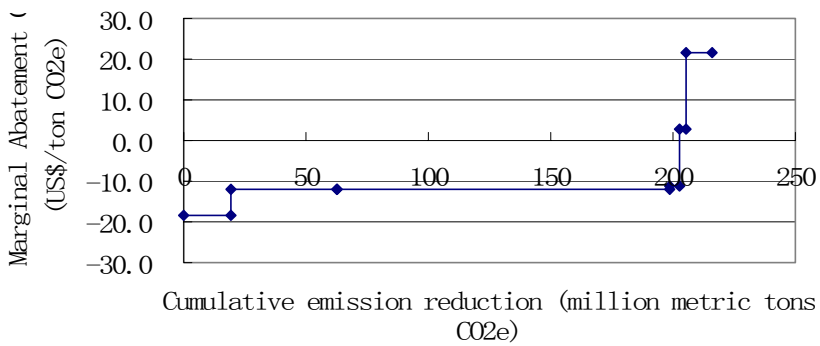

Figure 7-11 Marginal abatement cost curve of transport sector at 2020

Table 7-36 Cost of mitigation options and relevant emission reduction in 2020

Mitigation Option	Cost Effectiveness ($/metric ton CO_2e)	Total Emission Reduction (million metric tons CO_2e)	Total Cost (million $)	Cumulative Emission Reduction (million metric tons CO_2e)	Cumulative Net Cost (million $)	Average Cumulative Cost Effectiveness ($/metric ton CO_2e)
Transmission Technologies	-18.4	19.1	-350.4	19.1	-350.4	-18.4
Vehicle Technologies	-12.0	43.8	-523.7	62.8	-874.1	-13.9
Engine Technologies	-11.9	136.0	-1618	198.9	-2492	-12.5
Engine-Transmission-Vehicle Technologies	-11.1	3.8	-42.4	202.7	-2535	-12.5
BRT	2.6	2.8	7.5	205.5	-2527	-12.3
Fuel Switch	21.5	10.3	220.7	215.8	-2307	-10.7

When we read data in one table, we will easily find that the cost effectiveness of all vehicle related technologies is negative. It shows that within the cost range we have taken into accounts till now, these technologies are highly recommended to use. Each year, the oil saving benefits from installing or renewing certain technologies would exceed the value of apportionment of the total technology expense. However, we should also clarify that for some technologies, these costs are far lower than the cost after taking into account a broader range of potential costs: the fact of technical barriers, the cost of independent or cooperative R&D, the cost of technology transfer, the cost of management and training, and the cost of building other supportive facilities.

Also analyzing from a single table could tell us that the engine technologies are the greatest contributor to the total emission reduction. In 2010, the engine technologies contribute nearly 70% of the total emission reduction. And in 2015 and 2020, the percentage is respectively 66% and 62%. The second contributor is always vehicle technologies. And BRT, as its indirect influence in mitigation (it mainly changes the travel mode), has the least contribution to emission reduction. From the perspective of reaching sheer emission reduction goals, we should certainly first promote these engine technologies.

All these mitigation options are designed in the 2005 policies scenario. In the 2005 policies scenario, the CO2 emission in 2010, 2015 and 2020 is respectively 393.3, 514.9, and 642.9 million tons. So after the implementation of these mitigation options, the emission reduction rate could reach respectively 8.77%, 15.0% and 33.6%. A huge amount of emission has been reduced due to these mitigation options.

From all the three tables above, we can tell that the average cumulative cost effectiveness is all negative, which implies that in transport sector, after considering the oil saving benefits, all the mitigation options, although some with very large initial investment cost, will bring in net benefits.

VII.F Analysis of GHG mitigation scenarios

Six packages of mitigation options for the road transport analysis are discussed here. All vehicle related mitigation options are in the negative-cost range partly due to the limits of cost considered. We classify BRT as the option costing less than $10 per metric tons, and fuel switch costs more than $10. Therefore, we divide these options into three mitigation scenarios in this analysis. Mitigation scenario 1 contains with all zero- or negative-cost mitigation options, mitigation scenario 2 contains mitigation options costing less than $10 per metric tons, and the last scenario – Mitigation scenario contains all feasible mitigation options. See Table 7-37.

Table 7-37 Cost and mitigation effects of three Advanced Options (Mitigation) scenarios

	Mitigation Options Contained	Total Changes in Costs (million US$)	Initial cost (million US$)	Long-term cost (million US$)	Total Emission Reduction (million tons)	The average cost ($ per tonne)
Advanced Options Scenario #1 (zero- or negative-cost mitigation options)	Engine technologies, Transmission Technologies, Vehicle technologies, Engine-transmission-vehicle technologies	8840.6	253.2	-115893	1368.4	-84.7
Advanced Options Scenario #2 (costing less than $10 per metric tons)	Engine technologies, Transmission Technologies, Vehicle technologies, Engine-transmission-vehicle technologies, BRT	13289.2	480.4	-114803	1391.1	-82.5
Advanced Options Scenario #3 (all feasible mitigation options)	Engine technologies, Transmission Technologies, Vehicle technologies, Engine-transmission-vehicle technologies, BRT, fuel switch	22289.4	653.3	-105802	1497.2	-70.7

The time frame taken into accounts in this part is from 2000 to 2020. The vehicle related technologies are starting to be used since year 2006; the BRT systems, though constructing since 2000, are starting to have emission reduction effects since 2011; the fuel switch is starting to be used since 2010. All these mitigation options have emission reduction effects till 2020.

As the emission reduction effects of vehicle related technologies are presented in a percentage form, the emission reduction by vehicle technologies per year is educed by the fuel saving rates and the CO2 emission of target vehicles in the 2005 policies baseline. The oil savings by vehicle related technologies could be educed by the same way. It is obvious that since 2006, we will have the oil saving benefits each year. (Oil price is set to be constant at $0.55 for either gasoline or diesel here.) These oil saving benefits discounted back to year 2000 added together could tell us the total oil saving benefits. Discount rate is 10%. Cost information in Table 7-28 has first been organized to count the cost per vehicle in near term, mid term and long term, then divided by each vehicle's life time – 15 years in this research to get the cost per year. Different years will have different vehicle population. So multiplying the cost per vehicle per year by the vehicle population in that year could educe the cost for a specific year. Discounting the costs from 2006 to 2020 back to 2000 and adding them up together will tell us the total cost. As total cost and oil saving benefits are known now, we can educe the long-term cost (net cost). Divided by the total emission reduction, we can get the average cost for each tonne of CO2 emission reduction.

The infrastructure cost of BRT has been evenly split to years from 2011-2020 where there is CO2 emission reduction. Discounting each year's cost back to year 2000 will give us the total cost information. The CO2 emission reductions in 2011, 2015 and 2020 have been counted, in the way we described in the previous section. And we simply estimate the CO2 emission reduction between the year 2011 and 2015, and the year between 2015 and 2020, assuming that CO2 emission reduction will grow at a constant amount every year. We could also tell the oil saving from the CO2 emission reduction amount each year. Discounting the oil saving benefits every year back to year 2000 and adding them up will give us the total oil saving benefits. Long-term cost could be educed by total costs minus the oil saving benefits. Also divided by the total emission reduction, we can get the average cost for each tonne of CO2 emission reduction.

Emission reduction by fuel switch could easily be educed by the emission reduction rate multiplied with the original emission of target vehicles. Cost by fuel switch per year is educed by multiply the cost per tonne information by the emission reduction amount. Discounted these cost information back to year 2000 will give us the net cost of fuel switch. Divided by the total emission reduction, we can get the average cost for each tonne of CO2 emission reduction.

We define the initial costs as the sum of discounted-back-to-2000 investment cost (no oil saving benefits considered) in the first year when different options begin to have emission reduction effects.

The implementation of mitigation options could certainly bring some co-benefits. The fuel saving reached directly by those mitigation options in transport sector could effectively enhance energy security and independence because China had become one of the most important oil importers in the world nowadays. The CO2 emission reduction and the concomitant reduction in other vehicle-related pollutants would benefit the air quality improvements, increase economic productivity and competitiveness and protect the biodiversity. Besides, the large need in producing new vehicle components with advanced technologies and infrastructure development for BRT would bring more and more job opportunities to the society.

VII.G High Oil Price Sensitivity Analysis Based on Pre-2000 baseline

Crude oil prices and oil products prices have been rising in China since 2000, at a frequency of 3 or 4 times a year. Two rises in oil products happened in China in 2006, one in Mar. 26th and another in May 24th. The May 24th price rising is the biggest one ever since China published her Reformation Plan on Crude Oil and Oil Products Pricing in 1998. It has increased either the gasoline price or the diesel price by 500 RMB per ton, which is nearly 10% higher than their original price. As a result, the price of 93# gasoline has risen from 4.26 yuan (0.515 USD) at the beginning of 2006 to 5.09 yuan (0.615) right now (exchange rate of USD to RMB is assumed to be 1:8.27). Experts also say that the current oil price in China is still comparatively lower than other countries, and there will be space for the further price rising.

Special attention has been paid to the response from vehicles owners and potential vehicle buyers. At the last night before May 24th, a long vehicle queue showed up in the gas station in big cities in China, such as Beijing and Shanghai. Some vehicle owners are considering reducing the usage rate of vehicles, and some are thinking about switching to traveling by bus. According to certain survey, 98% of vehicle owners being interviewed said that they will think about adjusting their travel mode. And a survey carried out by Journal 'Vehicle Observer' shows that price-sensitive consumers are thinking about buying a lower class of vehicles. 80% of the interviewees imply that the rising price has influenced their plan to buy cars, among which 36.6% will delay their purchase. However, some researchers are still very optimistic about the Chinese vehicle market. They believe that the major trend of motorization in China will be very steady and the rise of oil price will mostly influence the composition and the fuel economy of new vehicles.

The key department which decides the oil price in China is the National Development and Reform Committee. Intervention from Chinese government has been playing nearly a decisive role on the oil pricing. And that is why the oil price in China is comparatively stable even when the oil price in the world has been experiencing an unprecedented jump. However, through the several times of oil price rising in China, we could also see the tendency for the oil price in China to gradually approach the average oil price in the world.

In this high oil price sensitivity analysis, we try to figure out how the emission baseline would change if China is under this rising oil price. However, first, it is impossible for China to apply world oil price immediately; there must be a buffering time. We assume that since 2015, China will totally follow the trend of the world oil price change. By 'following the trend', we do not mean that the oil price in China will be identical with the world oil price. Actually nowadays, in other market-economy countries which are very sensitive to world oil price change, they may still vary in the domestic product oil price. So in this research, we assume that China will have an identical rise and fall rate of product oil price with the variance rate of world crude oil price; and between the years 2007 to 2014, China will adjust its own rise and fall rate to gradually follow the trend. In 2004, 2005 and 2006, the rise rate of product oil price in China is respectively 22.94%, 14.58%, 12.21%, which is 0.87, 0.38 and 1.43 times (the average value of the three is 0.89) of the world crude oil price change rate. Assuming that the value of domestic rise and fall rate divided by the international rise and fall rate will grow at a constant value per year until the value reaches 1 in 2015, we can educe the value for years from 2007 to 2014 and then educe the 'actual' rise and fall rate of domestic oil price, and further get the price of product oil price in China. Figure 1 shows the change in world crude oil price and the domestic product oil price in China. It should be noted that we use the price of 90# gasoline to represent the domestic product oil price because the sales of 90# gasoline is the biggest.

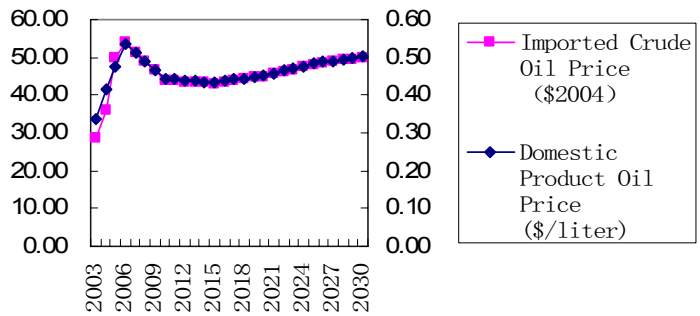

Figure 1 Comparison of world crude oil price and domestic product oil price in China

The product oil price change would influence the VKT and the vehicle population (mainly by influencing the number of new vehicles). In this research, we assume that the oil price change will not affect the FE level, because the FE level is to a large extend closely linked to the specific policy in the country. Table 1 shows our assumption for the new VP and VKT change according to a 100% rise in domestic product oil price. The change rate of new VP and VKT is in direct ratio to the change rate of domestic product oil price change rate.

Table 1 Assumption of influence to new VP and VKT under a 100% rise in domestic product oil price

	New VP	VKT
To HT, MT, HB, MB	-20%	-40%
To other vehicles (except cars)	-25%	-45%
To Cars	-30%	-50%
To Motorcycle	-40%	-60%

Note: HTs, MTs, HBs and MBs are less sensitive due to their commercial characteristics. Cars are more sensitive because the private vehicles are taking up a larger and larger portion in the total vehicle population and the individual buyers are very sensitive to the price. Motorcycles are the most sensitive because motorcycles are in the phasing-out period as the society improves.

By using these assumptions, we could educe a new series of vehicle population and VKT data, from which we can calculate a new version of vehicular oil consumption and CO2 emission. See Table 2 and Figure 2 and 3 below.

Table 2 Comparison of oil consumption and CO2 emission under high oil price scenario and pre-2000 baseline

	Oil consumption (million tons)		CO2 emission (million tons)	
	High Oil Price Scenario	Pre-2000 Baseline	High Oil Price Scenario	Pre-2000 Baseline
2005	82.51	89.01	260.26	280.76
2010	133.61	130.31	421.60	411.19
2015	171.30	170.92	540.86	539.63
2020	213.23	214.19	673.41	676.44

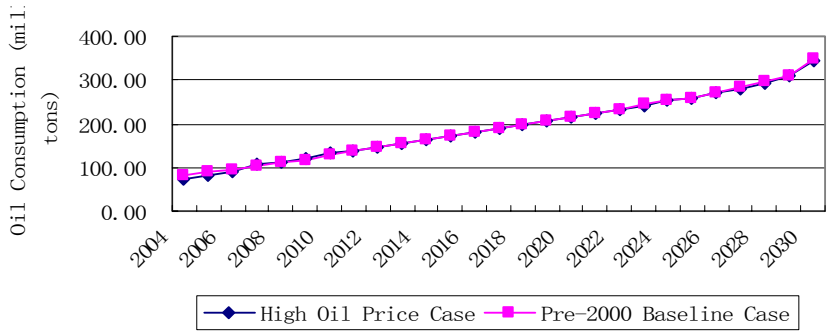

Figure 2 Comparison of oil consumption under high oil price scenario and pre-2000 baseline

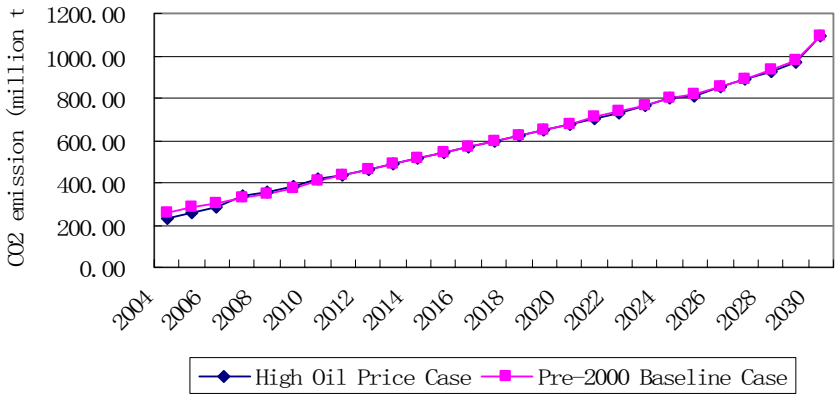

Figure 3 Comparison of CO2 emission under high oil price scenario and pre-2000 baseline

In the several oil price jumping years, China is experiencing its gradual adjustment to meet the global oil price change trend. However, when China is finally meeting the global oil price change trend, the global price seems to follow a quite stable growth tendency. That is one of the reasons that the high oil price case doesn't show a big influence to the baseline change. One big uncertainty exists in the settings of high oil price case – the sensitivity of VP and VKT to the oil price. There have been researches about the effects of high oil price towards Chinese economy, but few has pointed out the qualitative relationship between oil price and vehicle population, and the vehicle kilometers traveled per year. More researches and studies need to be done to calibrate this.

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VIII. Macro-economic Modeling Analysis

VIII.A Scenario Definition for Sectoral Approach

In our above analysis, energy conservation and GHG emission reduction potentials under different scenarios of several sectors were compared and their feasibilities were assessed according to the cost information. Emission reduction technologies with high priority were identified.

The foregoing analysis has some limitation in that the macroeconomic impact of each individual sector's mitigation option cannot be illuminated by a bottom-up analytical framework. Here we introduce a global trade CGE model named GTAP-E. Using this macroeconomic model, we simulate and analyze the macro-economic impacts of single sector's measures on China's gross economic, industry structures and commercial exports. As the space is limited, we take electricity sectoral mitigation policy analysis as example.

From the angles of promoting technology advancement indirectly and enhancing energy efficiency directly, two kinds of categories of scenarios are set up. One is to increase electric generation cost, the other one is to implement mitigation measures. We name them as cost scenarios and measures scenarios separately, and three sub-scenarios contained in each one are given names as Cost scenario 1, 2, and 3 and Measures scenario 1, 2, and 3 for convenience in the following discussion.

Table 8-1 sectoral approach scenarios in "top-down" assessment

	Production cost scenarios	Mitigation option scenarios
Sub-scenario1	Electric generation cost increases 2.5%, paid for by China.	Implementation of all mitigation measures costing less than \$5/metric ton CO_2 in electricity sector, paid for by China.
Sub-scenario2	Electric generation cost increases 5%, paid by China.	Implementation of all mitigation measures costing less than \$10/metric ton CO_2 in electricity sector, paid for by China.
Sub-scenario3	Electric generation cost increases 5%. 2.5% is paid by China, and additional total incremental cost is paid by international community in the form of a direct grant.	Implementation of all mitigation measures costing less than \$10/metric ton CO_2 in electricity sector, 5% is paid for by China. And additional total incremental cost is paid by international community in the form of a direct grant.

VIII.B Development of analytical approach：GTAP-E model

The model used in this research is extended version of the GTAP model called GTAP-E, which allows for the possibility of inter-fuel and inter-factor substitution in the production structure of firms and in the consumption behavior of private households and government sector. GTAP model is developed by Department of Agricultural Economics of PURDUE University. It is a kind of global static computable general equilibrium.

GTAP has been steadily expanding its capability towards facilitating global economic analyses of GHG emissions abatement. GTAP has successfully integrated global energy data sets, in particular, extended energy balances and energy prices and taxes, compiled by the International Energy Agency (IEA), into the GTAP input-output tables and bilateral trade data.

In order to adapt our research needs, we adjusted GTAP-E model and divided the world into 6 regions: EU, USA, Other developed countries, China, India, and Other developing countries.

Twenty sectors: Agriculture, forestry, fisheries, food, textile, manufacturing, pulp and paper, oil refining, chemical industry, metal and metallurgy, construction, trade, transport, services ,other mining, water, coal, oil, natural gas and electricity.

Figure 8-1 offers an overview of economic activity in a simplified version of the GTAP model. At the top of this figure is the regional household. Expenditures by this household are governed by an aggregate utility function that allocates expenditure across three broad categories: private, government, and savings expenditures. The model user has some discretion over the allocation of expenditures across these types of final demand. In the standard closure, the regional household's Cobb-Douglas utility function assures constant budget shares are devoted to each category. However, real government purchases and savings can also be dictated exogenously (i.e., fixed or shocked), in which case private household expenditure will adjust to satisfy the regional household's budget constraint. It is important to note that imports are traced to specific agents in the domestic economy, resulting in distinct import payments to rest of the world from private households, government households, and firms. This innovation departs from most models of global trade. It is especially important for the analysis of trade policy in regions where import intensities for the same commodity vary widely across uses.

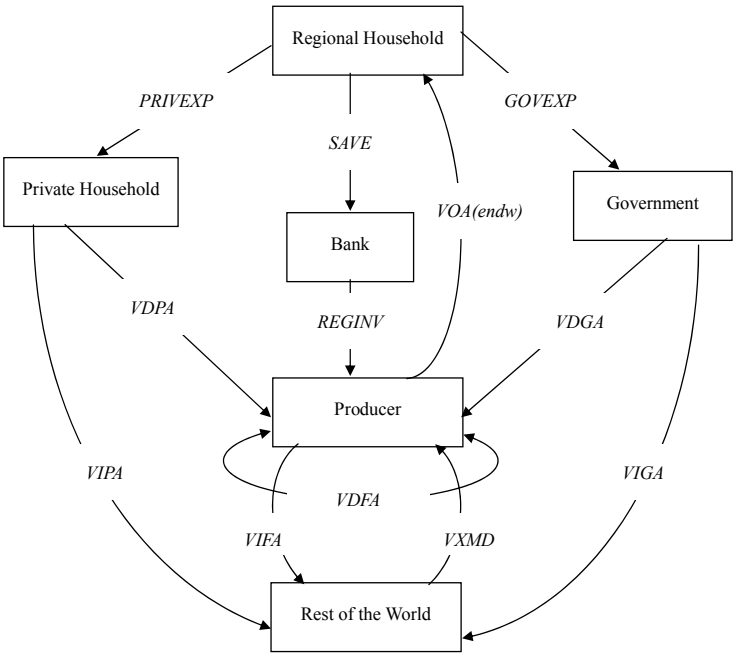
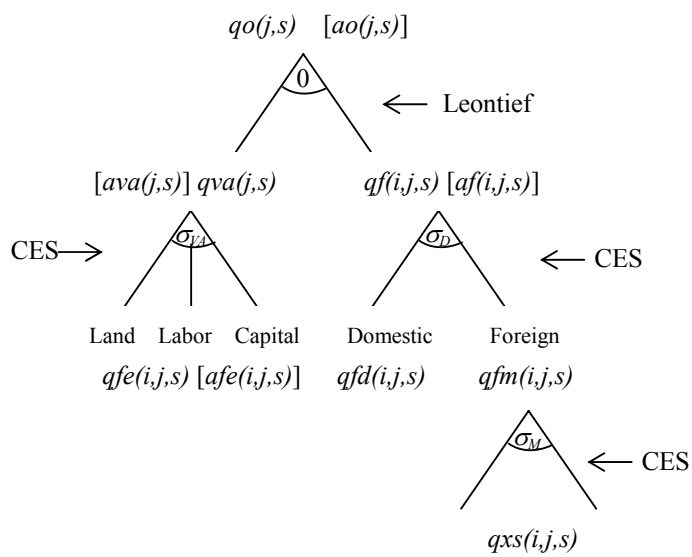


Figure 8-1.Structure of GTAP model

Regional household behavior is governed by an aggregate utility function, specified over composite private consumption, composite government purchases, and savings. The GTAP model employs a special case of the Stone-Geary utility function, whereby all subsistence shares are equal to zero. An index of current government expenditure is used to proxy the welfare derived from the government's provision of public goods and services to private households in the region. Then the aggregation of this index with private utility is adopted to make regional welfare based on the further assumption that the level of public goods provided in the initial equilibrium is optimal.

The following figure provides a visual display of the assumed technology for firms in each of the industries in the GTAP model. At the bottom of the inverted tree are the individual inputs demanded by the firm. For example, the primary factors of production are: land, labor, and capital. Firms also purchase intermediate inputs, some of which are produced domestically and some of which are imported. In the case of imports, the intermediate inputs must be "sourced" from particular exporters.



Recall
Figure 8-2. Standard GTAP Production Structure

Comparing with the GTAP model, one of the most critical variations of GTAP-E model is the incorporation of inter-fuel and fuel-factor substitutions into production function. On the production side, energy must be taken out of the intermediate input 'nest' to be incorporated into the 'value-added' nest. The incorporation of energy into the value-added nest is in two steps. Energy commodities are first separated into 'electricity' and 'non-electricity' groups. Some degree of substitution is allowed within the non-electricity group as well as between the electricity and the non-electricity groups. Next, the energy composite is then combined with capital to produce an energy-capital composite, which is in turn combined with other primary factors in a value-added-energy nest through a CES structure. In GTAP-E, the value of capital-energy substitution elasticity is assumed to be 0.5 for most industries (including electricity), and is set equal to 0.0 for coal, oil, gas, petroleum and coal products, and agriculture/forestry/fishery. This is based on the (low-to-middle) range of the values adopted by other models. The value of value added-energy substitution elasticity ranges from 0.2 to 1.45 and this seems to be slightly larger than the values adopted by other models, but these are the values currently used in the standard GTAP model.

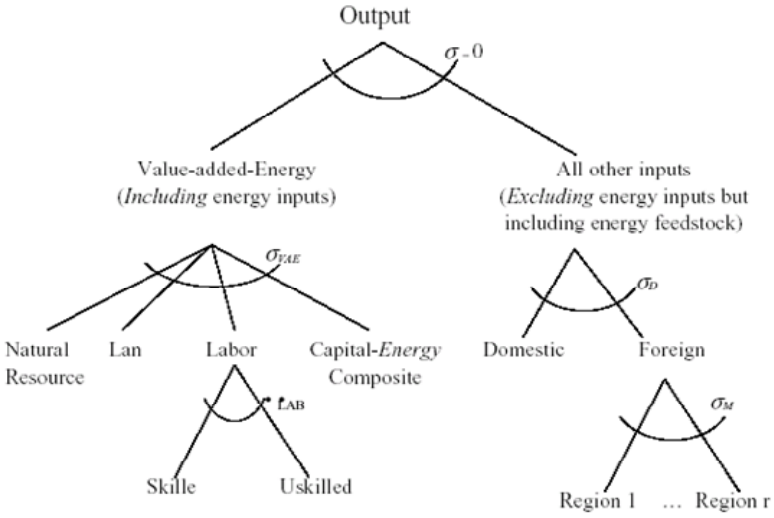


Figure 8-3. GTAP-E Production Structure

VIII.C Macro economic Impacts under different mitigation policy scenarios

Sectoral mitigation cost in cost scenario 3 is equal to that in cost scenario 2, so the mitigation effects are the same in the two scenarios. Suppose 2.5% sectoral cost from international community in the form of a direct grant is utilized for CO_2 mitigation and not industrial investment, and it will not impact China's national electricity demand and economic structure. So macro economic impacts in cost scenario 3 will be the same as that in cost scenario 1.

At present, electricity generation cost in China is about 0.0036~0.0060 US dollar/kWh, and total electricity generation cost is estimated as 4.96~8.27 billion US dollar in 2000. Global GDP is 61.03 trillion US dollar in 2000. Suppose global active capital accounts for 5% of global GDP, 2.5% increase of China's electricity generation cost is equal to $2.45\sim4.09\times10^{-6}$. This part of generation cost increase will make little impacts on global active capital. So we assume the macro economic impacts are the same in cost scenario 3 with cost scenario 1. We also can conclude that mitigation effects in measure scenario 3 are the same with measure scenario 2, and macro economic impacts in measure scenario 3 are the same with that in measure scenario 1. Consequently, we only give the results of cost scenario 1 and 2 and measure scenario 1 and 2 compared to baseline scenario without any mitigation measures.

In cost scenarios, we assume that electricity generation corporations need improve energy efficiency to pay off the increasing cost. As a result, technology upgrade and renovation is promoted indirectly. This category of scenarios is simulated through changing China's electricity generation cost directly in GTAP-E model. Based on Pigou's theory, carbon tax can optimize resources among electricity generation corporations, and corporations have to implement technologies with the same mitigation margins as tax rate at the end. Measure scenarios are simulated through imposing carbon tax on electricity sector in GTAP-E model

Using GTAP-E model we can analysis the change of hundreds economic variables under the above scenarios. But in order to simplify the analysis, we will focus on the change of GDP, CO2 mitigation, industrial products' price and output, industrial structure and commercial export value under different policy scenarios.

VIII.C.1 Changes of China's GDP

China's GDP falls 0.01%, 0.02%, 0% and 0.01% separately in four scenarios, as shown in Fig 8-4. It indicates that increasing China's electricity generation cost or implementing mitigation measures can decrease national GDP. The higher generation cost increase and the more mitigation options are implemented, the stronger GDP will get influenced.

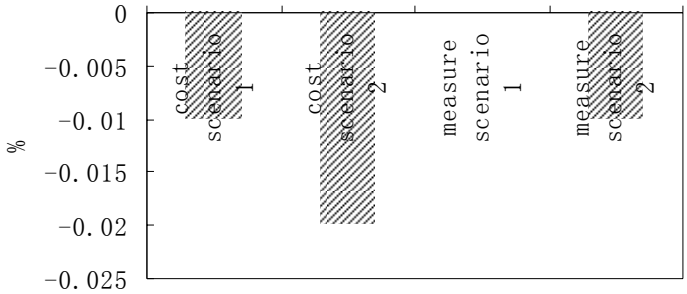


Fig 8-4. Change of China's GDP under different scenarios

VIII.C.2 Changes of China's anthropogenic CO_2 emissions

China's anthropogenic CO_2 emissions fall 0.4%, 0.73%, 0.51% and 0.9% separately under the four scenarios, as shown in Fig 8-5. It indicates that the higher sectoral producing cost increase and the more mitigation options are implemented, the greater CO_2 mitigation we will gain. Compared to the measure scenarios GDP falls more in cost scenarios, but mitigation effect is worse.

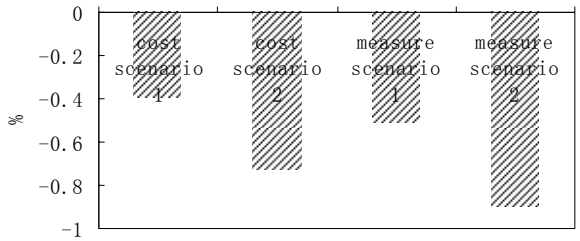


Fig 8-5. changes of China's anthropogenic CO_2 emissions under different scenarios

VIII.C.3 Changes of Chinese industrial production price and output

From Table 6-2 we can see that electricity price increases 1.64% and 3.26 when the generation cost increase 2.5% and 5%. Other industrial products' prices all fall slightly to meet the market equilibrium except pulp and paper, chemical industry, metal and metallurgy and water industry. Electricity price increases 0.83% and 1.62% when carbon tax rate is set at \$5/mt CO_2 and \$10/mt CO_2. From the results we can obviously conclude that imposing carbon tax will make less impacts on other industrial products' prices except coal industry. The most sensitive industry to electricity price changes are electricity, coal and gas under four scenarios. There is tight connection between commercial demand and supply in China's energy markets.

Table 6-2 Changes of industrial production prices under different scenarios

industry	Change rate of production market price×100			
	Cost scenario 1	Cost scenario 2	Measure scenario 1	Measure scenario 2
Agriculture	-0.01	-0.03	0	-0.01
forestry	-0.04	-0.08	-0.02	-0.05
fisheries	-0.03	-0.05	-0.01	-0.03
food	-0.01	-0.02	0	-0.01
textile	-0.01	-0.02	0	0
manufacturing	-0.01	-0.02	0	-0.01
pulp and paper	0	0	0	0
oil refining	-0.02	-0.04	0	-0.01
chemical industry	0.02	0.04	0.01	0.02
metal and metallurgy	0.01	0.03	0	0.01
construction	-0.01	-0.02	0	-0.01
trade	-0.03	-0.07	-0.01	-0.02
transport	-0.04	-0.08	-0.01	-0.03
services	-0.02	-0.04	-0.01	-0.01
other mining	-0.03	-0.06	-0.01	-0.02
water	0.12	0.24	0.07	0.13
coal	-1.25	-2.38	-1.85	-3.43
oil	-0.02	-0.05	0	0
natural gas	-0.5	-0.99	-0.31	-0.56
electricity	1.64	3.26	0.83	1.62

Table 8-3 reflects changes of China's industrial production compared to baseline scenario without any mitigation measures.

Table 8-3 impacts on industrial production under 4 scenarios

industry	Production changes (million dollar)			
	Cost scenario 1	Cost scenario 2	Measure scenario 1	Measure scenario 2
Agriculture	-2.94	-7.81	-3.47	-8.63
forestry	-7.20	-14.2	-5.94	-11.6
fisheries	-1.55	-3.46	-0.50	-1.32
food	1.98	2.23	0.30	-1.00
textile	87.0	175.6	15.9	33.3
manufacturing	114.1	230.1	55.8	110.1
pulp and paper	-7.10	-14.3	-3.63	-7.60
oil refining	-61.6	-118.4	6.21	10.6
chemical industry	-142.9	-282.0	-52.1	-105.6
metal and metallurgy	-203.5	-404.6	-70.5	-143.4
construction	-246.4	-490.4	-88.9	-178.3
trade	-2.22	-6.06	-5.06	-12.1
transport	0.73	1.14	-1.91	-4.55
services	-36.1	-80.1	-23.4	-52.7
other mining	-29.3	-58.2	-10.4	-21.1
water	-4.93	-9.82	-2.02	-4.01
coal	-73.0	-142.6	-111.5	-215.5
oil	3.98	7.34	2.76	5.37
natural gas	-35.6	-69.9	-19.4	-34.3
electricity	-678.1	-1331.3	-257.0	-500.6

Table 8-3 implies that as electricity generation cost increases and stricter mitigation measures are implemented, there will be more impacts on national industrial production outputs. Textile, manufacturing, chemical industry, metal and metallurgy, construction and coal are the most sensitive sectors towards mitigation policies implemented in electricity sector, among which outputs of textile and manufacturing will increase and the others will fall.

Fig 8-6 illustrates that coal and natural gas sectors' output change rates are the most obvious under four scenarios. Taking cost scenario 1 and measure scenario 1 as examples, electricity generation decrease 1.34% and 0.51% compared to baseline scenario without any mitigation measures, and outputs for coal and natural gas sectors fall 0.64%, 0.98% and 2.08%, 1.13%, respectively, in the two scenarios. It is concluded that there is a tight relationship among the energy products' demand and supply.

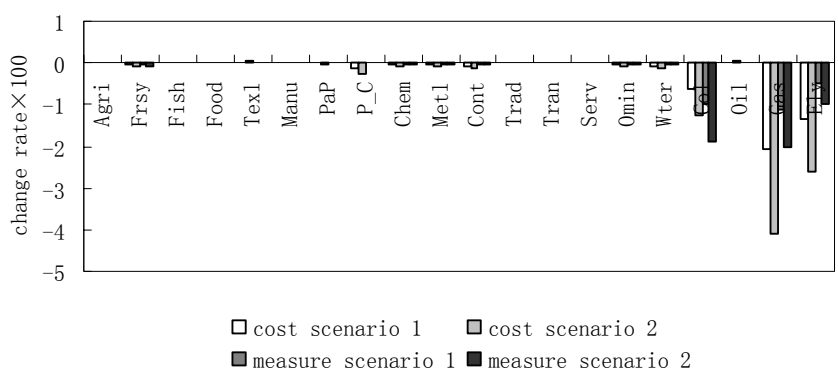


Fig 8-6 Impacts on China's industrial production outputs' change rate under 4 scenarios

VIII.C.4 Changes of industrial structure

Table 8-4, Table 8-5, Table 8-6 and Table 8-7 reveal the changes of intermediate inputs among sectors under 4 different scenarios.

Table 8-4 changes of intermediate inputs among sectors under cost scenario 1 (million dollar)

	Agri	Frsy	Fish	Food	Texl	Manu	PaP	P_C	Chem	Metl
Agri	-0.07	-0.07	-0.01	3.02	6.93	0.74	-0.17	0.00	-2.45	-0.18
Frsy	0.06	-0.48	0.00	0.01	0.01	1.21	0.02	-0.01	-2.06	-0.07
Fish	0.00	0.00	-0.08	0.08	0.00	0.01	0.00	0.00	-0.45	0.00
Food	0.21	-0.01	-0.09	1.04	1.75	0.04	0.00	0.00	-1.52	-0.06
Texl	0.01	-0.01	0.00	0.04	34.93	3.06	-0.18	-0.11	-4.33	-1.68
Manu	0.08	-0.19	0.02	0.18	1.77	51.86	-0.09	-1.59	-2.83	-11.73
PaP	0.00	-0.01	0.00	0.05	0.45	1.18	-1.57	-0.02	-1.69	-3.44
P_C	6.59	0.35	1.14	1.39	2.46	3.96	1.00	-4.45	20.69	12.15
Chem	-2.33	-0.34	-0.03	-0.37	2.05	1.64	-0.81	-0.95	-51.93	-7.60
Metl	-0.04	-0.08	-0.01	-0.11	0.34	8.92	-0.14	-0.69	-3.23	-66.16
Cont	-0.01	-0.02	0.00	0.00	0.08	0.11	-0.01	-0.06	-0.15	-0.19
Trad	-0.01	-0.14	-0.03	0.12	5.32	5.29	-0.50	-1.76	-6.64	-10.13
Tran	0.04	-0.13	0.01	0.04	1.24	1.64	-0.13	-1.22	-2.74	-6.50
Serv	-0.01	-0.31	-0.01	0.16	2.22	4.53	-0.15	-1.21	-4.52	-8.77
Omin	0.00	0.00	0.00	0.00	0.00	0.40	0.00	-0.04	-2.16	-13.84
Wter	0.00	0.00	0.00	0.00	0.06	0.07	-0.01	-0.08	-0.23	-0.28
Col	1.34	0.16	0.13	3.21	2.23	4.70	2.14	0.01	9.13	30.07
Oil	0.07	0.00	0.00	0.00	0.00	0.01	0.00	11.24	0.50	0.09
Gas	0.19	0.01	0.01	1.36	1.59	1.52	0.08	0.00	5.51	2.81
Ely	-23.40	-1.30	-3.07	-15.09	-24.44	-34.59	-11.33	0.00	-88.77	-108.12
	Cont	Trad	Tran	Serv	Omin	Wter	Col	Oil	Gas	Ely
Agri	-0.41	0.33	0.05	-0.01	-0.03	0.00	-0.52	0.00	0.00	-0.08
Frsy	-1.29	0.02	0.01	0.01	-0.02	0.00	-3.07	0.00	-0.01	-0.14
Fish	0.00	0.01	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00
Food	-0.14	0.49	0.02	-0.14	-0.01	0.00	-0.01	0.00	0.00	-0.01
Texl	-1.07	0.09	0.04	-0.17	-0.19	-0.02	-0.67	0.04	-0.26	-1.93
Manu	-18.59	2.09	1.96	2.75	-1.66	-0.24	-7.31	0.41	-3.08	-97.10
PaP	-0.19	-0.01	0.01	-0.91	-0.02	0.00	-0.10	0.01	-0.04	-0.51
P_C	1.19	2.26	1.93	13.84	0.56	0.17	0.00	0.00	-2.60	-125.92
Chem	-5.00	-0.63	-0.41	-2.14	-1.89	-0.22	-2.36	0.04	-1.06	-18.33
Metl	-91.42	-0.09	-0.06	-0.72	-0.86	-0.18	-6.57	0.10	-1.07	-5.78
Cont	-0.13	0.01	0.02	-0.74	-0.09	-0.02	-0.20	0.01	-0.10	-2.93
Trad	-12.80	0.73	0.44	-0.08	-1.13	-0.08	-2.80	0.05	-1.98	-16.89
Tran	-5.40	1.14	2.09	0.79	-1.50	-0.03	-1.51	0.03	-1.04	-10.66
Serv	-13.18	0.70	1.17	-1.36	-1.35	-0.28	-3.55	0.12	-1.21	-27.02
Omin	-6.28	0.00	0.00	-0.01	-7.13	0.00	-0.10	0.00	-0.03	-0.65
Wter	-0.25	-0.01	0.00	-0.11	-0.04	-0.35	-0.11	0.00	-0.13	-1.69
Col	0.35	0.29	0.37	2.44	0.80	0.03	-0.01	0.00	-1.05	-234.09
Oil	0.01	0.00	0.00	0.15	0.00	0.02	0.00	0.00	-0.01	-23.38
Gas	0.25	0.01	0.00	0.92	0.12	0.01	0.00	0.00	-3.23	-109.26
Ely	-7.21	-5.31	-3.28	-65.48	-6.55	-5.84	-0.02	0.00	-0.01	-216.52

Table 8-5 changes of intermediate inputs among sectors under cost scenario 2 (million dollar)

	Agri	Frsy	Fish	Food	Texl	Manu	PaP	P_C	Chem	Metl
Agri	-0.41	-0.15	-0.03	5.56	14.04	1.50	-0.33	0.00	-4.83	-0.35
Frsy	0.12	-0.94	0.01	0.02	0.01	2.41	0.04	-0.01	-4.05	-0.14
Fish	0.00	0.00	-0.19	0.10	0.00	0.02	0.00	0.00	-0.89	0.00
Food	0.31	-0.02	-0.21	1.90	3.54	0.09	0.00	0.00	-3.00	-0.12
Texl	0.02	-0.02	0.00	0.08	70.53	6.18	-0.36	-0.21	-8.52	-3.34
Manu	0.13	-0.38	0.01	0.34	3.56	104.17	-0.19	-3.04	-5.57	-23.29
PaP	0.00	-0.02	-0.01	0.07	0.91	2.38	-3.14	-0.04	-3.34	-6.84
P_C	13.07	0.70	2.27	2.75	4.86	7.82	1.97	-8.51	41.15	23.91
Chem	-4.74	-0.66	-0.06	-0.75	4.23	3.54	-1.60	-1.82	-102.41	-15.07
Metl	-0.09	-0.16	-0.02	-0.24	0.69	18.13	-0.28	-1.32	-6.38	-131.49
Cont	-0.02	-0.03	0.00	0.00	0.15	0.22	-0.02	-0.11	-0.29	-0.37
Trad	-0.06	-0.27	-0.06	0.15	10.73	10.67	-1.00	-3.37	-13.11	-20.14
Tran	0.05	-0.26	0.01	0.06	2.49	3.31	-0.26	-2.34	-5.41	-12.91
Serv	-0.08	-0.61	-0.03	0.28	4.48	9.12	-0.29	-2.32	-8.90	-17.43
Omin	0.00	0.00	0.00	0.00	0.00	0.81	0.00	-0.07	-4.27	-27.51
Wter	0.00	0.00	0.00	0.00	0.12	0.14	-0.03	-0.15	-0.45	-0.56
Col	2.61	0.31	0.25	6.26	4.36	9.20	4.16	0.01	17.62	58.31
Oil	0.14	0.00	0.00	0.01	0.01	0.02	0.00	35.66	1.06	0.18
Gas	0.38	0.02	0.02	2.65	3.10	2.97	0.16	0.01	10.70	5.47
Ely	-46.04	-2.54	-6.05	-29.65	-48.09	-68.02	-22.27	0.00	-174.38	-212.31
	Cont	Trad	Tran	Serv	Omin	Wter	Col	Oil	Gas	Ely
Agri	-0.82	0.66	0.10	-0.03	-0.06	0.00	-1.02	0.00	0.00	-0.15
Frsy	-2.56	0.03	0.01	0.02	-0.05	0.00	-5.99	0.01	-0.02	-0.27
Fish	0.00	0.00	0.00	-0.02	0.00	0.00	0.00	0.00	0.00	0.00
Food	-0.27	0.94	0.04	-0.31	-0.02	0.00	-0.03	0.00	0.00	-0.01
Texl	-2.12	0.16	0.07	-0.41	-0.37	-0.04	-1.32	0.07	-0.51	-3.83
Manu	-36.97	4.11	3.90	5.06	-3.28	-0.47	-14.27	0.77	-6.04	-193.63
PaP	-0.39	-0.05	0.01	-2.01	-0.03	-0.01	-0.20	0.01	-0.07	-1.00
P_C	2.36	4.51	3.99	27.43	1.11	0.34	-0.01	0.00	-5.09	-246.47
Chem	-9.94	-1.26	-0.82	-4.48	-3.74	-0.44	-4.62	0.06	-2.08	-36.05
Metl	-181.95	-0.18	-0.11	-1.52	-1.71	-0.35	-12.83	0.17	-2.10	-11.42
Cont	-0.25	0.00	0.04	-1.69	-0.17	-0.05	-0.38	0.01	-0.20	-5.75
Trad	-25.48	1.31	0.84	-0.48	-2.23	-0.16	-5.47	0.09	-3.89	-33.16
Tran	-10.74	2.08	4.12	1.40	-2.98	-0.05	-2.95	0.05	-2.03	-20.92
Serv	-26.22	1.23	2.32	-3.59	-2.69	-0.56	-6.93	0.23	-2.37	-53.09
Omin	-12.49	0.00	0.01	-0.03	-14.17	0.00	-0.20	0.00	-0.06	-1.28
Wter	-0.49	-0.01	-0.01	-0.24	-0.08	-0.70	-0.21	0.01	-0.26	-3.33
Col	0.68	0.55	0.71	4.75	1.57	0.05	-0.01	0.00	-2.06	-461.01
Oil	0.03	0.00	0.00	0.31	0.01	0.04	0.00	0.00	-0.01	-65.73
Gas	0.50	0.03	0.01	1.79	0.23	0.01	0.00	0.00	-6.46	-232.89
Ely	-14.18	-10.44	-6.45	-129.02	-12.88	-11.51	-0.03	0.00	-0.01	-423.62

Table 8-6 changes of intermediate inputs among sectors under measure scenario 1 (million dollar)

	Agri	Frsy	Fish	Food	Texl	Manu	PaP	P_C	Chem	Metl
Agri	-0.40	-0.06	0.00	0.98	1.48	0.36	-0.10	0.00	-0.89	-0.06
Frsy	0.03	-0.43	0.00	0.01	0.00	0.65	0.02	0.00	-0.66	-0.02
Fish	0.00	0.00	-0.03	0.02	0.00	0.00	0.00	0.00	-0.16	0.00
Food	-0.07	-0.01	-0.02	0.36	0.36	0.02	0.00	0.00	-0.55	-0.02
Texl	-0.01	-0.01	0.00	0.01	6.56	1.39	-0.11	0.01	-1.60	-0.59
Manu	0.00	-0.17	0.01	0.06	0.41	22.09	-0.09	0.21	-1.03	-4.02
PaP	0.00	-0.01	0.00	0.00	0.08	0.55	-0.88	0.00	-0.63	-1.21
P_C	3.56	0.18	0.56	1.02	1.52	2.71	0.72	0.49	11.87	9.52
Chem	-1.07	-0.25	-0.01	-0.15	-0.04	1.27	-0.36	0.05	-19.18	-2.69
Metl	-0.02	-0.07	0.00	-0.02	0.06	5.78	-0.06	0.07	-1.14	-22.13
Cont	-0.01	-0.01	0.00	0.00	0.01	0.05	-0.01	0.01	-0.05	-0.07
Trad	-0.05	-0.11	-0.01	0.02	0.99	2.57	-0.26	0.18	-2.42	-3.51
Tran	-0.01	-0.11	0.01	0.01	0.24	0.79	-0.07	0.12	-1.00	-2.25
Serv	-0.08	-0.26	0.00	0.04	0.44	2.08	-0.10	0.13	-1.66	-3.05
Omin	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	-0.79	-4.79
Wter	0.00	0.00	0.00	0.00	0.01	0.03	-0.01	0.01	-0.08	-0.10
Col	1.47	0.20	0.17	3.48	2.33	4.95	2.53	0.01	12.01	37.12
Oil	0.03	0.00	0.00	0.00	0.00	0.01	0.00	5.94	0.20	0.06
Gas	0.12	0.01	0.01	0.88	0.99	0.98	0.05	0.00	3.42	1.88
Ely	-12.21	-0.71	-1.57	-8.61	-13.28	-19.01	-6.26	0.00	-46.13	-60.96
	Cont	Trad	Tran	Serv	Omin	Wter	Col	Oil	Gas	Ely
Agri	-0.15	0.07	0.02	-0.03	-0.01	0.00	-0.79	0.00	0.00	-0.01
Frsy	-0.38	0.01	0.00	0.01	-0.01	0.00	-4.76	0.00	-0.01	-0.03
Fish	0.00	-0.03	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00
Food	-0.05	0.04	0.00	-0.10	0.00	0.00	-0.02	0.00	0.00	0.00
Texl	-0.39	-0.02	0.00	-0.16	-0.07	-0.01	-1.03	0.02	-0.14	-0.41
Manu	-6.69	0.57	0.61	0.44	-0.58	-0.10	-11.27	0.24	-1.68	-12.90
PaP	-0.07	-0.10	-0.01	-0.64	-0.01	0.00	-0.16	0.00	-0.02	-0.14
P_C	0.69	1.00	0.52	7.43	0.40	0.10	-0.01	0.00	-1.41	-34.91
Chem	-1.83	-0.30	-0.18	-1.11	-0.68	-0.09	-3.56	0.05	-0.58	-0.78
Metl	-32.52	-0.05	-0.02	-0.34	-0.30	-0.07	-9.99	0.07	-0.58	-1.57
Cont	-0.04	-0.01	-0.01	-0.52	-0.03	-0.01	-0.30	0.01	-0.06	-1.11
Trad	-4.62	-0.12	-0.08	-0.43	-0.40	-0.03	-4.28	0.03	-1.08	-6.25
Tran	-1.95	-0.08	0.48	0.08	-0.53	-0.01	-2.31	0.02	-0.56	-4.00
Serv	-4.79	-0.23	0.23	-1.82	-0.48	-0.12	-5.43	0.08	-0.66	-7.19
Omin	-2.27	0.00	0.00	-0.01	-2.53	0.00	-0.15	0.00	-0.02	-0.22
Wter	-0.09	-0.01	-0.01	-0.07	-0.01	-0.15	-0.17	0.00	-0.07	-0.37
Col	0.39	0.39	0.54	2.61	0.86	0.03	-0.01	0.00	-0.55	-343.70
Oil	0.01	0.00	0.00	0.07	0.00	0.01	0.00	0.00	0.00	-5.19
Gas	0.16	0.01	0.00	0.56	0.08	0.00	0.00	0.00	-1.62	-61.93
Ely	-3.72	-2.73	-1.67	-33.97	-3.54	-2.92	-0.03	0.00	0.00	-10.31

Table 8-7 changes of intermediate inputs among sectors under measure scenario 2 (million dollar)

	Agri	Frsy	Fish	Food	Texl	Manu	PaP	P_C	Chem	Metl
Agri	-1.06	-0.13	-0.01	1.52	3.11	0.71	-0.20	0.00	-1.80	-0.12
Frsy	0.06	-0.84	0.01	0.01	0.00	1.28	0.03	0.00	-1.35	-0.04
Fish	0.00	0.00	-0.07	-0.02	0.00	0.01	0.00	0.00	-0.33	0.00
Food	-0.24	-0.02	-0.08	0.56	0.75	0.04	0.00	0.00	-1.12	-0.04
Texl	-0.01	-0.02	0.00	0.01	13.76	2.75	-0.22	0.02	-3.25	-1.20
Manu	-0.03	-0.34	0.00	0.11	0.85	43.81	-0.21	0.38	-2.09	-8.21
PaP	-0.01	-0.01	0.00	-0.03	0.16	1.09	-1.82	0.00	-1.27	-2.46
P_C	6.94	0.35	1.09	1.96	2.94	5.23	1.39	0.84	23.07	18.25
Chem	-2.29	-0.49	-0.02	-0.34	-0.02	2.43	-0.74	0.08	-38.87	-5.46
Metl	-0.06	-0.13	-0.01	-0.07	0.13	11.20	-0.12	0.11	-2.31	-45.13
Cont	-0.02	-0.03	0.00	0.00	0.03	0.11	-0.01	0.01	-0.11	-0.13
Trad	-0.14	-0.22	-0.02	-0.03	2.06	5.07	-0.54	0.31	-4.91	-7.13
Tran	-0.04	-0.22	0.00	0.00	0.50	1.56	-0.14	0.21	-2.03	-4.57
Serv	-0.20	-0.52	-0.02	0.05	0.91	4.12	-0.20	0.22	-3.37	-6.21
Omin	0.00	0.00	0.00	0.00	0.00	0.36	0.00	0.01	-1.60	-9.75
Wter	0.00	0.00	0.00	0.00	0.02	0.07	-0.01	0.01	-0.17	-0.20
Col	2.79	0.37	0.32	6.60	4.42	9.41	4.78	0.02	22.60	70.10
Oil	0.06	0.00	0.00	0.01	0.00	0.01	0.00	11.84	0.39	0.11
Gas	0.22	0.01	0.01	1.62	1.82	1.80	0.09	0.01	6.18	3.45
Ely	-23.83	-1.37	-3.07	-16.69	-25.84	-36.94	-12.18	0.00	-89.92	-118.27
	Cont	Trad	Tran	Serv	Omin	Wter	Col	Oil	Gas	Ely
Agri	-0.30	0.14	0.04	-0.07	-0.02	0.00	-1.53	0.00	0.00	-0.01
Frsy	-0.78	0.01	0.01	0.01	-0.01	0.00	-9.20	0.00	-0.01	-0.06
Fish	0.00	-0.09	0.00	-0.02	0.00	0.00	0.00	0.00	0.00	0.00
Food	-0.10	0.02	0.01	-0.23	-0.01	0.00	-0.04	0.00	0.00	0.00
Texl	-0.78	-0.05	0.01	-0.36	-0.14	-0.02	-1.99	0.05	-0.25	-0.81
Manu	-13.42	1.05	1.17	0.53	-1.18	-0.20	-21.78	0.46	-2.96	-25.12
PaP	-0.14	-0.22	-0.02	-1.43	-0.01	0.00	-0.30	0.01	-0.04	-0.27
P_C	1.34	1.96	1.00	14.48	0.77	0.19	-0.01	0.00	-2.48	-69.00
Chem	-3.67	-0.63	-0.38	-2.41	-1.38	-0.18	-6.88	0.09	-1.02	-1.51
Metl	-65.30	-0.11	-0.05	-0.77	-0.61	-0.14	-19.30	0.14	-1.03	-3.05
Cont	-0.09	-0.03	-0.01	-1.20	-0.06	-0.02	-0.58	0.01	-0.10	-2.15
Trad	-9.26	-0.42	-0.24	-1.10	-0.81	-0.06	-8.27	0.07	-1.91	-12.17
Tran	-3.90	-0.39	0.85	0.01	-1.08	-0.02	-4.46	0.03	-1.00	-7.79
Serv	-9.59	-0.65	0.44	-4.30	-0.98	-0.23	-10.49	0.16	-1.16	-14.01
Omin	-4.54	0.00	-0.01	-0.02	-5.13	0.00	-0.30	0.00	-0.03	-0.42
Wter	-0.18	-0.02	-0.01	-0.15	-0.03	-0.29	-0.32	0.01	-0.13	-0.72
Col	0.74	0.73	1.02	4.95	1.64	0.05	-0.02	0.00	-0.98	-672.24
Oil	0.01	0.00	0.00	0.13	0.01	0.02	0.00	0.00	-0.01	-10.74
Gas	0.28	0.02	0.00	1.01	0.14	0.01	0.00	0.00	-2.87	-114.91
Ely	-7.25	-5.32	-3.26	-66.37	-6.88	-5.71	-0.05	0.00	-0.01	-20.23

Results from GTAP-E model simulation give electricity demand by other sectors, as shown in Fig 8-7. Main electricity consuming sectors are agriculture, food, textile, manufacturing, pulp and paper, chemical industry, metal and metallurgy, services and electricity itself. Fig 8-8 illustrates that implementing mitigation policies induces increase of electricity price. As a result, electricity demand for other sectors will fall down, especially for the main electricity consuming sectors, such as textile, chemical industry, metal and metallurgy, services and electricity itself. This is compatible with the data in Fig 8-7. Fig 8-8 also shows that measure scenarios have lower impacts on intermediate inputs among sectors than cost scenarios.

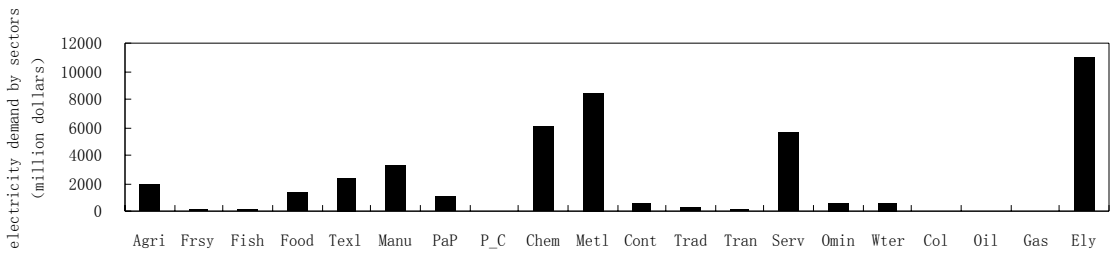


Fig 8-7 electricity demand by sectors in baseline scenario

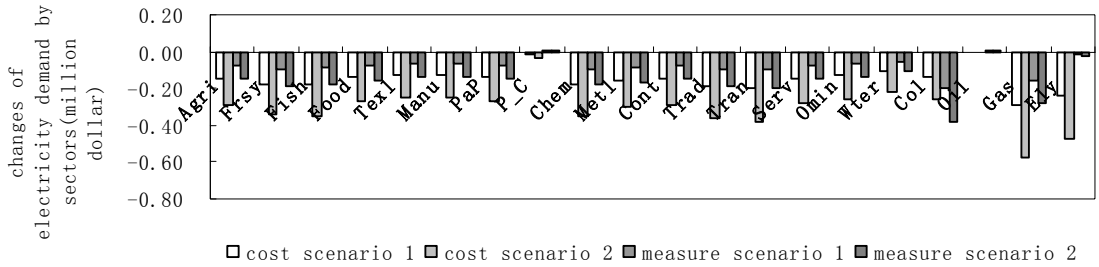


Fig 8-8 changes of electricity demand by sectors under different scenarios

To compare changes of intermediate inputs of different sectors under electricity sectoral mitigation scenarios, we choose chemical industry, metal and metallurgy, services and electricity as target sectors, the results are drawn as Fig 8-9, Fig 8-10, Fig 8-11 and Fig 8-12. Trends for changes of intermediate inputs demand are similar in chemical industry, metal and metallurgy and services industry. Either increasing electric generation cost or implementing mitigation measures can raise electricity price. Main electricity consuming sectors need to decrease electricity inputs to balance cost-effect. Intermediate inputs from oil refining, coal and natural gas grow to satisfy sectoral energy demand. Increases of intermediate inputs from oil refining and coal industry are quite obvious, for coal is the most important primary energy resource, and oil is key element for industrial production and fuel combustion of transportation. Also, we can conclude that cost scenarios have stronger impacts on intermediate inputs of sectors than measure scenarios.

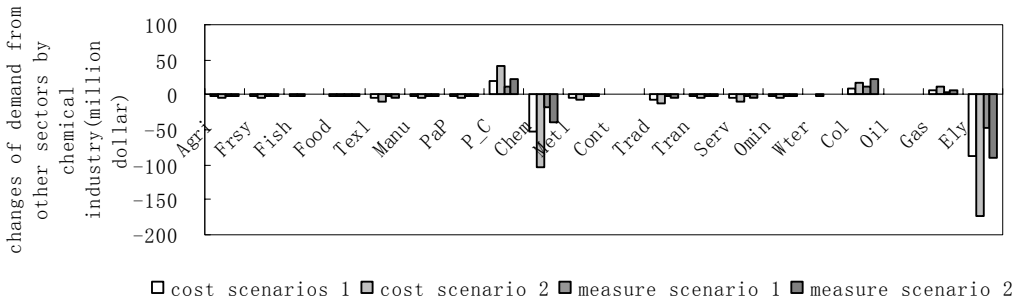


Fig 8-9 changes of demands from other sectors by chemical industry under different scenarios

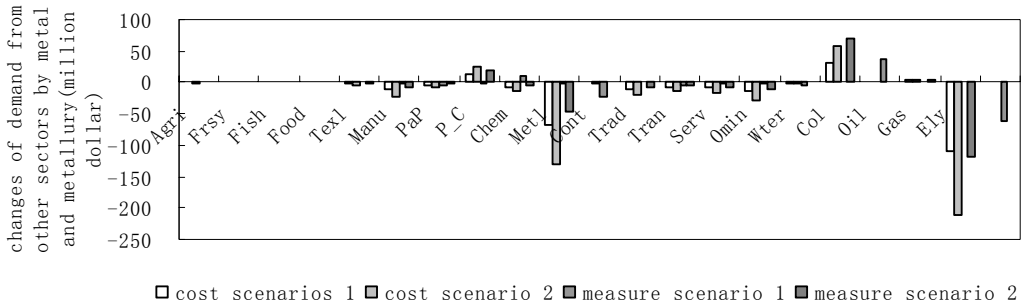


Fig 8-10 changes of demands from other sectors by metal and metallurgy under different scenarios

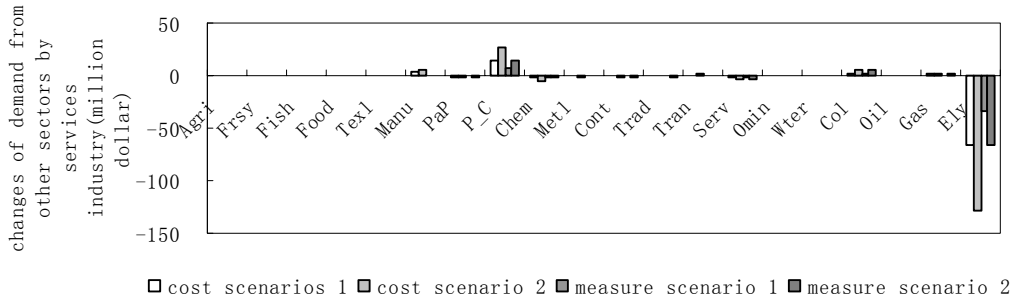


Fig 8-11 changes of demands from other sectors by services industry under different scenarios

Changes of demands from other sectors by electricity sector are quite different. Because the raise of electricity price induce the decrease of national electricity demand, Fig 8-12 shows that inputs from other sectors in electricity sector all fall down, especially from manufacturing, oil refining, natural gas and electricity itself.

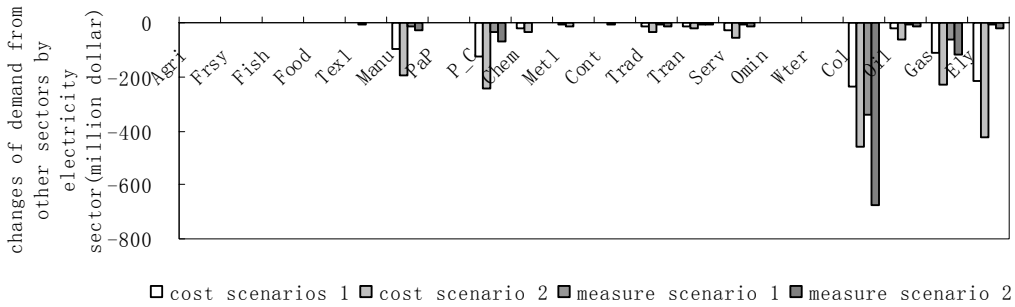


Fig 8-12 changes of demands from other sectors by electricity sector under different scenarios

VIII.C.5 Changes of commercial exports

Table 8-8, Table 8-9, Table 8-10 and Table 8-11, respectively, show changes of China's commercial exports under different scenarios compared to baseline scenario without any sectoral mitigation policy. Exports from chemical industry, metal and metallurgy, water industry and electricity sector fall down obviously after implementing sectoral mitigation policies. These four sectors are compatible with those sectors whose prices rise in Table 8-2. Price is one of the key elements of commercial export. Other sectors' exports increase, and textile, and manufacturing and coal industry are the most sensitive sectors.

Table 8-8 changes of China's commercial export under cost scenario 1 (million dollar)

	EU	US	Other developed countries	India	Other developing countries	Total
Agri	0.99	0.48	1.5	0.13	1.74	4.84
Frsy	0.04	0.01	0.14	0	0.04	0.23
Fish	0.05	0.03	0.2	0	0.11	0.39
Food	0.86	0.87	3.51	0.01	1.83	7.08
Texl	11.37	16.43	14.95	0.21	11.83	54.79
Manu	57.92	89.04	52.55	1	39.17	239.68
PaP	0.05	0.12	0.06	0	0.06	0.29
P_C	0.06	0.04	0.4	0.14	0.66	1.30
Chem	-8.67	-10.2	-8.25	-0.86	-11.3	-39.28
Metl	-5.4	-8.27	-5.86	-0.28	-6.43	-26.24
Cont	0.36	0.06	0.19	0	0.08	0.69
Trad	18.11	10.82	9.16	0.71	8.67	47.47
Tran	8.58	3.98	2.12	0.15	2.56	17.39
Serv	10.82	4.75	3.82	0.32	4.52	24.23
Omin	0.11	0.1	0.16	0.06	0.16	0.59
Wter	-0.22	-0.1	-0.08	0	-0.08	-0.48
Col	3.93	0.2	31.42	1.87	33.42	70.84
Oil	1.46	2.28	7.94	0.48	3.1	15.26
Gas	1.54	0.36	5.48	0	1.73	9.11
Ely	-3.06	-0.41	-0.69	-0.12	-2.55	-6.83

Table 8-9 changes of China's commercial export under cost scenario 2 (million dollar)

	EU	US	Other developed countries	India	Other developing countries	Total
Agri	2.05	0.99	3.09	0.27	3.59	9.99
Frsy	0.08	0.03	0.28	0	0.07	0.46
Fish	0.1	0.05	0.41	0	0.23	0.79
Food	1.75	1.78	7.14	0.03	3.73	14.43
Texl	23.04	33.33	30.29	0.42	24	111.08
Manu	115.83	178.24	105.16	2.01	78.39	479.63
PaP	0.11	0.26	0.13	0	0.13	0.63
P_C	0.14	0.08	0.84	0.31	1.41	2.78
Chem	-17.07	-20.08	-16.24	-1.69	-22.25	-77.33
Metl	-10.77	-16.46	-11.66	-0.55	-12.79	-52.23
Cont	0.71	0.11	0.38	0	0.15	1.35
Trad	36.19	21.63	18.31	1.42	17.33	94.88
Tran	17.15	7.95	4.23	0.3	5.12	34.75
Serv	21.67	9.53	7.66	0.63	9.07	48.56
Omin	0.22	0.19	0.32	0.11	0.31	1.15
Wter	-0.43	-0.2	-0.16	-0.01	-0.15	-0.95
Col	7.8	0.4	62.15	3.7	65.96	140.01
Oil	3.41	5.31	18.49	1.12	7.23	35.56
Gas	3.3	0.78	11.74	0.01	3.7	19.53
Ely	-5.79	-0.78	-1.3	-0.23	-4.84	-12.94

Table 8-10 changes of China's commercial export under measure scenario 1 (million dollar)

	EU	US	Other developed countries	India	Other developing countries	Total
Agri	0.37	0.18	0.57	0.05	0.67	1.84
Frsy	0.02	0.01	0.08	0	0.02	0.13
Fish	0.02	0.01	0.1	0	0.06	0.19
Food	0.34	0.35	1.4	0.01	0.76	2.86
Texl	2.6	3.85	3.53	0.05	2.83	12.86
Manu	21.07	32.66	19.35	0.37	14.51	87.96
PaP	-0.02	-0.04	-0.02	0	-0.02	-0.1
P_C	0.02	0.01	0.1	0.04	0.18	0.35
Chem	-3.41	-4.03	-3.25	-0.33	-4.41	-15.43
Metl	-0.86	-1.42	-1.07	-0.05	-1.22	-4.62
Cont	0.15	0.02	0.08	0	0.03	0.28
Trad	6.69	3.99	3.42	0.27	3.28	17.65
Tran	3.23	1.48	0.8	0.06	0.99	6.56
Serv	3.2	1.41	1.16	0.1	1.4	7.27
Omin	0.04	0.03	0.06	0.02	0.06	0.21
Wter	-0.12	-0.05	-0.04	0	-0.04	-0.25
Col	5.97	0.31	47.82	2.84	50.81	107.75
Oil	0.15	0.23	0.85	0.05	0.33	1.61
Gas	0.92	0.22	3.27	0	1.03	5.44
Ely	-1.58	-0.21	-0.36	-0.06	-1.33	-3.54

Table 8-11 changes of China's commercial export under measure scenario 2 (million dollar)

	EU	US	Other developed countries	India	Other developing countries	Total
Agri	0.8	0.39	1.21	0.11	1.43	3.94
Frsy	0.05	0.02	0.16	0	0.04	0.27
Fish	0.05	0.03	0.2	0	0.12	0.4
Food	0.7	0.71	2.88	0.01	1.55	5.85
Texl	5.51	8.16	7.45	0.11	5.98	27.21
Manu	41.95	65.1	38.52	0.74	28.89	175.2
PaP	-0.04	-0.07	-0.03	0	-0.03	-0.17
P_C	0.03	0.02	0.21	0.08	0.36	0.7
Chem	-6.89	-8.14	-6.57	-0.67	-8.92	-31.19
Metl	-1.98	-3.21	-2.38	-0.12	-2.7	-10.39
Cont	0.3	0.05	0.17	0	0.07	0.59
Trad	13.42	8	6.85	0.54	6.56	35.37
Tran	6.46	2.96	1.6	0.12	1.98	13.12
Serv	6.51	2.87	2.35	0.2	2.84	14.77
Omin	0.08	0.07	0.11	0.04	0.11	0.41
Wter	-0.24	-0.11	-0.09	0	-0.08	-0.52
Col	11.78	0.6	94.03	5.58	99.58	211.57
Oil	0.33	0.51	1.84	0.11	0.72	3.51
Gas	1.72	0.41	6.13	0	1.93	10.19
Ely	-3.04	-0.41	-0.68	-0.12	-2.54	-6.79

China's commercial exports under baseline scenario without any mitigation policy simulated in GTAP-E model are shown in Fig 8-13, which implies that manufacturing and textile are major export industries, followed by chemical industry, metal and metallurgy, trade, and services. We also can see that they are big electricity consuming sectors (Fig 8-8), so they will get more impacts under mitigation scenarios.

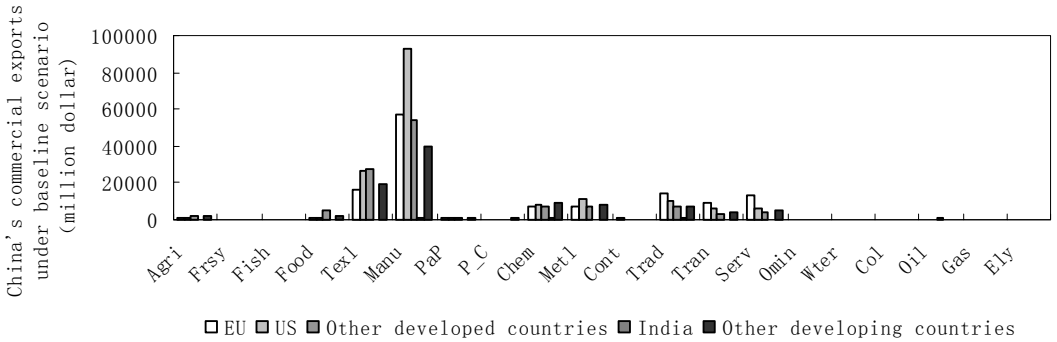


Fig 8-13 China's commercial exports under baseline scenario

The following figures take textile, manufacturing, coal, chemical industry and metal and metallurgy for examples. Research on industrial exports under electricity sectoral mitigation policy is carried on.

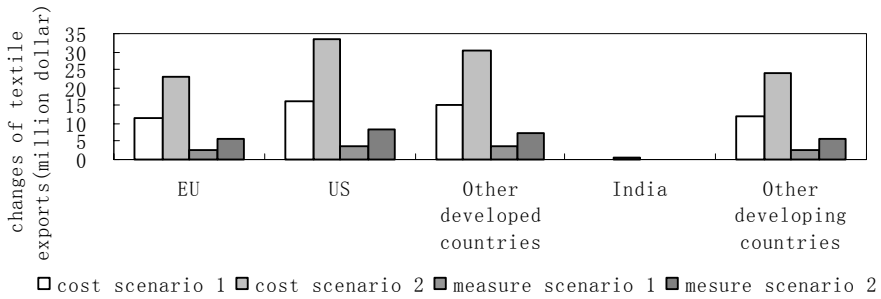


Fig 8-14 Changes of China's textile export under different scenarios

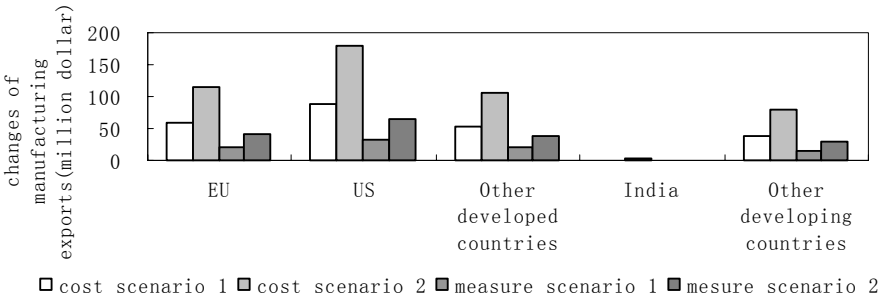


Fig 8-15 Changes of China's manufacturing export under different scenarios

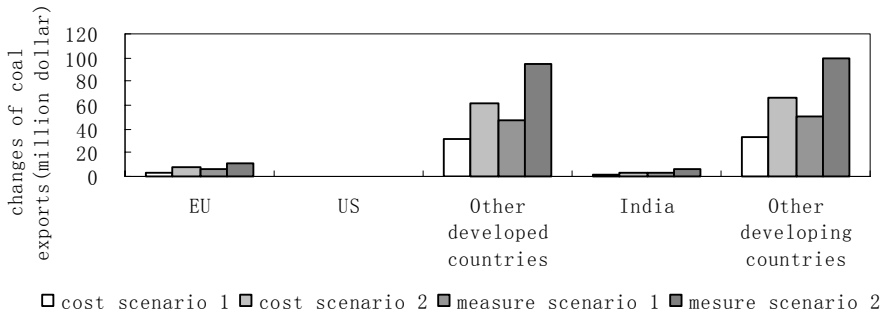


Fig 8-16 Changes of China's coal export under different scenarios

Exports from China's textile, manufacturing, coal industry to other countries and territories increase. Incremental exports from textile and manufacturing mainly focus on developed countries, and incremental exports from coal mainly focus on areas except EU and US.

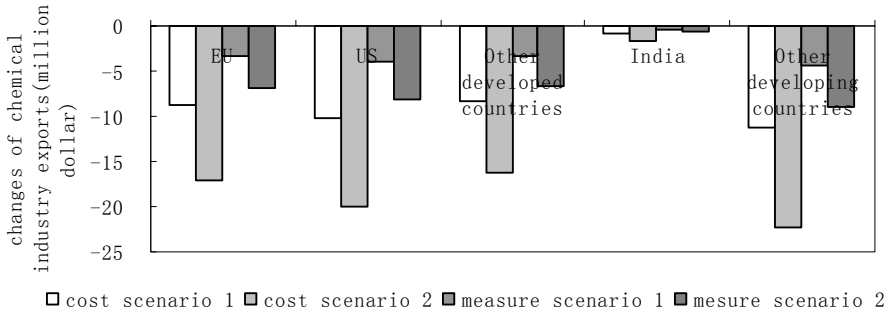


Fig 8-17 Changes of China's chemical industry export under different scenarios

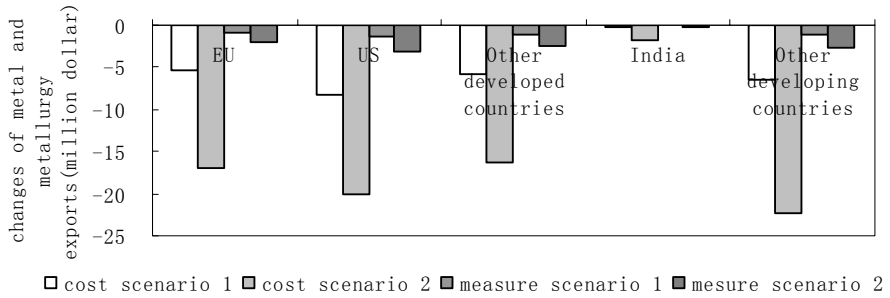
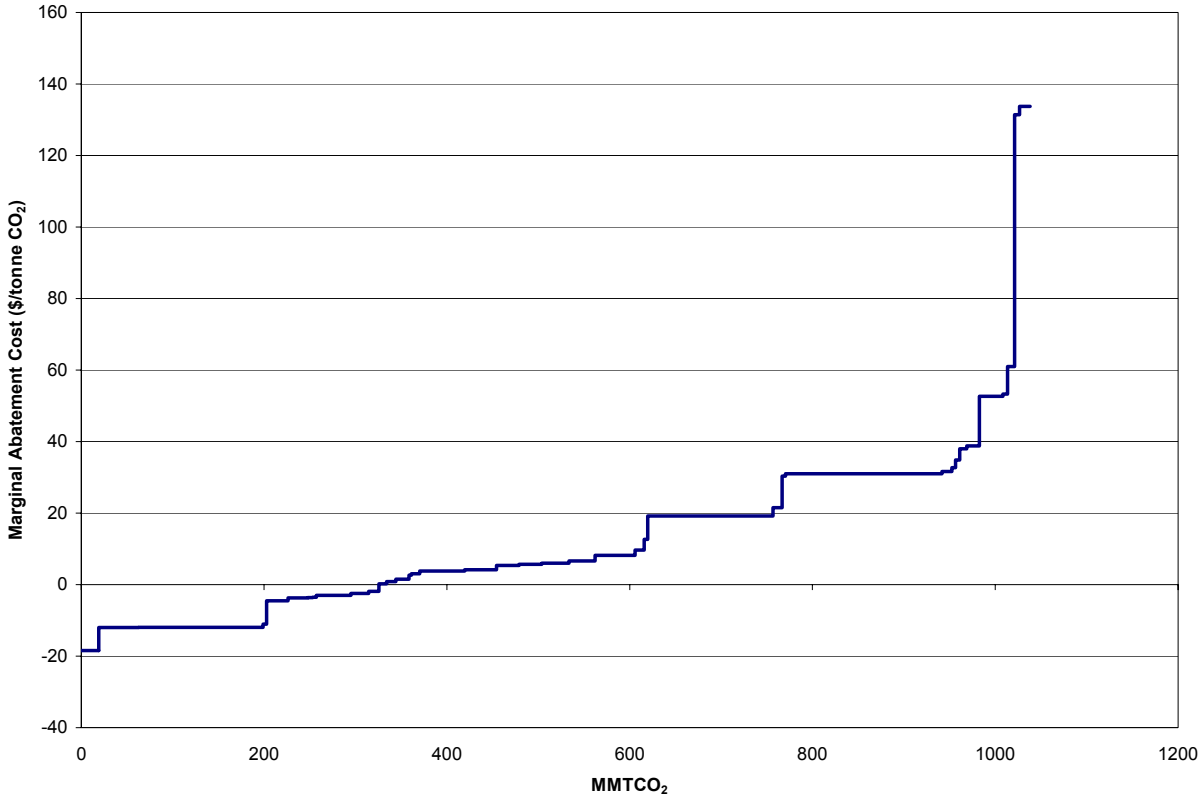


Fig 8-18 Changes of China's metal and metallurgy export under different scenarios

Correspondingly, exports from chemical, metal and metallurgy fall, mainly because of a decrease in imports in other countries except India.

From the above comparison, we can see cost scenarios have greater impacts on exports from textile, manufacturing, chemical industry, metal and metallurgy than measure scenarios. But the impacts on coal industry are the opposite. To understand this we can go back to the previous discussion on changes of industrial productions' price and outputs. Coal price rises more in measure scenarios than that in cost scenarios, so outputs of coal decrease more obviously in measure scenarios, and induce more decline on exports.

Appendix I: Integrated Marginal Abatement Cost (MAC) Curve for 2020



Marginal Abatement Costs and Annual Reductions by Measure for 2020

Marginal Abatement Cost ($/tonne CO_2e)	Total Emission Reduction ($MMTCO_2e$)	Cumulative Reduction ($MMTCO_2e$)	Mitigation Options	Sector
-18.4	19.1	19.1	Transmission Technologies	Transportation
-12.0	43.8	62.9	Vehicle Technologies	Transportation
-11.9	136.0	198.9	Engine Technologies	Transportation
-11.1	3.8	202.7	Engine-Transmission-Vehicle Technologies	Transportation
-4.5	23.5	226.2	Preventative Maintenance	Cement
-3.8	21.5	247.7	Use of Waste Derived Fuels	Cement
-3.6	5.7	253.4	CFBC (Circulating Fluidized Bed Combustion)	Electricity
-3.6	3.6	257.0	Establish energy management center	Iron and Steel
-3.0	38.0	295.0	Demand side management	Electricity
-2.4	19.5	314.5	Process management and Control	Cement
-1.9	11.3	325.8	Kiln Shell Heat Loss Reduction	Cement
0.2	8.2	334.0	High-Efficiency Motors and Drives	Cement
0.9	10.2	344.2	Active Additives	Cement
1.5	14.3	358.5	Composite Cement	Cement
2.6	2.8	361.3	BRT	Transportation
3.0	9.1	370.4	Advanced coke oven	Iron and Steel
3.8	49.1	419.5	Conversion to Multi-stage pre-heater kiln	Cement
4.1	34.8	454.3	Combustion System Improvement	Cement
5.4	24.6	478.9	Advanced blast furnace technology	Iron and Steel
5.7	25.1	504.0	Reconstruction of conventional thermal power	Electricity
6.0	29.7	533.7	Supercritical/Ultra supercritical plant	Electricity
6.6	28.6	562.3	High-efficiency roller mills	Cement
8.2	43.6	605.9	Adjust ratio of iron/steel	Iron and Steel
9.7	10.2	616.1	High-efficiency Powder Classifiers	Cement
12.7	3.7	619.7	Efficient transport systems	Cement
19.2	136.9	756.6	Nuclear power	Electricity
21.5	10.3	766.9	Fuel Switch	Transportation
30.4	3.5	770.5	Dry coke quenching	Iron and Steel
31.0	171.2	941.7	Hydropower	Electricity
31.6	10.8	952.4	Advanced sinter machine	Iron and Steel
32.7	4.2	956.6	Natural gas	Electricity
34.9	4.4	961.1	Advanced direct steel rolling machine	Iron and Steel
38.0	7.6	968.7	Wind power	Electricity
38.8	14.1	982.8	IGCC (Integrated Gasification Combined-Cycle) & PFBC (Pressurized Fluidized Bed Combustion)	Electricity
52.7	25.6	1008.4	Smelt reduction technology	Iron and Steel
53.3	5.0	1013.4	CCS (Carbon Capture and Storage)	Electricity
61.0	7.6	1021.0	Advanced converter	Iron and Steel
131.4	5.7	1026.7	Advanced EAF	Iron and Steel
133.7	11.4	1038.1	Solar thermal	Electricity

Appendix II: Oil Price Assumptions

Since the market for oil is an international market, it was decided that a single global forecast of future oil prices would be used in all sectors in all three countries. Two forecasts were considered, both from the US Energy Information Administration: the *Annual Energy Outlook 2005* (AEO 2005), and the *International Energy Outlook 2004* (IEO). The AEO 2005 is a projection of domestic energy supply and demand in the United States, but also includes a projection of world oil prices. The available AEO edition was more recent than the IEO, so it was decided to use the AEO 2005 prices.[46] The AEO 2005 includes a reference case forecast and several sensitivity scenarios; the reference case oil prices were used for the analysis. These oil prices are shown below:

Annual World Oil Price Assumptions

Year	Reference Case Price (2003 $ per barrel)
1996	23.25
1997	20.48
1998	13.2
1999	18.55
2000	29.2
2001	22.64
2002	24.1
2003	27.73
2004	35
2005	33.99
2006	30
2007	27.35
2008	26.15
2009	25.3
2010	25
2011	25.35
2012	25.69
2013	26.04
2014	26.39
2015	26.75
2016	27.1
2017	27.45
2018	27.79
2019	28.14
2020	28.5
2021	28.86
2022	29.22
2023	29.58
2024	29.94
2025	30.31

[46] At the time the analysis was conducted, oil price projections incorporating the recent increase in oil prices were not available. CCAP and the China team therefore conducted an alternative sensitivity scenario using higher oil prices from a recent projection to provide comparison. The results of this analysis can be seen in Chapter VII.

Appendix III: Workshop Summary and Participants, March 2006

Agenda

Time Slot	Speaker/Topics
9:55-10:00	Presenter: Mr. Xuedu LU **Welcome**
10:00-10:20	Presenter: Mr. Jake Schmidt, CCAP **Project Introduction**
10:20-10:40	Presenter: Mr. Can Wang, Tsinghua **Analysis of CO2 Emission Scenario and Mitigation Technology in China's Different Sectors: Background and Summary**
10:40-11:10	Presenter: Mr. Ke Wang, Tsinghua **Analysis of CO2 Emission Scenario and Mitigation Technology in China's Iron and Steel Sector**
11:10-12:00	**Comment and Discussion**
13:30-14:00	Presenter: Ms. Ying Zhang, Tsinghua **Analysis of CO2 Emission Scenario and Mitigation Technology in China's Electricity Sector**
14:00-14:40	**Comment and Discussion**
14:40-15:10	Presenter: Ms. Wenjia Cai, Tsinghua **Analysis of CO2 Emission Scenario and Mitigation Technology in China's Transport Sector**
15:10-15:50	**Comment and Discussion**
16:10-16:30	Presenter: Mr. Bin Du, Tsinghua **Technology Analysis of Industrial Water Saving and Energy Saving in China**
16:30-17:00	Presenter: Mr. Can Wang, Tsinghua **Macroeconomic Analysis of Emission Reduction in China's Different Sector and Main Results of the Project**
17:00-17:30	**Discussion**

Background and Rationale

This workshop was organized by Tsinghua University. The purpose of this workshop was to give report on the interim sector analysis results and to receive comments and suggestions from experts and governors in China.

The entire world is facing more and more serious climate change damages, which are believed to be caused by human beings using huge amount of fossil fuels and emitting vast greenhouse gases. This project, *Assisting Developing Country Climate Negotiators through Analysis and Dialogue*, intends to work with leading in-country partner organizations to analyze greenhouse gas mitigation options in four key developing countries – Brazil, China, India and Mexico. The project team will conduct in-dept micro- and macroeconomic analyses of greenhouse gas mitigation options and costs, develop a suite of potential domestic policies for the most promising options, and assess the implications of post-2012 international climate policies in these key "case study" countries.

In this workshop, project team members from Tsinghua University introduced their interim analysis results in iron/steel, electricity and transportation sector. Contents mainly include two parts: the greenhouse gas emission forecasts for those sectors through 2020, and, the emission reduction cost curves for mitigation options/technologies in each sector. Building on this bottom-up quantitative analysis,

CCAP and Tsinghua will then conduct preliminary assessments of a set of promising policies for implementation of mitigation options in selected sectors, develop preliminary evaluations of potential co-benefits in environmental, health and other areas, and analyze the macro-economic implications of the policies. The policy analysis will include both domestic options and international strategies.

Summary of Presentations and Comments

By Wenjia CAI from Tsinghua University

Mr. Xuedu LU opened the workshop, followed by **Mr. Jake Schmidt** giving a brief introduction to this project and the role of CCAP in it. Next, **Mr. Can Wang** presented the background, framework, model, scenarios of the project in China and gave out some preliminary result from sector analysis. Wang mentioned energy and environment models were added into the original GTAP model to help analyze the environmental policies in developing countries.

The first sector analysis report was given by **Mr. Ke Wang,** about the analysis of CO2 emission scenario and mitigation technology in China's Iron/Steel sector. According to his presentation, China ranks the highest in iron/steel production in the world ever since 1996. Energy intensity per ton steel production is very high in China, about 1.5 times as in Japan. Main reasons of higher energy intensity are characteristics of production process, small proportion of advanced equipment and inefficient management. Forecast for iron/steel production has been updated lately, while the whole production through 2020 can still be divided into three parts: fast increasing before 2010, slowly increasing after 2010, and a constant phase through 2020. Three scenarios had been developed to analyze the potential emission and the mitigation technology. In scenario 3, the most environmental-friendly scenario, the emission reduction potential is promising; however, it is costly at the same time. We need a lot of money to implement.

Ms. Chunxia Zhang and **Mr. Dao Huang** made comments to Wang's presentation. Comments include: 1) the trend of production should be affirmed, but some problems seemed to be with the calculation and the energy structure; 2) it is difficult to estimate the GDP and I&S production as the many uncertain factors in China so more flexible changes are needed; 3) adjustments to the mitigation options are needed, such as, adjusting iron and steel ratio option needs more discussion and proportion of emissions is too high to reach; there will be a very small potential for option "increasing coal power injection level" to develop; EAF is difficult to utilize in China given the shortage of waste steel; increased used of coke oven is useful, but not a priority; utilization of excess heat should be added as an option; 4) interactive effects between sectors are important and needed. More free comments were made concerning to the production trend, the mitigation option and the need to address ways of problem solving in high cost scenario.

The second sector analysis report was given by **Ms. Ying Zhang**, about the analysis of CO2 emission scenario and mitigation technology in China's electricity sector. According to her presentation, coal fire plants produced 81% of total electricity in China while hydro power plants took up 18% and nuclear power plants 1.2%. After the completion of three Gorges dam in 2009, the dam will be the largest hydro power plant in the world. An important regulation published by government in 1997 said that any plant below 25 MW cannot be produced. But small scale generators have continued to be build, in remote areas and small cities. Three scenarios had been developed to analyze the potential emission and the mitigation options. CCS potential is uncertain. Major contributors to emission reductions go to hydro power plants, CCS and nuclear plants. She also made conclusions that 1) CO2 emission will be very high over time; 2) in short term, it is very important to increase government management and increase publicity about this, while in long term, emission reduction will depend more on CCS, hydro power and new technologies.

Mr. Xuedu LU commented that some of the objectives in electricity sector are too ambitious. **Mr. Yong Zhao** affirmed with the general conclusion, but suggested verification on some figures due to the drastic capacity expansion and the systemic change, esp. the division of national electricity corporation. Zhao also predicted that the decreasing trend of electricity consumption by secondary industry as well as the coal intensity. Another comment is from a representative from **NDRC** who stated her preference to the methodology and trends rather than the concrete data. She also suggested that capital guarantees should be considered when making scenarios, which was why she thought scenario 2 and 3 were very hard to implement. Ms. Chen from **WWF** and **Mr. Xuedu LU** suggested not to be too optimistic about CCS, which is time- and money-consuming.

The third sector analysis report was given by **Ms. Wenjia Cai**, about the analysis of CO2 emission scenario and mitigation technology in China's transport sector. According to her presentation, transport sector takes up 1/3 of total fuel in China and half of the transport fuel consumption is from passenger vehicles. Three scenarios had been developed to analyze the potential emission and the mitigation options. Transport sector would have a very large emission reduction potential due to the implementation of vehicle technologies, BRT and fuel substitution (mainly petrol and diesel to LPG and CNG). It was concluded that 1) vehicle technologies are most effective for emission reduction; however, more work has to be done with the cost information; 2) BRT is a comparatively low investment and can be developed in short term; 3) national communications and government participation are needed to help implement those mitigation options.

Mr. Hezhong Tian, **Mr. Haiyang Gao** and **Mr. Xuedu LU** made comments to this presentation. They agreed on the situation of fuel consumption in road transport sector and the projection on vehicle population. Other comments include: 1) maybe China needs a leap-frog in developing vehicle technologies; 2) the passenger mileage and fuel economy data need to be updated; 3) more thoughts should be given to the increase usage of diesel vehicles because some of diesel emissions are carcinogenic; 4) BRT may not be applicable in all parts of the country; 5) fuel substitution from petrol and diesel to LPG and CNG is not sustainable, so it could not solve the problem; 6) cost information should be polished to be more persuasive; 7) more things need to considered, such as biodiesel, hybrid electric vehicles, road condition and urban developing, people's driving habits.

Mr. Bin DU made a presentation in Technology Analysis of Industrial Water Saving and Energy Saving in China, which was a brief introduction of his PhD dissertation. It also utilized the scenario analysis method.

Finally, **Mr. Can Wang** made a conclusion presentation on the main results of all sectors in China. It used GTAP-E model as an analysis tool, which analyzed the effects given by emission reduction to GDP, import and export, trade and employment. He also made a sum-up about the emission reduction in each sector and identified the key mitigation options and the corresponding cost. After analyzing the barriers to achieve emission reduction, he also gave out the suggestions for further research.

Mr. Wen Gang suggested that we should be more flexible about phase II, either expand or narrow scope. Other comments include: 1) there are two costs when looking at international negotiations; one is the country's ability to pay, and the other is the incremental cost; 2) more channels should be explored to get capital; 3) we need more different methodologies to reach a more appropriate estimation of energy consumption and energy saving.

Participant List

Name	Organization
From Government	
Mr. Guangsheng Gao	NDRC (National Development and Reform Commission)
Ms. Cuihua Sun	NDRC
Mr. Xuedu Lu	MOST (Ministry of Science and Technology)
Mr. Ping Fu	MOST
Mr. Gao Li	Administrative Center for China Agenda 21, MOST
Mr. Wei Su	MOFA (Ministry of Foreign Affairs)
Ms. Qingchen Chao	CMA (China Meteorological Administration)
Ms. Mengheng Zhang	SEPA (State Environmental Protection Administration of China)
From CCAP	
Mr. Jake Schmidt	CCAP
Mr. Matthew Ogonowski	CCAP
From NGOs	
Mr. Yingnan Liang	CAST (China Association of Science and Technology)
Ms. Dongmei Chen	WWF
Ms. Liming Qiao	WWF
Dr. Gang Wen	GEF-China
From Industry	
Dr. Yong Zhao	China Huaneng Group, Technical and Economics Research Institute
Ms. Chunxia Zhang	Central Iron & Steel Research Institute
Mr. Dao Huang	China Iron & Steel Association
Dr. Haiyang Gao	China Automative Technology & Research Center
From Academy	
Dr. Can Wang	Tsinghua University
Dr. Bin Du	Tsinghua University
Mr. Ke Wang	Tsinghua University
Ms. Wenjia Cai	Tsinghua University
Ms. Ying Zhang	Tsinghua University
Ms. Di Wang	Tsinghua University
Mr. Martin Resnier	Tsinghua University
Ms. Ronghua Bao	Tsinghua University
Dr. Hezhong Tian	Beijing Normal University
Translator	
Ms. Yuan Li	Beijing Foreign Studies University

Appendix IV: Phase II

I. Policy Analysis for Phase II

In Phase II, the team will conduct an-depth analysis of policies that could be used to implement key mitigation options in China. Potential implementation policies are discussed below for the following measures:

- Electricity: Energy efficiency improvement, Integrated gasification combined cycle (IGCC) plants, Renewable energy utilization; etc.
- Iron and Steel: Energy management systems, Advanced production technologies; etc.
- Transportation: Vehicle efficiency improvements, Bus rapid transit (BRT); etc.

I.A. Legal and regulatory framework for environmental policy relevant to each technical mitigation option

In China, the framework for environmental policies relevant to energy conservation and technical mitigation can be classified into three levels in terms of their scope. The highest level provides general direction and guidance. The second are those that specify the objectives and development plans. The third level consists of practical and specific incentives and managerial guidelines. In general, the first two classes are made by central government and its relevant ministries, while the third one is decided by local governments, including the provincial and municipal governments as well as county governments. Basically, policies set by local governments play more direct and practical roles.

At the beginning stage after China's establishment, environmental protection was more or less a by-product of the predominant policies for combating hunger and illness. But in 1978, environmental protection became part of the constitution of China and a year later the national environment law was enacted. The policy of government is clearly directed towards a greater emphasis on energy and environment under the framework of the National Sixth, Seventh, Eighth, Ninth, and Tenth Five-Year Plan. At the very beginning of the 1980s the central government announced that it would lay equal emphasis on development of energy suppliers and energy conservation, with the latter assuming a higher priority in the short term. Conservation policy has concurrently been refined and formalized, and the setting of energy conservation policy has gradually been coordinated with that in other areas, such as materials consumption efficiency and environmental protection. In the 1990s, some specific steps were introduced to implement the agreed environmental goals. The most current key national environment and energy policies which relate to the technical mitigation options we discussed here are: China's Agenda 21, Energy Conservation Law, 11th Five-Year Plan and Clean Product Promotion Law. For example, China determined to reduce energy consumption per unit of GDP by 20 percent and the total volume of major pollutant discharges by 10 percent between 2006 and 2010, according to the 11th Five-Year (2006-2010) Plan. It is the first time that China combines energy-efficiency with the indexes of economic growth, price, employment and balance of payments for macro-control of its economy. The China Renewable Energy Law was issued in 2005 and took into effect on January 1st of 2006. One of the primary aims of the newly established law is to promote the renewable energy reach 15% share in the energy structure in China up to 2020.

Since entering 21st century, China has looked to rely more on both market mechanisms and mandate regulation for energy efficiency improvement. The relevant policies recently set up include:

- Clean Production Promotion Law affected on January 1st 2003.
- Environmental Impact Assessment Law affected on September 1st 2003, which prohibits low energy efficiency or backward technologies in proposed construction projects.

- Updated equipment (design) energy efficiency standards, the scope of which was enlarged to cover more industrial equipment such as boilers, motors, fans, pumps and transformers.
- Pilot energy efficiency voluntary agreement for steel industry.
- Goal of decreasing energy intensity per unity GDP for 11th five-year plan period.
- China medium and long term energy conservation plan.
- Support the R&D activities on key energy efficient technologies.
- TOU (time of use) tariff and two-part tariff are used for industrial enterprises.

To achieve the goal of decreasing energy intensity by 20% in the 11th five-year plan period, multiple discussions on ensuring policies and measures have been conducted. In the industrial sector, the following measures will possibly be adopted in the near future:

- To establish a China top-1000 energy-intensive enterprises management system to monitor and cut their energy consumption;
- To enlarge energy efficiency voluntary agreement activity in the top-1000 energy-intensive enterprises based on the pilot project led in the steel industry;
- To have a preliminary idea on introducing an energy tax. But there are many uncertainties to implement it.
- To revise the Energy Conservation Law for better implementation under market conditions.

A systematic and comprehensive review of the existing legal and regulatory framework for environmental policy will be needed for each technical mitigation option that will be further analyzed in Phase II. The policy should be identified based on both the overview of the existing framework and the suggestions of the potential policies in the next sub-section.

I.B. Detailed description of the policy or policies analyzed for each individual option

Potential policies to be analyzed for Phase II for each technical mitigation option summarized above are as follows respectively:

- For energy efficiency improvement in electricity:
    - energy intensity targets set by the central government and local governments or set by specific industrial regulator;
    - capacity building efforts to increase public awareness of the advantages of energy efficiency improvements;
    - fuel pricing or fuel taxes to promote energy conservation, etc.
- For penetration of integrated gasification combined cycle (IGCC) plants:
    - subsidies or tax breaks for research and development of CCS technology
    - technology transfer from and/or technology cooperation with developed countries
- For renewable energy utilization:
    - expanded RES goal or mandate with an increase in either the total renewable share or specific share requirements for particular plant types;
    - direct incentives such as a production tax credit, price and capital investment subsidies, and tax breaks for new units;
    - fuel taxes.
- For energy management systems in iron and steel:
    - government-run voluntary assistance program, in which energy officials would work with interested plant managers to provide information and training to encourage development of such systems.
- For installation of advanced production technologies in iron and steel:

    - direct incentives for new capital investments, also for research and development of new technologies.
    - CDM
    - technology transfer from and/or technology cooperation with developed countries
- For vehicle efficiency improvements:
    - fuel pricing and fuel taxes
    - financial incentives or tax breaks
    - stricter emissions standards for criteria pollutants
    - government-run voluntary assistance program (VAP) to provide information and training to production companies, maintenance companies or individuals
    - direct subsidy (SUB) from government on investment, R&D
    - technology transfer from and/or technology cooperation with developed countries
- For bus rapid transit (BRT):
    - public sector financing and/or support from international financial institutions
    - urban planning

I.B.i Key barriers to implementation

Although China has a series of policies for environment and energy, especially regarding energy-intensive industrial sectors, most policies are shortage of implementing arrangement. Even some policies addressing very specific problems, e.g. listing encouraged and/or prohibited technologies in some industrial sectors, they are guidelines or directions rather then measures.

The goals of most existing policies are expressed in qualitative rather than quantitative terms. The costs, savings, expected efficiency gains and CO2 emissions implied by the policies are usually ambiguous. Furthermore, there are few monitoring and review mechanisms for any policy. Financial support to energy efficiency improvement is usually part of many policies, but the specific policy seldom makes sure the scale of financial support. Policy itself and the supportive funding are always separated. These institutional barriers to large extend affect the effectiveness and efficiency of the existing policies in environment and energy issue.

One of the key barriers to implement advanced technologies are various kinds of costs. High technology barriers have made it extremely hard to utilize certain kind of environmental-friendly technology to a large extent. Besides, it is also astonishing to face the expenses to construct suited factories and product lines, to train necessary labors and technicians, to maintain the right working order and to manage and operate.

Even in the case of large scale equipment and advanced technology being adopted, the performance is not as good as it could be. This is a phenomena recognized by most industrial experts in China. The low management level and shortage of well trained staff in lots of such plants are critical causes of this conflict.

Specifically, the key barrier to BRT in China is the current laggard public transport system. Although China has advocated for public transport for a long time, there has not been a very clear management system that prefers and promotes public transport. Public transport is characterized by low efficiency, congestion, and poor services. Moreover, the land planning in China is not so satisfying that creates a virtual barrier for BRT's quick expansion.

The key barrier for fuel switch in China is cost. Although LPG and CNG have lower sales price than gasoline and diesel, the comparatively weak network of gas station makes it inconvenient to refill LPG and CNG. Most drivers have not felt the obvious advantage of switching to these environmental-friendly

fuels. Besides, the higher maintenance fee for LPG and CNG engines has also withdrawn some people's willingness for fuel switch.

I.C. Key actors and players associated with policy implementation

On national level, the key actors and players associated with implementation of above mentioned policies include the following authorities and their local branches:

- the National Development and Reform Commission (NDRC)
- the Ministry of Science and Technology (MOST)
- the State Environmental Protection Administration (SEPA)
- the national association of relevant industries (e.g. the national steel association), etc.

I.C.i. Potential funding methods/programs for implementing the necessary measures i

Potential methods to help implement those mitigation options include capacity building, such as setting up the right political environment or market and training the right people, to meet the requirements of those mitigation options. The Chinese government can also use direct regulation methods, to influence the technology development trend and the transport market. More importantly, international financial and technical aids such as loans, technology transfer and joint collaboration would help China overcome financial and technical barriers in an effective and efficient way.

I.C.ii. Recommendations

To promote the technical mitigation options to be implemented in China, policy design and even pilot demonstration will be needed. Since China has no specific policy on CO2 emission control while setting ambitious goals to improve energy efficiency and diversify energy supply, it is practicable and acceptable to help design policy with effect on promoting CO2 mitigation by facilitate the implementation of energy efficiency measures. The targeted participants for the Phase II activities will thus be not only officials involved in the climate change negotiation but also those from relevant authorities in charge of environmental and energy policy issue. Based on the analysis of Phase I, some recommendations are given as following:

- The targeted technical mitigation options should be further screened out from the sectors of electricity, cement, steel, and/or transportation.
- The policies aiming to promote the identified technology should be selected through close discussion with both climate officials and industrial regulators, e.g., the Energy Bureau under NDRC, the Pollution Control Department under SEPA.
- Facilitate the dialogue and collaboration between climate change official and industrial/energy regulator through the Phase II activities will benefit the incorporation of climate policy into domestic development policy/plan in China.

Appendix V: Areas for Future Research in China

In this project, a detailed analysis of each sector was conducted given such considerations as data availability, applicability of individual mitigation options to specific national and local circumstances in China, and other issues. In the course of the analysis a number of sectors, mitigation options and areas were thus identified but not fully analyzed. Some of these areas could potentially yield promising opportunities for achieving additional mitigation opportunities, opportunities that could be assessed with further research. The key potential areas identified in the first phase of the project that might be considered for future research are detailed below.

- ***Oil refining***: This sector was not analyzed because the available baseline data is for chemicals and oil refining combined; separate data for the refining sector in China is not currently available.
- ***Electricity***: Transmission costs were not included in this analysis, because under the scope of the project the methodology used links costs with specific mitigation options, but not with electricity transmission and distribution. Cogeneration was not analyzed as a mitigation option because the share in the current electricity generation profile is very low, and its potential is projected to remain limited under different possible scenarios.
- ***Agriculture, residential, commercial:*** These sectors were not analyzed for the following reasons: 1) their respective shares in the national GHG emissions inventory are comparatively low and the mitigation potential is limited; 2) potential technical mitigation options in these sectors that would be appropriate in the Chinese context are currently quite uncertain; and 3) there is a lack of readily available and reliable data and research in these sectors. Further research to collect appropriate data and evaluate mitigation options in these sectors could therefore be useful in analyzing their potentials.
- ***Forestry***: This sector was not analyzed because the potential for afforestation and reforestation is minimal. According to China's Annual Environmental Conditions Report, deforestation has been quite minimal in the country in recent years. Illegal logging and activities likely to lead to deforestation were also prohibited under the Forest Law passed in 1998.
- ***Energy intensity target***: China's national energy intensity target under the Eleventh Five Year Plan was not included in the analysis of any of the sectors. To date there has been no specific implementation plan created to achieve the target, so the future development path is unclear. Recent media reports have also begun to doubt the feasibility and practicality of realizing the target before 2010.
- ***A2 and B2 scenarios***: For this project it was originally intended that all emission scenarios would be analyzed under two different baseline conditions based on the IPCC SRES scenarios, with one (B2) being more environmentally benign that the other (A2). Based on expert in-country judgment on likely future trends, however, it was decided that in China these two scenarios would in fact be very similar, so a separate analysis of the A2 and B2 scenarios was not conducted.

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