國立交通大學

經營管理研究所

博 士 論 文

No.117

中國大陸各區域之有效率的能源與廢棄物減量目標

Efficient Energy Savings and Waste Abatements for Regions in Mainland China

研 究 生：李曜純

指導教授：胡均立　教授

中 華 民 國 九十六 年 四月

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中文摘要

能源的改變與轉換使得任何事情都有可能發生。我們買能源、出售能源，吃能源、浪費能源、儲存能源，更為能源而戰。能源是經濟活動的動力，它包含所有經過轉換而被使用的自然資源。但是過度地使用能源將引起能源短缺、能源危機、能源價格上漲及環境污染等問題。這些環境污染更將透過食物鏈而間接危害所有生物的健康和生命。

中國大陸目前正從一個耗能、低效率且嚴重污染的經濟發展模式過渡成一個節能、高效率且少污染的經濟發展模式。在新燃料及替代能源具可行性及經濟性以前，為維持經濟發展的需要，節能與減廢便成為中國大陸在制定環境政策上的兩大主軸。

本研究主要在計算2000-2003年期間中國大陸27個地區其三種主要能源與三種主要工業廢棄物之有效率的減量。本研究以單一產出項(實質國內生產毛額) 與五個投入項 (勞動、實質資本存量、耗煤量、耗汽油量及耗電量) 透過資料包絡分析法計算出每年每個地區之每種能源的目標消耗量。相同的，本研究也以單一產出項 (實質國內生產

毛額) 與五個投入項 (勞動、實質資本存量、固體廢棄物產量、廢水量及廢氣量) 透過相同的方法計算出每年每個地區之每種廢棄物的目標廢棄量。

有別於傳統著重於效率的DEA模型，本研究的主要貢獻在於建立一個投入項的減量指標，透過目標消耗量 (廢棄量) 與實際消耗量 (實際廢棄量) 計算出每年每個地區在每一種能源 (廢棄物) 上之有效率的減量比率。本研究主要發現如下：1. 在2000-2003年間，東部地區每一年都最有效率於三種能源與三種廢棄物上。2. 上海與廣東皆處於生產的效率前緣並成為中國大陸所有地區的標竿。3. 陝西和甘肅擁有最高的三種能源減量比率與三種廢棄物減量比率，代表此兩者是全中國大陸最無效率的兩個地區。4. 在三種能源減量與三種廢棄物減量中，煤耗減量與固體廢棄物減量是中國大陸當前最緊急的任務。

關鍵詞：永續發展、空氣污染、資料包絡分析法、煤、汽油、電、固體廢棄物、廢水、廢氣

Efficient Energy Savings and Waste Abatements for Regions in Mainland China

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ABSTRACT

Energy changes and transformations make things happen. We buy energy, sell energy, eat energy, waste energy, talk a little about conserving energy, and fight over energy. Energy, a motive force of the economic activity, includes all natural resources that can be used after changing. However, overusing energy will cause the energy shortage, energy crisis, the price of energy going up, and environment pollution. In particular, environment pollution will endanger the organism's health and life through the food chain indirectly.

Mainland China is in a transition period from a highly energy-consuming, low-efficiency, and heavily polluting economic development pattern to an energy saving, high-efficiency, and less polluting economic development pattern. Before new and alternative fuels become available, improving energy saving and waste reducing are two necessities for mainland China to design national environmental policy while remaining its economic development possibilities.

This thesis's main contribution is to create an input abatement index which different from the traditional DEA model. This thesis computes the efficient abatements of three major types of energy and three major types of industrial waste for twenty-seven regions in mainland China during the period 2000-2003. The data envelopment analysis (DEA) with a single output (real GDP) and five inputs (labor, real capital stock, coal consumption, gasoline consumption, and electricity consumption) is used to compute the target energy inputs of each region for each year. Besides, a single output (real GDP) and five inputs (labor, real capital stock, solid wastes, waste water, and waste gas) is used to compute the target waste inputs of each region for each year by the same method.

The efficient abatements ratios of each region in each year then are obtained by comparing the target inputs to the actual inputs. Our major findings are as follows: 1. East area contains most of the efficient regions with respect to three major types of energy and three major types of waste in every year during the research period. 2. Shanghai and Guangdong are producing outputs efficiently with respect to the Chinese production frontier and to be the benchmark for regions in mainland China. 3. Shaanxi and Gansu have the high target abatements ratios of all energy and all waste, implying that the two regions are most inefficient in mainland China. 4. Comparing to the three major types of energy and three major types of waste, coal consumption saving and solid waste reduction is mainland China's most urgent task.

Keywords: sustainable development, air pollution abatement, data envelopment analysis, coal, gasoline, electricity, solid wastes, waste water, waste gas

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盼了整整六年，終於等到這光榮的一刻。回顧這六年來，交雜著無數次的歡笑與淚水，更曾因數度被退稿而感到深深的痛苦與無力。然而，正因為這一切是如此的得來不易，讓我倍加珍惜這甜美的果實。

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李曜純　謹致

中華民國 96 年 4 月 17 日

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List of Abbreviations

C	Central area
CO_2	C arbon dioxide
C_XH_Y	Hydrocarbon
CRS	Constant Returns to Scale
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
E	East Area
GDP	Gross domestic product
KWH	Kilowatt Hour
NO_2	Nitrogen Oxygen
O_3	Ozone
OTE	Overall Technical Efficiency
PTE	Pure Technical Efficiency
SE	Scale Efficiency
SO_2	Sulfur Dioxide
VRS	Variable Returns to Scale
W	West Area
RMB	Renminbi

Chapter 1 Introduction

1.1 Research motivation

Energy changes and transformations make things happen. We buy energy, sell energy, eat energy, waste energy, talk a little about conserving energy, and fight over energy. Energy, a motive force of the economic activity, includes all natural resources that can be used after changing. The International Energy Outlook (2002) predicts that world energy consumption will increase by 60 % from 1999 to 2020. Energy demand in developing Asia is projected to more than double between by 2020.

However, overusing energy will cause the energy shortage, energy crisis, the price of energy going up, and environment pollution. The production costs of energy rise, which raises manufacturing costs. For the consumer, the price of energy rises, leading to reduced consumer confidence and spending, higher transportation costs and general price rises. In particular, environment pollution will endanger the organism's health and life through the food chain indirectly. Therefore, energy saving has been a crucial issue for sustainable development. Before new and substitute fuels become available, energy saving is a must in order to make economic growth possible.

The causes of rapid Asian economic growth and its sustainability have generated considerable debates since the early 1990s (e.g., World Bank, 1993; Krugman, 1994; Kim and Lau, 1994, 1995; Young, 1994, 1995; Chen, 1997; Drysdale and Huang, 1997; Krüger et al., 2000; Chang and Luh, 2000). China, India, and other developing countries are considered the largest energy consumers that are also the largest emitters of greenhouse gases should be involved in the efforts to solve these global problems (Isakov, 2006).

China has abundant energy mine, the per capita usable volume of energy is relatively low. Kambara (1992) and Dorian (1994) showed that the aggregate demand for the energy increased correspondingly, but the aggregate supply of energy was relatively insufficient. The energy used inefficiency result from the uneven mineral distribution, unbalanced region development, and the infrastructure insufficient. In order to satisfy the economic sustainable development, social advancement, population growth, and energy demand increased, the energy supply must suffice the energy demand. Therefore, how to guarantee the steady energy sources form the energy topics in safe, diplomacy, and trade (U.S.-China Economic and Security Review Commission, 2004).

However, China's energy consumption accounts for approximately 58% of East Asia's (excluding Japan) total energy consumption. All forms of energy will increase, for energy demand and use will increase, as well as GDP. In fact, GDP will increase at 7% annually, a rate higher than the 4.7% per year increase of total energy consumption in China.

Of the 39.7 quadrillion Btu of total primary energy consumed in China in 2001, 63.4% was coal, 25.8% was oil, 6.9% hydroelectricity, and 3.1% natural gas (EIA, 2003). By 2020 projections indicate that China will be responsible for approximately 16.1% of world energy consumption. Therefore, the energy crisis becomes a great challenge of economic development of China. Energy efficiency improvement is the key to sustainable energy management. Hu and Kao (2007) use the DEA approach to construct environmental-energy efficiency indicators for APEC economies. Hu et al. (Forthcoming) find total-factor water efficiency of regions in China by the DEA. Hu and Wang (2006) also indicate that China can improve its energy efficiency in various regions without reducing its potential economic growth.

Besides, China is in a transition period from a highly energy-consuming, low-efficiency, and heavily polluting economic development pattern to an energy saving, high-efficiency, and less polluting economic development pattern (WSSD, China Country profile 2002). Solid wastes in China produced from industry and consumption amounted to 1,004 million tons and 148 million tons during 2003, respectively. Waste water discharged from industry and consumption totaled up to 21,200 million tons and 24,700 million tons, respectively. SO_2 emitted from industry and consumption was 17 million tons and 3.67 million tons, respectively (China Statistical Yearbook 2003). These numbers show that China has to deal with huge amounts of waste while pursuing its economic growth. It is now an urgent task for China to simultaneously deal with these pollution while keeping its high economic growth rates.

1.2 Research purpose

The main interest of this study is to address the issues related to the analysis of targets of energy saving and waste reducing and the potential application and strengths of DEA for regions in mainland China. Different from the traditional DEA model which emphasized efficiency, this thesis creates an input abatement index. It is main contribution of this thesis too. This study can provide additional suggestions for energy and environmental policies of mainland China.

The first purpose of this study is to calculate relative overall technical efficiency (OTE) for regions in mainland China from period 2000-2003 based on DEA model. Through the DEA model, efficient regions and inefficient regions are shown when considering inputs and outputs.

The second purpose is to analyze the target abatement of individual input. These inputs include three types of energy and three types of waste. Generally speaking, coal, oil, and electricity are the three main types of energy; and solid waste, waste water, and waste gas are the three major types of pollution as energy transformed. The difference between actual input and target input is the abatement target. Therefore, we can know the efficient abatement target of three types of energy and three types of waste for regions in mainland China.

The third purpose is to establish abatement ratio by comparing the target input to the actual input. The abatements ratios present the possible energy savings and waste abatements without reducing the maximum potential economic outputs. Moreover, this result provides some suggestions about the environmental improvement for regions in mainland China without reducing real economic growth.

Energy savings and waste abatements are influenced by industrialization and economic income level. Therefore, the fourth purpose concerns the relation between the average abatements ratios and three areas in mainland China. Three areas include east, central, and west. We can find which area is significant efficiency on which one input more than other areas.

The fifth purpose is to find the benchmark for regions in mainland China according above-mentioned methods. The regions with most abatements ratios can learn and transfer the experts and technologies from the benchmark regions to improve their efficiency on energy and waste.

This study use panel data approach to analyze the energy savings and waste abatements. The results will provide policy suggestions for regions in mainland China to evaluate and identify their policies and programs according their income level, and to improve their overall technical efficiency by adjusting their energy and waste.

1.3 Organization of the dissertation

This dissertation is organized as follows and shown as Figure 1: Chapter 1 presents the motives and purposes of the study, and introduces the structure of this study. Chapter 2 discusses the current energy and waste situations and prior literatures related this study. Chapter 3 proposes a research design that includes the explanation how to construct the abatements ratios based on DEA model. Abatements ratios include energy savings ratios and waste abatements ratios. Summary statistics of the empirical data also are shown in this chapter. Chapter 4 presents and discusses the empirical results. Finally, Chapter 5 concludes this dissertation.

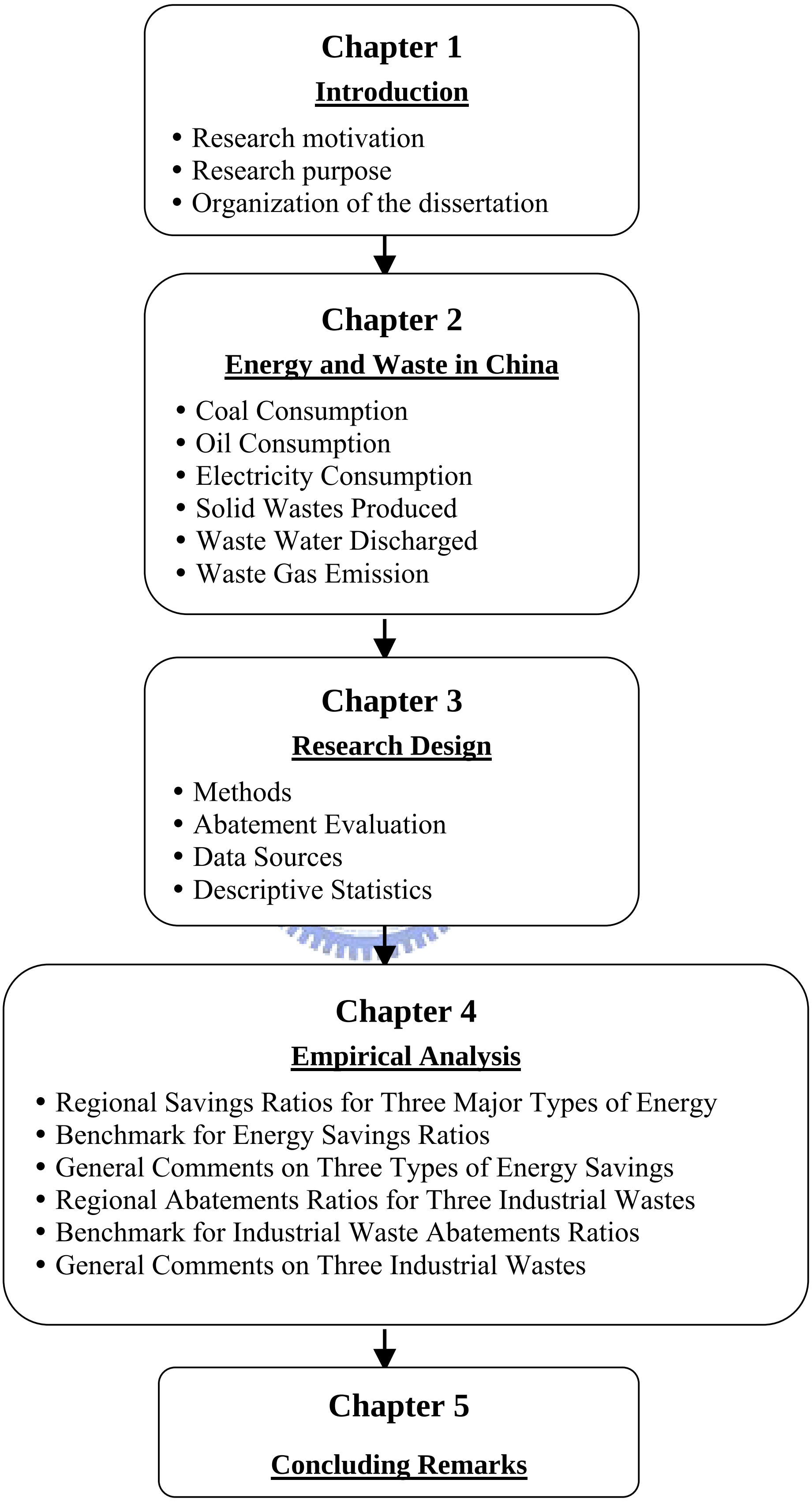

Figure 1 Research flow chart

Chapter 2 Energy and Waste in Mainland China

2.1 Three major Types of Energy

For people to live on our planet, we need energy. We need energy for heat, for light, and for transportation. When it's cold, we need energy for heat. When it's dark, we need energy for light. When we want to travel, we need energy for transportation. We need energy to run our factories and cars for example. Therefore, this part presents the three main types of energy: coal, oil, and electricity.

2.1.1 Coal Consumption

Coal use steadily increased in China until 1995, then declined for a few years and now continues to rise. Coal consumption in China makes up 70% of energy use and is the biggest consumer and producer of coal in the world. The development and production of the coal industry provides stability in China's economic growth. Since 1949, China has suffered mostly from a shortage of coal. China's coal consumption in 2003 was 1.64 billion tons, but total coal available for consumption was 1.58 billion tons. A shortage of coal has limited the growth of the steel industry in China. Therefore, China's coal import is up to 11.09 million tons in 2003. Table 1 shows the coal consumption by sector, and industry is the biggest department of coal consumption.

However, major pollutants generated from coal burning are carbon dioxide and sulfur dioxide. These pollutants cause acid rain and global warming, and health deterioration in China's population. China's coal use discharges 19 million tones of sulphur dioxide into the atmosphere annually and affects 30 percent of the economy's territory with acid rain. China is not the only country suffering from acid rain problems. Other Asian countries, such as Japan, Taiwan, S. Korea, and the Philippines have all reported acid rain problems originating from China's coal burning pollution.

Table 1 Coal consumption by sector unit: 10,000tons

Consumption by Sector	1995	%	2000	%	2002	%	2003	%
1.Farming, Forestry, Animal Husbandry, Fishery and Water Conservancy	1856	1.35	1647	1.32	1622	1.19	1683	1.03
2.Industry	117570	85.40	111730	89.72	124195	90.92	150568	91.96
3.Construction	439	0.32	536	0.43	553	0.41	577	0.35
4.Transport, Storage and Post	1315	0.96	1139	0.92	1055	0.77	1067	0.65
5.Wholesale, Retail Trade and Hotel, Restaurants	977	0.71	814	0.65	809	0.59	860	0.53
6.Others	1986	1.44	761	0.61	767	0.56	800	0.49
7.Residential Consumption	13530	9.83	7907	6.35	7602	5.57	8174	4.99
Total Coal Consumption	**137676**		**124537**		**136605**		**163732**	

Data source: China Statistical Yearbook 2005.

In summary, coal burning in China is having a significant impact on the physical environment, as well as the population in China, and the overall world atmosphere. Due to the rapid increase of health problems, government actions are being taken to reduce the burning of coal and move toward cleaner technologies and renewable energies. Zhijun and Kuby (1997) enhanced the model by adding investment variables for improving efficiency on coal and electricity. They found that these energy demands in the year 2000 can be satisfied with less cost and pollution than in the supply-side-only results.

2.1.2 Oil Consumption

China is the world's second largest oil consumer, behind the U.S, but its oil consumption grows by 7.5% per year, seven times faster than the U.S.'. Growth in

Chinese oil consumption has accelerated mainly because of a large-scale transition away from bicycles and mass transit toward private automobiles. Consequently, by year 2010 China is expected to have 90 times more cars than in 1990. With automobile numbers growing at 19% a year, projections show that China could surpass the total number of cars in the U.S. by 2030. As Table 2, oil consumption of industry is decreasing, but oil consumption of transport is creasing rapidly.

Table 2 Oil consumption by sector unit: 10,000 tons

Consumption by Sector	1995		2000		2002		2003	
		%		%		%		%
1.Farming, Forestry, Animal Husbandry, Fishery and Water Conservancy	1203	7.49	1496	6.67	1674	6.76	1681	6.20
2.Industry	9349	58.20	11404	50.82	12489	50.40	13686	50.45
3.Construction	242	1.51	344	1.53	410	1.66	430	1.59
4.Transport, Storage and Post	2863	17.83	5509	24.55	6156	24.85	7093	26.15
5.Wholesale, Retail Trade and Hotel, Restaurants	333	2.08	545	2.43	593	2.39	682	2.52
6.Others	1390	8.65	1882	8.39	1978	7.98	1916	7.06
7.Residential Consumption	682	4.25	1256	5.60	1477	5.96	1635	6.03
Total Oil Consumption	**16064**		**22439**		**24779**		**27126**	

Data source: China Statistical Yearbook 2005.

Another contributor to the sharp increase in automobile sales is the very low price of gasoline in China. Chinese gasoline prices now rank among the lowest in the world for oil-importing countries, and are a third of retail prices in Europe and Japan, where steep taxes are imposed to discourage gasoline use (Luft, 2006).

At current production rates they are likely to last for less than two decades. In order to deal with more and more oil demands, China imported up to 95.80 million tons of crude oil in the first eight months in 2006, up 15.3 percent over the same period of last year (NDRC, 2006). Moreover, this problem has put a strain on the world's current oil contracts, and the issue has become so serious that Chinese president took a trip to Gabon to secure a deal with Total Gabon for oil. China's new energy plan reflects Beijing's concern about the rising cost of energy and the country's growing dependence on imported oil (Oster, 2006).

China's expectation of growing future dependence on oil imports has brought it to acquire interests in exploration and production in places like Kazakhstan, Russia, Venezuela, Sudan, West Africa, Iran, Saudi Arabia and Canada. But despite its efforts to diversify its sources, China has become increasingly dependent on Middle East oil. 58% of China's oil imports come from the region. By 2015, the share of Middle East oil will stand on 70%.

2.1.3 Electricity Consumption

Total electricity consumption in China has also increased due to an increasing economy and population. China's electrical power demands have increased, and the areas affected by blackouts will be larger than in 2003. China's electricity consumption in 2003 was 1903.16 billion kilowatt hours (KWH), and total oil available for consumption was 1903.22 billion KWH. Table 3 shows the electricity consumption by sector, and industry is still the biggest department of coal consumption. Increasing power demand as the country continues its modernization drive has put immense pressure on power grids in some areas, especially in the relatively developed coastal regions like Shanghai and Guangdong (NDRC, 2003).

Meanwhile, increased industrial output, lower prices and demand for high power-consuming appliances such as air-conditioners are causing power shortages in 16 provinces. Moreover, the situation has become so serious that east China will have electrical power shortages the year round, instead of just in the summer. To cope with the problem of power supply, China launched a west-to-east power transmission project in 2000, making it one of China's major strategies in energy development and an important step for developing the west regions.

Table 3 Electricity consumption by sector unit: 100 million KWH

Consumption by Sector	1995		2000		2002		2003	
		%		%		%		%
1.Farming, Forestry, Animal Husbandry, Fishery and Water Conservancy	582	5.81	673	5.00	776	4.75	773	4.06
2.Industry	7659	76.42	9653	71.66	11793	72.21	13899	73.03
3.Construction	159	1.59	154	1.15	164	1.00	189	1.00
4.Transport, Storage and Post	182	1.82	281	2.09	338	2.07	396	2.09
5.Wholesale, Retail Trade and Hotel, Restaurants	199	1.99	393	2.92	500	3.06	623	3.27
6.Others	234	2.34	643	4.77	758	4.65	911	4.79
7.Residential Consumption	1005	10.03	1672	12.41	2001	12.25	2238	11.76
Total Electricity Consumption	**10023**		**13471**		**16331**		**19031**	

Data source: China Statistical Yearbook 2005.

Steenhof (2006) presents analysis of the effect of changes in the industrial sector on electricity demand, an important economic sector contributing to these above patterns as it consumes nearly 70% of the electricity generated in China. He found that both increased industrial activity and fuel shifts helped increase industrial sector electricity demand between 1998 and 2002 by using decomposition analysis. Edvardsen and Førsund (2003) and Jamasb and Pollitt (2003) analyzed the benchmarking of the electricity industry in Europe and Northern Europe at the plant level.

2.2 Three Major Types of Waste

China has seen the fruit of its rapid economic growth over the past two decades, but severe environmental problems have accompanied this. Issues of environment pollution and resources consumption had endangered China's fast economic growth and become the most critical situation in the world. About 70-80% of rivers and 90% of supply water in major cities are seriously polluted. According to 2001 data, 16 out of 20 the most polluted cities in the world are located in China; acid rain covers 1/3 of land in China; and 5 billion tons of soil tons is eroded every year. Natural resources have been the edge of extinction, and 14 kinds of important mineral are estimated to exhaust in next 20 years. However, solid wastes, waste water, and waste gas are the most common pollutants, called three wastes, caused earth pollution, water pollution, air pollution, mutual pollution, even global pollution. Therefore, this part presents the China's three major types of waste: solid wastes, waste water, and waste gas.

2.2.1 Solid Wastes Produced

With the development of chemical industry in China, the poisonous and harmful solid wastes also increase. There are 1200 million tons solid wastes in China during 2004, and 9.95 million tons among them are hazardous wastes. 'Solid wastes' means the waste in solid or semi-solid state generated in the production and construction, daily life and other activities, which might pollute the environment. Solid wastes have not passed strict security treatment, and have already become serious pollutants. Solid wastes not only influence the view of the city, but also pollute water, gas, and soil greatly. These pollutions cause the harmful substance, and accumulate in the crops. Which enter the human body through the food chain, then cause various kinds of diseases, and harm human's health finally.

In 2006, Russian scientists test water quality for Songhua River in northeast of China, they find poisonous offal, such as chlorine phenol, wasted papers, and cellulose.

The consistency of poisonous offal has already exceeded 50 times acceptable level (Songhua River News 2006). Table 4 shows the industrial solid wastes produced by sector during 2000-2003. The sector of mining & quarrying produces the biggest solid wastes, and the sector of production & supply of electric power, gas & water is the second.

Table 4 Industrial Solid wastes produced by sector unit: 10,000 tons

Produced by Sector	2000	%	2001	%	2002	%	2003	%
Mining & Quarrying	39203	47.57	35903	37.30	37483	36.00	35577	32.77
Food, Beverage & Tobacco Industry	2050	2.49	1937	2.01	2230	2.14	1481	1.36
Textile Industry	437	0.53	538	0.56	544	0.52	77	0.07
Leather, Furs, Down & Related Products	52	0.06	78	0.08	94	0.09	137	0.13
Papermaking & Paper Products	763	0.93	1021	1.06	1071	1.03	1057	0.97
Printing & Record Medium Reproduction	13	0.02	41	0.04	139	0.13	1521	1.40
Petroleum Processing & Coking	895	1.09	1106	1.15	1302	1.25	7442	6.85
Raw Chemical Materials & Chemical Products	4920	5.97	5702	5.92	6050	5.81	259	0.24
Medical & Pharmaceutical Products	183	0.22	241	0.25	200	0.19	288	0.27
Chemical Fiber	329	0.40	355	0.37	352	0.34	81	0.07
Rubber Products	77	0.09	72	0.07	75	0.07	34	0.03
Plastic Products	27	0.03	33	0.03	35	0.03	2457	2.26
Nonmetal Mineral Products	1504	1.82	1960	2.04	1966	1.89	1424	1.31
Cement Manufacturing	815	0.99	1071	1.11	1156	1.11	15317	14.11
Smelting & Pressing of Ferrous Metals	12072	14.65	11858	12.32	14232	13.67	3436	3.16
Smelting & Pressing of Nonferrous Metals	2949	3.58	4477	4.65	3607	3.46	87	0.08
Metal Products	69	0.08	76	0.08	106	0.10	180	0.17
Machine Building, Electric Machinery, & Electronic Equipment Manufacturing	786	0.95	829	0.86	1002	0.96	829	0.76
Production & Supply of Electric Power, Gas & Water	13274	16.10	28377	29.48	32089	30.82	36380	33.51
Other Industries	2005	2.43	575	0.60	391	0.38	509	0.47
Total Produced	82419.99		96250		104124		108573	

Data source: China Statistical Yearbook 2001-2004.

Industrial solid waste is divided into two parts: recycle and un-recycle. Recycle means that the industry converts the solid waste into resources, energy, and other raw materials by retrieving, processing, and exchanging. At present, China is the largest importer of solid waste in the world. Many solid wastes are sold from the U.S. to China every year and become the raw materials of paper mills, steel mills, and other factories. Some solid wastes are made into products by workers with very low salaries, for example, parts for cars and toys, which are then sold back to the U.S. The ratios of industrial solid wastes utilized are 45.6%, 45.9%, 52.1%, 51.9%, and 54.8% during the 1999-2003 period (China Statistical Yearbook 2003). However, a large number of renewable resources are not recycled and lead to economic losses of up to US$30 billion per year (SoE 2000).

There are many examples of industrial solid waste management from several countries that have recently become interested in industrial solid wastes. For case studies of industrial solid wastes and recycling, Casares et al. (2005) investigated Asegra in Spain and Donnelly (2002) researched the United States and Germany. Moreover, Hogland and Stenis (2000) described a method of organization for an industrial solid waste management system in Sweden, which is characterized by an energy recovery and material recovery system.

Other countries such as Finland, Australia, Austria, Canada (Raymond and Cohen-Rosenthal 1998), and the United States (Deppe et al. 2000) refer to the concept of an 'eco-industrial park', which integrates business, environmental excellence, and community relations to create economic opportunities and improved ecosystems.

2.2.2 Waste Water Discharged

In 2005 a chemical firm of Jilin in China exploded, resulting in 100 tons of benzene flowing into Songhua River causing the water supply system of Harbin to be shut down (Chen 2006). Currently, there are 400 medium and small-sized cities in China, discharging 10 billion tons of waste water every year (ACCA21). Table 5 shows the industrial waste water discharged by sector during 2000-2003. The sectors of papermaking & paper products and raw chemical materials & chemical products discharges the biggest waste water, and the sector of production & supply of electric power, gas & water is still the second.

Most of the chemical pollutants that industrial plants discharge are heavy metals, particularly cadmium, zinc, organic-metallic compounds, phosphates, nitrates, and potassium, which have caused many deaths of fishes, plants, and animals. Waste water pollution has affected the ocean's ecosystem, rivers, estuaries, lakes, and groundwater, such as increased temperature and decreased oxygen within the water, and cause the respiration and metabolism of aquatic plants and animals (Benarde 1989).

Moreover, many waterborne diseases have affected China for the past several years through groundwater contamination. Most of these municipal pollutants contribute to the increase in disease transmissions of waterborne diseases. Moreover, waterborne diseases are commonly contracted when bathing in fecal- and urine-polluted streams and canals or can be transmitted by the bite of an insect vector that breeds in polluted waters. Several examples of waterborne diseases are cholera, typhoid, and dysentery, which occur at a higher rate in developing countries such as China.

Pesticides in drinking water have also been a problem to the health of a community (Vighi and Funari 1995). Not only do pesticides affect humans, but also the environment in terms of groundwater contamination which can affect the natural hydrologic cycle. From an environmental analysis, the disruption of the environment and the ecosystem is altering the natural capital of China.

Table 5 Industrial waste water discharged by sector unit: 10,000 tons

Discharged by Sector	2000	%	2001	%	2002	%	2003	%
Mining & Quarrying	127952	6.67	125804	6.20	108651	5.30	109063	5.72
Food, Beverage &Tobacco Industry	164304	8.57	147512	7.27	159094	7.76	165417	8.67
Textile Industry	125649	6.55	132698	6.54	136600	6.67	146530	7.68
Leather, Furs, Down & Related Products	13008	0.68	10905	0.54	11874	0.58	13106	0.69
Papermaking & Paper Products	352876	18.40	316242	15.59	323648	15.80	325573	17.07
Printing & Record Medium Reproduction	1749	0.09	2755	0.14	1902	0.09	2263	0.12
Petroleum Processing & Coking	48500	2.53	41741	2.06	54869	2.68	53762	2.82
Raw Chemical Materials & Chemical Products	337346	17.59	330514	16.30	321416	15.69	312825	16.40
Medical & Pharmaceutical Products	34381	1.79	32634	1.61	36691	1.79	35874	1.88
Chemical Fiber	53134	2.77	59695	2.94	53954	2.63	48847	2.56
Rubber Products	8124	0.42	7070	0.35	7597	0.37	6865	0.36
Plastic Products	2994	0.16	2588	0.13	2476	0.12	2344	0.12
Nonmetal Mineral Products	42422	2.21	46197	2.28	44483	2.17	47181	2.47
Cement Manufacturing	24115	1.26	28055	1.38	26023	1.27	27718	1.45
Smelting & Pressing of Ferrous Metals	220528	11.50	191745	9.45	190268	9.29	177456	9.31
Smelting & Pressing of Nonferrous Metals	32871	1.71	37451	1.85	34050	1.66	31761	1.67
Metal Products	11817	0.62	11742	0.58	14124	0.69	15910	0.83
Machine Building, Electric Machinery, & Electronic Equipment Manufacturing	91779	4.79	84377	4.16	83639	4.08	103001	5.40
Production & Supply of Electric Power, Gas & Water	186594	9.73	380478	18.76	410810	20.05	249079	13.06
Other Industries	37525	1.96	37944	1.87	26724	1.30	32360	1.70
Total Discharged	1917668		2028147		2048893		1906935	

Data source: China Statistical Yearbook 2001-2004.

Considering the social, environmental, economical, and technical aspects concerning the waste water treatment projects, several projects have been proposed within China to deal with the waste water pollution problem. The projects include the analysis and recommendations for financial, social, environmental, and technical issues to help improve China's waste water management practices. With the waste water treatment plants proposed in China, its environment, population, agriculture, and economy can all improve dramatically.

2.2.3 Waste Gas Emission

Air pollution alone contributes to the premature deaths of more than a quarter of a million people each year (World Bank 1997). One of the main sources of air pollution is industrial waste gas emission. The main source of industrial waste gas emission includes heavy carbon monoxide (CO_2), sulfur dioxide (SO_2), hydrocarbon (C_XH_Y), ozone (O_3), nitrogen oxygen (NO_2), etc., in the air.

China is currently third largest acid rain belt in the world. During the last ten years, because SO_2 missions have increased day by day, China is now only behind Europe and North America. The dangers from acid rain upon the environment include: degradation of forests, lakes become acidic, fish die, farmland and soil turn acidic, poisonous heavy metal pollution increases, and vegetables and fruits drop in production on a large scale.

Table 6 shows the industrial waste gas emission by sector during 2000-2003. The sector of production & supply of electric power, gas & water emissions the biggest waste gas, and the sectors of nonmetal mineral products, cement manufacturing, and smelting & pressing of ferrous metals juxtapose the second.

Dangers from waste gas emission to mankind are: asthma, coughing, headaches, and allergies of the eyes, nose, and throat. Most of the existing analyses of air pollution abatement focus on its benefit evaluation (Kumar and Rao, 2001), its possible impacts on economic activities (Xie, 2000; Resosudarmo, 2003), or strategies to achieve it (Vlek et al. 2004). Economically efficient air pollution abatement receives relatively much less attention (Hu, 2006).

Table 6 Industrial waste gas emission by sector unit: 100 million m^3

Emission by Sector	2000	%	2001	%	2002	%	2003	%
Mining & Quarrying	3541	2.20	4089	1.73	4126	1.61	4375	1.49
Food, Beverage & Tobacco Industry	3218	2.00	2935	1.24	3797	1.48	4420	1.51
Textile Industry	1577	0.98	1937	0.82	2162	0.84	2612	0.89
Leather, Furs, Down & Related Products	125	0.08	166	0.07	153	0.06	119	0.04
Papermaking & Paper Products	2553	1.59	3283	1.39	3913	1.53	4004	1.36
Printing & Record Medium Reproduction	49	0.03	215	0.09	141	0.05	142	0.05
Petroleum Processing & Coking	3915	2.43	4205	1.78	4763	1.86	7381	2.51
Raw Chemical Materials & Chemical Products	8787	5.46	10366	4.38	10817	4.22	11989	4.08
Medical & Pharmaceutical Products	473	0.29	582	0.25	1655	0.65	1615	0.55
Chemical Fiber	2750	1.71	2811	1.19	3090	1.20	2724	0.93
Rubber Products	476	0.30	431	0.18	443	0.17	479	0.16
Plastic Products	193	0.12	246	0.10	185	0.07	188	0.06
Nonmetal Mineral Products	27336	16.98	34062	14.38	36176	14.10	39615	13.50
Cement Manufacturing	22850	14.19	27975	11.81	30264	11.80	32302	11.01
Smelting & Pressing of Ferrous Metals	21343	13.26	25015	10.56	29028	11.32	33841	11.53
Smelting & Pressing of Nonferrous Metals	8533	5.30	9958	4.20	9320	3.63	9939	3.39
Metal Products	425	0.26	487	0.21	786	0.31	431	0.15
Machine Building, Electric Machinery, & Electronic Equipment Manufacturing	3586	2.23	4444	1.88	4551	1.77	4776	1.63
Production & Supply of Electric Power, Gas & Water	48028	29.83	101722	42.95	109998	42.89	130698	44.53
Other Industries	1236	0.77	1892	0.80	1119	0.44	1841	0.63
Total Emission	160994		236821		256487		293491	

Data source: China Statistical Yearbook 2001-2004.

An economy's macroeconomic policies generally have two objectives: the creation of wealth and good living conditions for citizens. Gross domestic product (GDP) is commonly used in assessing an economy's wealth, but it does not constitute a measure of wealth without dealing with environmental issues adequately. Although the energy savings and waste abatements are mutually beneficial to China and the rest of the world, people may worry that a drastic reduction in the three wastes will hamper economic growth. Therefore, given the limited availability of economically viable alternative energy sources, reducing total domestic energy use and waste produces without sacrificing economic growth is an important issue for economies all over the world (de Nooij et al., 2003). Moreover, this concept is also called ‘green GDP.’ Green GDP is derived from GDP through a deduction of negative environmental and social impacts.

The future will involve conflicts between environmental protection and economic growth. Therefore, energy saving and waste reducing are hence important for all economies. This thesis tries to find out the efficient regional target energy savings ratios and target waste abatements ratios with respect to China’s own production frontier. Efficient abatements not only are feasible under China’s current best technology, but they also will not reduce the maximum potential economic output.

Chapter 3 Research Design

3.1. Methodology of Data Envelopment Analysis (DEA)

DEA is known as a mathematical programming method for assessing the comparative efficiencies of a decision-making unit (DMU). In our study a region is counted as a DMU. DEA is a non-parametric method using linear programming to construct a non-parametric piecewise frontier over the data for an efficiency measurement. DEA does not need to specify either the production functional form or weights on different inputs and outputs. Comprehensive reviews of the development of an efficiency measurement can be found in Lovell (1993). There are K inputs and M outputs for each of these N DMUs.

The envelopment of the i-th DMU can be derived from the following linear programming problem:

$$\begin{aligned} &\text{Min}_{\theta,\lambda} \quad \theta \\ &\text{s.t.} \quad -y_i + Y\lambda \geq 0, \\ &\qquad \theta x_i - X\lambda \geq 0, \\ &\qquad \lambda \geq 0, \end{aligned} \tag{1}$$

where θ is a scalar representing the efficiency score for the i-th DMU; λ is an $N\times1$ vector of constants; y_i is an $M\times1$ output vector of DMU i; Y is an $M\times N$ output matrix constituted by all output vectors of these N DMUs; x_i is a $K\times1$ input vector of DMU i; and X is a $K\times N$ input matrix constituted by all input vectors of these N DMUs. The efficiency score will satisfy $0 \leq \theta \leq 1$, with a value of 1 indicating a point on the frontier and hence a technically efficient DMU (Coelli et al. 1998). The above procedure constructs a piecewise linear approximation to the frontier by minimizing the quantities of the K inputs required to meet the output levels of the i-th DMU. The weight λ serves to form a convex combination of observed inputs and outputs. It is an input-orientated measurement of efficiency.

Equation (1) is known as the constant returns to scale (CRS) DEA model (Charnes et al. 1978). This model finds the overall technical efficiency (OTE) of each DMU. The variable returns to scale (VRS) DEA model (Banker et al. 1984) further decomposes the overall technical efficiency into pure technical efficiency (PTE) and scale efficiency (SE): OTE = PTE × SE. In order to pursue overall technical efficiency with energy and waste, this study adopts the CRS DEA model. Furthermore, both output-oriented and input-oriented CRS DEA models generate exactly the same efficiency scores, target inputs, and target outputs. However, the results of a VRS DEA model can be drastically changed by shifting from an output orientation to an input orientation.

3.2 Abatement Evaluation

Labor and capital are two major inputs in production. When measuring a nation's overall output, GDP is commonly used. For example, Färe et al. (1994) analyzed the productivity growth of OECD countries, by considering labor and capital as inputs and GDP as an output. Chang and Luh (2000) adopted similar inputs and outputs to analyze the productivity growth of ten Asian economies.

The change in income, energy, and waste is a three-way relation: First, increasing income deteriorates the environmental condition directly, because waste is generally a by-product of the energy consumption and is costly to dispose. Conversely, the growth of income is accompanied by the public increasing its demand for better environmental quality through driving forces such as control measures, technological progress, and the structural change of consumption. GDP, waste, and energy should be both taken into account in order to correct a nation's output. Therefore, in the following analytical process, energy and waste are considered respectively as inputs in order to find the target input levels by the DEA approach.

However, the crude oil can be divided into liquefied petroleum gas, gasoline, light oil, diesel oil, heavy oil, and pitch, etc. after distilling. Besides petrol, the others can be used for generating electricity. In order to avoid repeated calculation on energy consumption, this thesis selects gasoline as an input variable. Therefore, this thesis takes the economic production function that is constructed by data envelopment analysis to analyze regional efficiencies in China. First, three major types of energy (coal, gasoline, and electricity) are considered in conjunction with the inputs of labor and capital stock (that are normally used in economic efficiency and productivity analysis) as the total inputs in order to produce economic output (GDP). Second, this thesis treats three kinds of waste (solid wastes, waste water, and waste gas) as proxies for the cost of environmental goods used for production. Oates and Schwab (1988), López (1994), Smulders (1999), de Bruyn (2000), and Hu et al. (2005) treated the pollution as a proxy for the cost of environmental goods. Three kinds of waste therefore are considered in conjunction with the inputs of labor and capital stock as the total inputs in order to produce economic output (GDP). Figure 2 shows the production model for evaluating efficient abatements.

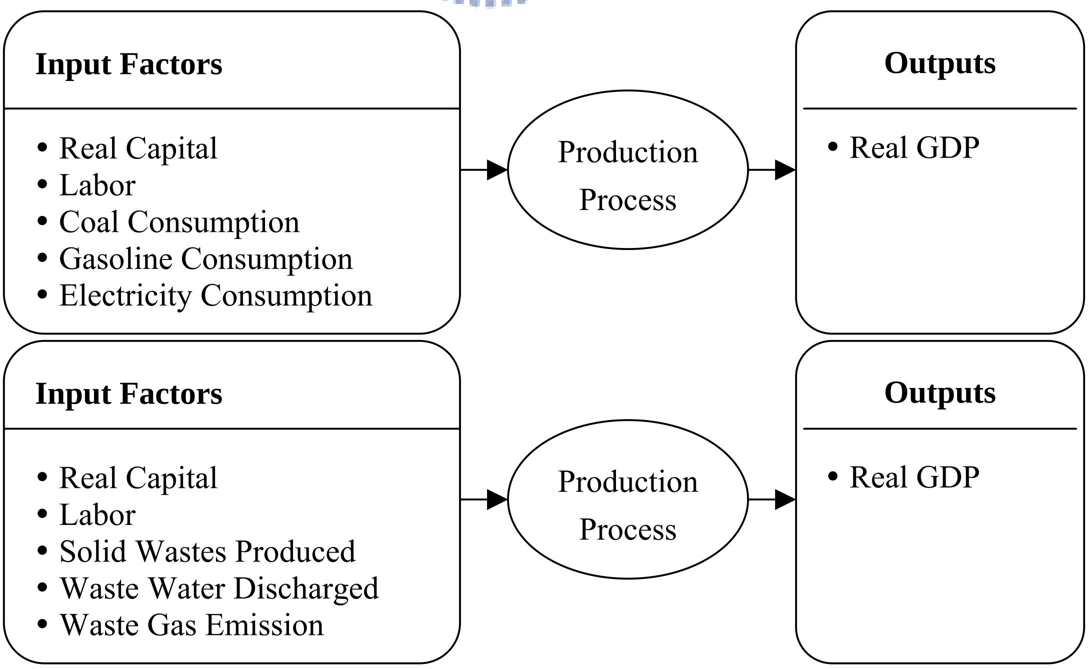

Figure 2 Production model for evaluating efficient abatements

The target inputs and outputs for a DMU to be efficient can be computed by the DEA approach. The efficiency frontier can shift from year to year. DEA calculates the year-specific frontier with regional output and input (cross-sectional) data in each year. The target inputs of a DMU for a year are found by comparing its actual inputs to the efficiency frontier in that year. By this method, each region's target amounts of coal consumption, gasoline consumption, electricity consumption, solid wastes produced, waste water discharged, and waste gas emission in each year can be found by comparing their actual consumption to the total-factor efficiency frontier of that year - that is, the efficiency frontier in each year represents the feasible and best performance of China in that year. Therefore, an imposition of an arbitrary abatement target with a developed economy's standard is avoided herein.

Hu (2006) constructed a total-factor air pollution abatement ratio index to compute how far away a region's air pollution emission is from the efficient level. The higher the abatement ratio is, the lower the total-factor efficiency will be. The target input (energy or waste) abatements ratios of the regions are then computed from dividing the target input amount by the actual input amount:

$$\text{Target Input Abatement Ratio}_{k\,(i,\,t)} = 1 - \text{Target Input}_{k\,(i,\,t)} / \text{Actual Input}_{k\,(i,\,t)}, \qquad (2)$$

where it is in the *i*-th region and the *t*-th year for *k*-th input. Different from the traditional DEA model which emphasized efficiency, this thesis creates an input abatement index. It is main contribution of this thesis too. As equation (2) shows, the abatement ratio represents how far away a region's three major types of energy or waste are from the efficient levels. Therefore, the efficient target energy savings ratios for each region in each year are then obtained by dividing the target energy consumption by the actual energy consumption; and the efficient target waste abatements ratios for each region in each year are then obtained by dividing the target waste and by the actual waste. The actual value is always larger than or equal to the target value such that the abatements ratios will always be between zero and unity.

The DEA approach was originally intended for use in microeconomic environments to measure the performance of schools, hospitals, and the like, and it is also ideally suited to macroeconomic performance analysis. However, to the best our knowledge, the existing literature of efficient energy target savings ratios and efficient waste target abatements ratios do not simultaneously incorporate the various energy and waste. For example, Hu (2006) uses three air emissions as inputs to compute the efficient air pollution abatement ratios in China. Hu and Lee (Forthcoming) find the target waste abatement of the three wastes for twenty-seven regions in China through the DEA. Färe et al. (2004) used DEA to construct an environmental performance index focusing on pollution.

3.3 Data Sources

The data of regional labor employment are established from the China Statistical Yearbook. Data of GDP output in each region are collected respectively as stated previously. Real capital stocks in 1996 prices are constructed based on Li's method (Li 2003).[1] Monetary inputs and outputs such as GDP and capital stock are deflated to 1996 values.

From the perspective of China's development and political factors, its provinces, autonomous regions, and municipalities are usually divided into three major areas: the east area (abbreviated as 'E'), the central area (abbreviated as 'C'), and the west area (abbreviated as 'W'). There is an apparently economic disparity between the coastal

[1] The capital stock data are not available in the *China Statistical Yearbook*. In this study, every regional capital stock in a specific year is calculated by the authors according to this formula: capital stock in the previous year + capital formation in the current year – capital depreciation in the current year. All the nominal values are deflated in 1995 prices before summations and deductions. This thesis finds the initial capital stock (capital stock data in 1995) from the research of Li (2003).

and inland areas. Regional economic disparities are due to greater access to world markets, better infrastructure, a higher-educated labor force, and the government's preferential policies on foreign investment for the east area (World Bank 1997).

From China Energy Statistical Yearbook, we establish the three types of energy dataset for 27 regions in mainland China (24 provinces and 3 municipalities) during 2000 to 2003. There are Beijing (E), Tianjin (E), Hebei (E), Shanxi (C), Inner Mongolia (C), Liaoning (E), Jilin (C), Heilongjiang (C), Shanghai (E), Jiangsu (E), Zhejiang (E), Anhui (C), Fujian (E), Jiangxi (C), Shandong (E), Hennan (C), Hubei (C), Hunan (C), Guangdong (E), Guangxi (E), Sichuan (W), Guizhou (W), Yunnan (W), Shaanxi (W), Gansu (W), Qinghai (W), and Xinjiang (W). From China Statistical Yearbook, we establish the three types of waste dataset for 27 regions in mainland China (24 provinces and 3 municipalities) during 2000 to 2003. Note that Chongqing became a municipality out of Sichuan in 1997 and in this study its outputs and inputs are included in Sichuan.

There are five inputs and one output in the DEA model to calculate the target energy savings. In order to avoid repeated calculation, this paper only regarded final consumptions as energy inputs. The five inputs are capital stock, number of employed persons, coal consumption, gasoline consumption, and electricity consumption. There are also five inputs and one output in the DEA model to calculate the target waste abatements. The five inputs are capital stock, number of employed persons, industrial solid wastes produced, industrial waste water discharged, and industrial waste gas emission. The only one output is GDP of a specific region. These include aggregated input and output proxies. Three inputs of energy and three inputs of waste are treated as the cost of production, and they are China's three types of most important energy and waste. The values of monetary inputs and outputs such as GDP and capital are in 1996 prices. This thesis uses the software Deap 2.1, kindly provided by Coelli (1996), for computing the target inputs and outputs of each region in each year.

3.4 Descriptive Statistics

Summary statistics of these inputs and output ordered by year and area are shown in Tables 7 and 8, respectively.

Table 7 Summary statistics of inputs and outputs by year

		2000	2001	2002	2003
Output					
Gross Domestic Product	Mean	2623	2687	2728	2848
(100 million RMB)	Std. Dev.	1833	1889	1935	2055
Common Inputs					
Capital Stock	Mean	11647	12366	13105	13943
(100 million RMB)	Std. Dev.	8607	8979	9376	9853
Number of Employed Persons	Mean	2305	2291	2334	2374
(10,000 persons)	Std. Dev.	1535	1536	1522	1540
Energy Inputs					
Volume of Coal Consumption	Mean	5396	5624	6166	7077
(10,000 tons)	Std. Dev.	3311	3487	4077	4588
Volume of Gasoline Consumption	Mean	125	136	144	158
(10,000 tons)	Std. Dev.	64	76	81	93
Volume of Electricity Consumption	Mean	501	565	611	699
(100 million KWH)	Std. Dev.	296	366	377	448
Waste Inputs					
Volume of Industrial Solid Wastes Produced	Mean	3001	3271	3479	3687
(10,000 tons)	Std. Dev.	2090	2253	2326	2439
Volume of Industrial Waste Water Discharged	Mean	71237	74350	76004	77926
(10,000 tons)	Std. Dev.	53685	61966	62891	62839
Volume of Industrial Waste Gas Emission	Mean	5046	5890	6411	7283
(100 million m3)	Std. Dev.	2892	3597	3830	4395

Notes: (1) The monetary values are in 1996 prices.
(2) Data source: *China Energy Statistical Yearbook* 2004-2005, and *China Statistical Yearbook* 2001-2004.

Table 8 Summary statistics of inputs and outputs by area

		Area of Mainland China		
		East	*Central*	*West*
Output				
Gross Domestic Product	Mean	4002	2196	1385
(100 million RMB)	Std. Dev.	2070	910	1258
Common Inputs				
Capital Stock	Mean	19616	8885	6989
(100 million RMB)	Std. Dev.	9734	3297	5817
Number of Employed	Mean	2404	2430	2070
(10,000 persons)	Std. Dev.	1395	1418	1806
Energy Inputs				
Volume of Coal Consumption	Mean	6580	7145	3870
(10,000 tons)	Std. Dev.	3973	4155	2392
Volume of Gasoline Consumption	Mean	180	126	98
(10,000 tons)	Std. Dev.	77	71	63
Volume of Electricity Consumption	Mean	820	471	396
(100 million KWH)	Std. Dev.	442	194	245
Waste Inputs				
Volume of Industrial Solid Wastes Produced	Mean	3572	3737	2541
(10,000 tons)	Std. Dev.	2686	1897	1783
Volume of Industrial Waste Water Discharged	Mean	102217	63640	46370
(10,000 tons)	Std. Dev.	62448	34449	64264
Volume of Industrial Waste Gas Emission	Mean	8262	5625	3535
(100 million m^3)	Std. Dev.	4164	2618	2158

Notes:
(1) The monetary values are in 1996 prices.
(2) Data source: *China Energy Statistical Yearbook* 2004-2005, and *China Statistical Yearbook* 2001-2004.

The east area has the highest GDP, capital stock, gasoline consumption, electricity consumption, and. the most waste water discharged and waste gas emission The central area has the largest number of employed people, the highest coal consumption, and the most solid wastes.

As shown in Table 9, all inputs have positive correlation coefficients with the output - that is, all inputs satisfy the isotonicity property with the output.

Table 9 Correlation coefficients between inputs and the output

Part I: Single output, Common inputs, and energy inputs

	Real Capital Stock	Labor	Coal	Gasoline	Electricity
Real GDP	0.81	0.68	0.47	0.81	0.93

Part II: Single output, Common inputs, and waste inputs

	Real Capital Stock	Labor	Solid Wastes	Waste Water	Waste Gas
Real GDP	0.81	0.68	0.82	0.79	0.29

4. Empirical Analysis

This section is divided into two parts: Part 4.1 presents empirical results of mainland China's energy; and part 4.2 shows the empirical results of mainland China's waste.

4.1 Energy of Mainland China

4.1.1 Regional Savings Ratios for Three Major Types of Energy

After the DEA computation, this part shows the regional target savings ratios of coal consumption, gasoline, and electricity consumption during 2000-2003, and the average regional target savings ratios of coal, gasoline, and electricity during 2000-2003. Figures show the trends of regional target savings ratios in the three major areas of mainland China.

4.1.1.1 Savings Ratios for Coal Consumption

As Table 10, the east area has two regions with coal consumption savings ratios always higher than 30% throughout the research period: Tianjin (02) and Liaoning (06). The central area has six regions with coal consumption target savings ratios always higher than 30%: Shanxi (04), Inner Mongolia (05), Jilin (07), Heilongjiang (08) and Hubei (17), especially Shanxi (04) and Inner Mongolia (05) with target savings ratios higher than 80%. The west area has five regions with coal consumption target savings ratios always higher than 30%: Guizhou (22), Yunnan (23), Shaanxi (24), Gansu (25), Qinghai (26), and Xinjiang (27), especially Guizhou (22) and Gansu (25) with target savings ratios higher than 60%.

Table 10 Actual consumption and target savings ratios of coal for regions in Mainland China during 2000-2003

ID	Region	Area	2000		2001		2002		2003	
			Actual Consumption	*Savings Ratios*	*Actual Consumption*	*Savings Ratios*	*Actual Consumption*	*Savings Ratios*	*Actual Consumption*	*Savings Ratios*
01	Beijing	E	2720	18.25	2675	10.84	2531	6.75	2674	3.43
02	Tianjin	E	2473	41.38	2635	41.66	2929	43.63	3205	42.22
03	Hebei	E	12115	0.00	12641	61.83	13739	61.90	14851	55.91
04	Shanxi	C	14262	92.92	14856	92.83	18055	91.59	20502	89.78
05	Inner Mongolia	C	5908	85.75	6265	85.50	6864	84.67	9025	85.35
06	Liaoning	E	9582	50.91	9084	58.72	9355	56.92	10454	59.58
07	Jilin	C	4213	74.62	4484	75.09	4664	71.10	5202	62.80
08	Heilongjiang	C	5815	68.26	5537	63.82	5543	57.53	6490	0.00
09	Shanghai	E	4496	0.00	4610	0.00	4737	0.00	5018	0.00
10	Jiangsu	E	8770	0.00	8963	34.42	9663	13.28	10849	17.88
11	Zhejiang	E	5385	31.67	5527	29.66	6595	18.83	7267	14.43
12	Anhui	C	5909	0.00	6366	0.00	6679	0.00	7489	38.48
13	Fujian	E	2160	0.00	2205	0.00	2711	0.00	3272	0.00
14	Jiangxi	C	2469	55.30	2584	0.00	2557	0.00	3089	0.00
15	Shandong	E	8698	0.00	11098	0.00	12938	0.00	15166	0.00
16	Hennan	C	8725	31.22	9325	18.89	10333	30.93	11420	24.73
17	Hubei	C	6051	61.06	6096	50.93	6483	48.01	7238	42.92
18	Hunan	C	3335	0.00	4100	0.00	4287	0.00	4984	0.00
19	Guangdong	E	5890	0.00	6088	0.00	6649	0.00	7910	0.00
20	Guangxi	E	2228	9.43	2228	8.45	2133	12.35	2621	13.28
21	Sichuan	W	7804	60.46	7386	56.16	8515	22.71	9900	22.74
22	Guizhou	W	5146	75.70	4946	77.22	5199	85.10	6794	87.70
23	Yunnan	W	3062	43.99	3101	33.28	3556	39.44	4614	48.27
24	Shaanxi	W	2766	66.91	3133	54.56	3451	52.13	3961	49.85
25	Gansu	W	2480	71.14	2551	67.75	2798	67.76	3219	76.47
26	Qinghai	W	522	70.88	642	74.05	620	53.05	675	48.67
27	Xinjiang	W	2702	69.30	2734	69.26	2898	67.22	3184	62.53
	Area Average									
		E	5865	13.78	6159	22.33	6725	19.42	7571	18.79
		C	6298	52.13	6623	43.01	7273	42.65	8382	38.23
		W	3497	65.48	3499	61.75	3862	55.35	4621	56.60

Notes: 1. Actual consumption is in 10,000 tons.
2. Savings ratios are in percentage terms.

Table 10 and Figure 3 describe the 2000-2003 average coal consumption savings ratios in each area. The coal consumption savings ratios of the east area are the lowest, and which of the central is the highest With respect to coal consumption, the east, central, and west areas are the most, medium, and least efficient, respectively. Among the three major types of energy, the coal consumption target savings ratios are generally the highest, implying that coal consumption may be the most critical task for saving energy in mainland China.

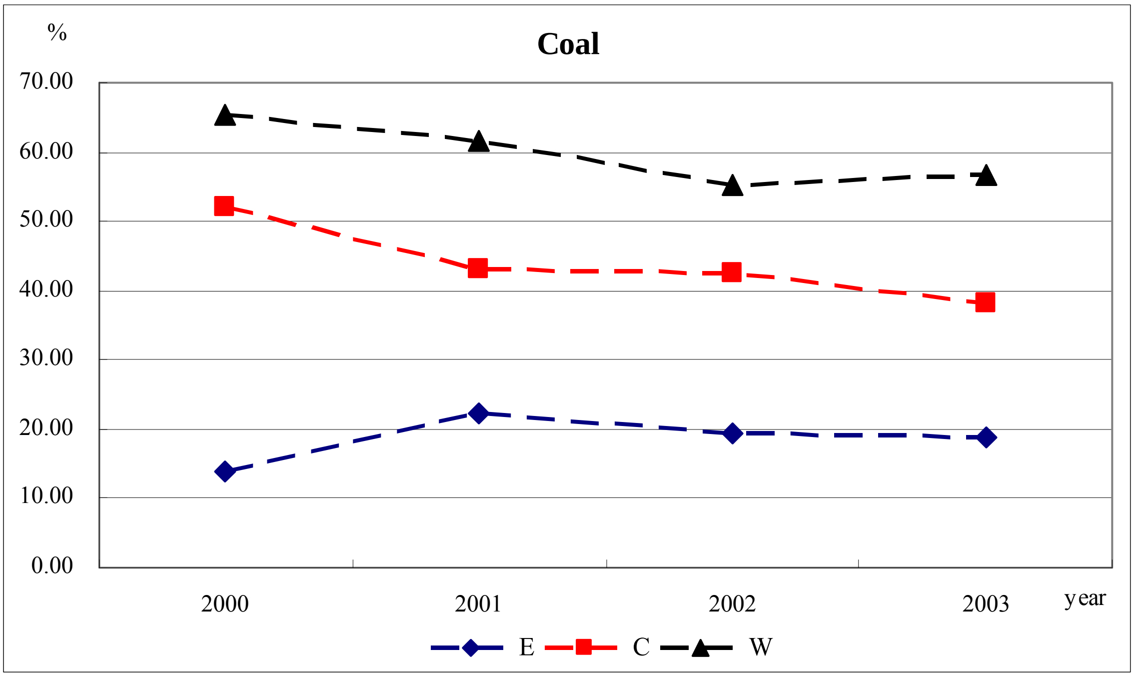

Figure 3 The average target of coal savings ratios in the three major areas of Mainland China

Table 11 shows the Mann-Whitney test on target coal savings ratios for three major areas in mainland China during 2000-2003. It presents that the target savings ratios of west area is always significantly more than east area, which of the west area is not significantly more than central area; and which of central area is not significantly more than east area. Summary of target coal savings for three areas, east area is most efficient, and west area and central area are more inefficient.

Table 11 Mann-Whitney test on target coal savings ratios for three major areas

Area	Average Ratio (%)	Mann-Whitney U Statistic	Z Test	P value
Year = 2000				
East	13.78			
Central	52.13	80	2.317	0.009***
East	13.78			
West	65.48	76	3.396	0.000***
Central	52.13			
West	65.48	37	0.582	0.280
Year = 2001				
East	22.33			
Central	43.01	65	1.177	0.119
East	22.33			
West	61.75	69	2.762	0.002***
Central	43.01			
West	61.75	39	0.794	0.214
Year = 2002				
East	19.42			
Central	42.65	66	1.254	0.105
East	19.42			
West	55.35	67	2.581	0.005***
Central	42.65			
West	55.35	37	0.582	0.280
Year = 2003				
East	18.79			
Central	38.23	64	1.101	0.135
East	18.79			
West	56.60	68	2.671	0.004***
Central	38.23			
West	56.60	42	1.111	0.133

Note: ***represents significance at the 0.01 level.

4.1.1.2 Savings Ratios for Gasoline Consumption

The east area has two regions with gasoline consumption target savings ratios always higher than 30% throughout the research period: Beijing (01) and Tianjin (02). The central area has two regions with gasoline consumption target savings ratios always higher than 30%: Shanxi (04) and Hubei (17). The west area has five regions with gasoline consumption target savings ratios always higher than 30%: Guizhou (22), Shaanxi (24), Gansu (25), Qinghai (26), and Xinjiang (27), especially Gansu (25) with target savings ratios higher than 60%.

Table 12 and Figure 4 show the 2000-2003 average gasoline consumption target savings ratios in each area. The east, central, and west areas have the lowest, medium, and highest gasoline consumption savings ratios, respectively. With respect to gasoline consumption, the east, central, and west areas are the most, medium, and least efficient, respectively.

Average gasoline consumption target savings ratios of east and west areas are stable throughout the research period, which of central area are decreasing. However, the average target savings ratios of the west area always stayed above 40% during the 2000-2003 period, showing no significant improvement at all.

Table 13 shows the Mann-Whitney test on target gasoline savings ratios for three major areas in mainland China during 2000-2003. It presents that the target savings ratios of west area is significantly more than east area, which of west area is significantly more than central area; and which of the central area is not significantly more than east area. Summary of target gasoline savings for three areas, east area and central are more efficient, and west area is most inefficient.

Table 12 Actual consumption and target savings ratios of gasoline for regions in mainland China during 2000-2003

ID	Region	Area	2000		2001		2002		2003	
			Actual Consumption	*Savings Ratios*	*Actual Consumption*	*Savings Ratios*	*Actual Consumption*	*Savings Ratios*	*Actual Consumption*	*Savings Ratios*
01	Beijing	E	106.60	33.52	138.69	44.35	152.00	37.95	165.22	39.56
02	Tianjin	E	112.43	57.02	116.27	55.35	94.76	36.09	106.42	36.51
03	Hebei	E	136.44	0.00	141.85	0.35	147.41	1.22	157.00	1.39
04	Shanxi	C	88.84	45.93	88.77	44.64	89.23	41.83	89.27	36.80
05	Inner Mongolia	C	64.81	38.00	72.10	40.75	79.35	36.64	83.12	29.51
06	Liaoning	E	149.47	22.27	235.79	43.42	236.10	32.90	227.94	28.80
07	Jilin	C	90.67	41.95	93.61	39.34	96.99	33.14	103.41	17.07
08	Heilongjiang	C	244.04	63.54	269.84	63.95	258.57	56.95	310.17	0.00
09	Shanghai	E	132.25	0.00	137.33	0.00	160.09	0.00	173.24	0.00
10	Jiangsu	E	187.30	0.00	247.71	3.50	293.39	4.02	339.17	3.75
11	Zhejiang	E	196.19	16.21	212.87	16.63	231.44	7.41	262.15	4.91
12	Anhui	C	68.54	0.00	70.35	0.00	73.90	0.00	76.70	2.57
13	Fujian	E	105.11	0.00	106.35	0.00	132.76	0.00	138.66	0.00
14	Jiangxi	C	58.46	8.13	60.37	0.00	82.19	0.00	59.63	0.00
15	Shandong	E	188.52	0.00	188.92	0.00	176.83	0.00	209.51	0.00
16	Hennan	C	120.86	3.97	124.03	3.77	119.50	6.73	121.99	2.66
17	Hubei	C	169.17	32.22	185.55	35.91	232.78	37.04	292.86	54.12
18	Hunan	C	115.40	0.00	113.70	0.00	134.63	0.00	135.93	0.00
19	Guangdong	E	301.16	0.00	324.82	0.00	344.58	0.00	375.04	0.00
20	Guangxi	E	65.87	9.43	65.87	8.45	84.37	12.47	116.70	33.38
21	Sichuan	W	209.31	28.27	222.10	30.41	236.88	22.71	247.53	24.65
22	Guizhou	W	46.46	35.45	47.83	36.45	50.48	35.22	58.94	38.04
23	Yunnan	W	90.79	32.71	111.47	46.61	97.60	29.28	106.10	32.80
24	Shaanxi	W	103.51	56.98	78.16	42.84	95.00	41.76	105.43	43.28
25	Gansu	W	98.41	68.82	103.96	69.39	97.37	64.04	97.82	63.29
26	Qinghai	W	16.31	54.59	17.61	52.67	16.00	48.53	17.16	48.67
27	Xinjiang	W	101.93	63.72	86.35	56.45	86.70	47.61	91.35	45.77
	Area Average									
		E	152.85	12.59	174.22	15.64	186.70	12.01	206.46	13.48
		C	113.42	25.97	119.81	25.37	129.68	23.59	141.45	15.86
		W	95.25	48.65	95.35	47.83	97.15	41.31	103.48	42.36

Notes: 1. Actual consumption is in 10,000 tons.
2. Savings ratios are in percentage terms.

Table 13 Mann-Whitney test on target gasoline savings ratios for three major areas

Area	Average Ratio (%)	Mann-Whitney U Statistic	Z Test	P value
Year = 2000				
East	12.59			
Central	25.97	68	1.405	0.079*
East	12.59			
West	48.65	70	2.852	0.002***
Central	25.97			
West	48.65	48	1.747	0.040**
Year = 2001				
East	15.64			
Central	25.37	57	0.569	0.284
East	15.64			
West	47.83	66	2.491	0.006***
Central	25.37			
West	47.83	49	1.852	0.032**
Year = 2002				
East	12.01			
Central	23.59	63	1.025	0.152
East	12.01			
West	41.31	69	2.762	0.002***
Central	23.59			
West	41.31	45	1.429	0.076*
Year = 2003				
East	13.48			
Central	15.86	52	0.190	0.425
East	13.48			
West	42.36	69	2.762	0.003***
Central	15.86			
West	42.36	54	2.381	0.008***

Note: *** represents significance at the 0.01 level; ** represents significance at the 0.05 level; * represents significance at the 0.1 level.

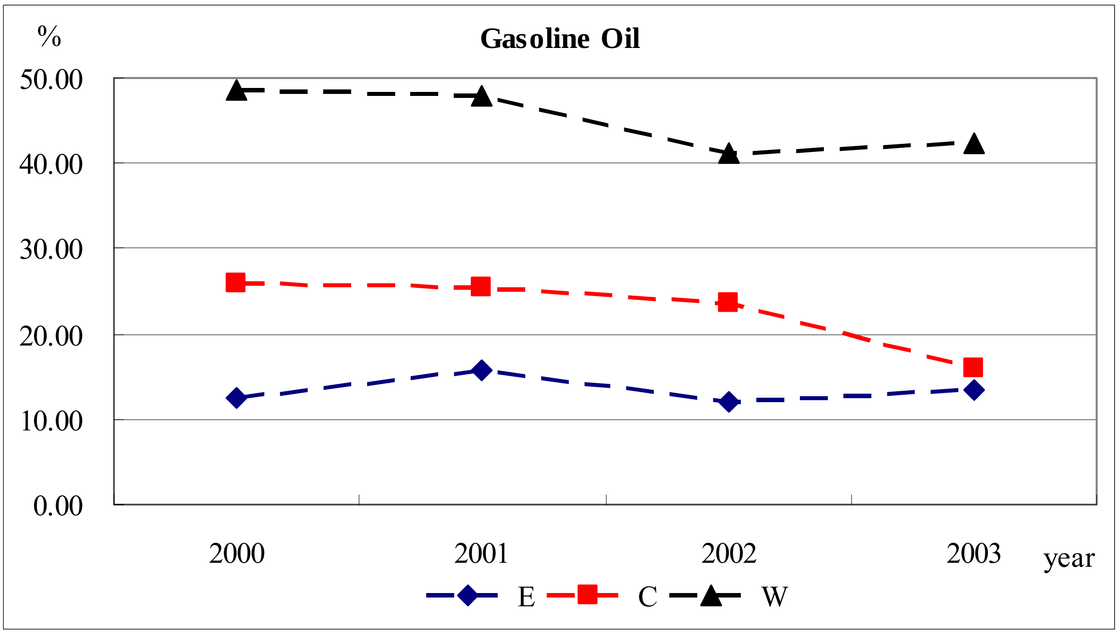

Figure 4 The average target of gasoline savings ratios in the three major areas of mainland China

4.1.1.3 Savings Ratios for Electricity Consumption

As Table 14, the east area has one region with electricity consumption target savings ratios always higher than 20% throughout the research period: Liaoning (06). The central area has two regions electricity consumption target savings ratios always higher than 30%: Shanxi (04) and Inner Mongolia (05), especially Shanxi (04) with target savings ratios higher than 50%. The west area has four regions with electricity consumption target savings ratios always higher than 30%: Guizhou (22), Shaanxi (24), Gansu (25), and Qinghai (26), especially Guizhou (22) and Qinghai (26) with target savings ratios higher than 60%.

Figure 5 show the 2000-2003 average electricity consumption savings ratios in each area. The west area always had higher target savings ratios than others. With respect to electricity consumption, the east, central, and west areas are the most, medium, and least efficient, respectively.

Table 14 Actual consumption and target savings ratios of electricity for regions in mainland China during 2000-2003.

ID	Region	Area	2000 Actual Consumption	2000 Savings Ratios	2001 Actual Consumption	2001 Savings Ratios	2002 Actual Consumption	2002 Savings Ratios	2003 Actual Consumption	2003 Savings Ratios
01	Beijing	E	384.48	23.45	398.30	17.06	436.00	6.75	461.24	3.43
02	Tianjin	E	236.55	12.83	250.47	9.81	281.00	8.86	313.00	3.52
03	Hebei	E	809.33	0.00	869.55	23.29	965.08	16.49	1098.99	16.45
04	Shanxi	C	506.09	61.25	557.08	62.41	628.83	56.43	731.77	55.23
05	Inner Mongolia	C	256.07	36.79	279.68	34.70	320.44	33.27	406.62	29.51
06	Liaoning	E	796.53	31.22	809.42	30.10	859.20	28.00	886.88	22.04
07	Jilin	C	300.57	27.94	323.36	23.74	344.54	21.52	359.40	17.07
08	Heilongjiang	C	397.24	12.98	468.13	11.11	463.02	6.27	503.63	0.00
09	Shanghai	E	559.42	0.00	592.99	0.00	645.71	0.00	745.97	0.00
10	Jiangsu	E	971.82	0.00	1078.44	3.50	1244.60	4.02	1505.13	3.75
11	Zhejiang	E	742.89	13.50	855.29	12.19	1015.84	7.41	1240.35	4.91
12	Anhui	C	338.92	0.00	359.62	0.00	389.94	0.00	445.44	2.57
13	Fujian	E	403.02	0.00	439.98	0.00	497.86	0.00	585.35	0.00
14	Jiangxi	C	209.39	1.65	222.29	0.00	246.56	0.00	299.53	0.00
15	Shandong	E	1000.49	0.00	1560.20	0.00	1230.02	0.00	1395.72	0.00
16	Hennan	C	717.62	12.85	808.41	3.77	927.56	20.61	1054.64	24.99
17	Hubei	C	503.02	12.60	526.03	8.53	567.43	7.82	629.20	5.51
18	Hunan	C	406.20	0.00	439.68	0.00	476.00	0.00	546.95	0.00
19	Guangdong	E	1334.58	0.00	1458.43	0.00	1687.83	0.00	2031.29	0.00
20	Guangxi	E	322.02	27.25	322.02	21.84	356.95	12.35	414.93	12.15
21	Sichuan	W	769.87	25.22	866.82	26.30	954.27	22.71	1052.98	19.47
22	Guizhou	W	334.76	63.85	449.05	72.51	491.67	66.31	551.07	63.82
23	Yunnan	W	317.25	30.66	347.07	32.90	393.46	36.75	409.79	25.03
24	Shaanxi	W	314.39	45.69	344.69	42.84	373.86	41.76	421.92	37.23
25	Gansu	W	295.34	57.77	306.09	55.98	342.86	57.15	398.33	51.17
26	Qinghai	W	115.96	74.25	111.81	67.75	132.67	66.29	158.51	67.87
27	Xinjiang	W	182.98	21.38	197.62	20.84	212.24	19.42	234.62	10.57
	Area Average									
		E	687.38	9.84	785.01	10.71	838.19	7.63	970.80	6.02
		C	403.90	18.45	442.70	16.03	484.92	16.21	553.02	14.99
		W	332.94	45.55	374.74	45.59	414.43	44.34	461.03	39.31

Notes: 1. Actual consumption is in 100 million KWH.
2. Savings ratios are in percentage terms.

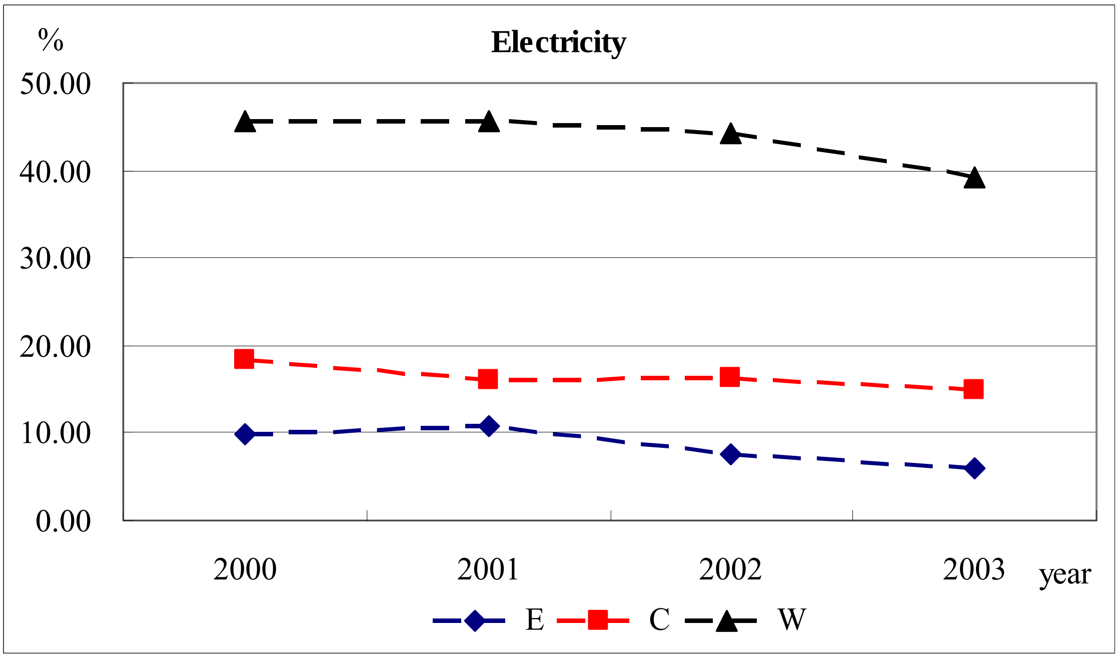

Figure 5 The average target of electricity savings ratios in the three major areas of mainland China

During the 2000-2003 period, the average electricity consumption target savings ratios in three areas were stable. However, the average electricity consumption savings ratios of the west area stayed around 40% during the 2000-2003 period, showing no significant improvement.

Table 15 shows the Mann-Whitney test on target electricity savings ratios for three major areas in mainland China during 2000-2003. It presents that the target savings ratio of west area is significantly more than central area, which of the west area is significantly more than east area; and which of central area is not significantly more than east area. Summary of target electricity savings for three areas, east area and central area are more efficient and west area is most inefficient.

Table 15 Mann-Whitney test on target electricity savings ratios for three major areas

Area	Average Ratio (%)	Mann-Whitney U Statistic	Z Test	P value
Year = 2000				
East	9.84			
Central	18.45	64	1.102	0.135
East	9.84			
West	45.55	71	2.943	0.002***
Central	18.45			
West	45.55	53	2.276	0.011**
Year = 2001				
East	10.71			
Central	16.03	54	0.342	0.366
East	10.71			
West	45.59	73	3.125	0.000***
Central	16.03			
West	45.59	54	2.382	0.009***
Year = 2002				
East	7.63			
Central	16.21	60	0.798	0.213
East	7.63			
West	44.34	75	3.306	0.000***
Central	16.21			
West	44.34	55	2.488	0.006***
Year = 2003				
East	6.02			
Central	14.99	61	0.874	0.191
East	6.02			
West	39.31	73	3.125	0.000***
Central	14.99			
West	39.31	52	2.170	0.015**

Note: ***represents significance at the 0.01 level; **represents significance at the 0.05 level.

4.1.2 Benchmark for Types of Energy Savings Ratios

From Tables 10, 12, 14 and 16 the five regions in mainland China are found to always have zero target savings ratios of three major types of energy, implying that their three major types of energy are efficient during the research period. One of these regions is located in the central area: Hunan (18), others are located in the east area:

Shanghai (09), Fujian (13), Shandong (15), and Guangdong (19). It shows that the above five regions are the benchmark for the industrial three major types of energy savings ratios.

4.1.3 General Comments on Three Types of Energy Savings

From Table 17, the four-year average target savings ratios of coal consumption for the east, central, and west areas are respectively 18.58%, 44.00%, and 59.80%. The four-year average target savings ratios of gasoline consumption for the east, central, and west areas are respectively 13.43%, 22.70%, and 45.04%. The four-year average target savings ratios of electricity consumption for the east, central, and west areas are respectively 8.55%, 16.42%, and 43.70%.

Our empirical findings of this part show that the east area has most of the efficient regions with respect to the three major types of energy. The east area has the lowest average target savings ratios for the three major types of energy. Therefore, the west area consumed the highest grade of energy, but they still cannot provide better living standard. This means that the least-developed west area is using environmental goods inefficiently.

Comparing to those cases of gasoline and electricity, the average target savings ratios for coal consumption are relatively much higher in all three areas. This shows that coal reduction is mainland China's most urgent task.

Table 16 Average overall technical efficiency for regions in mainland China during 2000-2003

ID	Region	Area	*2000*	*2001*	*2002*	*2003*
01	Beijing	E	0.82	0.89	0.93	0.97
02	Tianjin	E	0.87	0.90	0.93	0.97
03	Hebei	E	1.00	1.00	0.99	0.99
04	Shanxi	C	0.54	0.55	0.58	0.63
05	Inner Mongolia	C	0.63	0.65	0.67	0.71
06	Liaoning	E	0.78	0.70	0.72	0.78
07	Jilin	C	0.72	0.76	0.79	0.83
08	Heilongjiang	C	0.87	0.89	0.94	1.00
09	Shanghai	E	1.00	1.00	1.00	1.00
10	Jiangsu	E	1.00	0.97	0.96	0.96
11	Zhejiang	E	0.87	0.88	0.93	0.95
12	Anhui	C	1.00	1.00	1.00	0.97
13	Fujian	E	1.00	1.00	1.00	1.00
14	Jiangxi	C	0.98	1.00	1.00	1.00
15	Shandong	E	1.00	1.00	1.00	1.00
16	Hennan	C	0.96	0.96	0.93	0.97
17	Hubei	C	0.87	0.92	0.92	0.95
18	Hunan	C	1.00	1.00	1.00	1.00
19	Guangdong	E	1.00	1.00	1.00	1.00
20	Guangxi	E	0.91	0.92	0.88	0.88
21	Sichuan	W	0.75	0.74	0.77	0.81
22	Guizhou	W	0.65	0.64	0.65	0.62
23	Yunnan	W	0.76	0.74	0.74	0.75
24	Shaanxi	W	0.54	0.57	0.58	0.63
25	Gansu	W	0.51	0.53	0.53	0.53
26	Qinghai	W	0.45	0.47	0.52	0.51
27	Xinjiang	W	0.79	0.79	0.81	0.89

Table 17 Average annual target savings ratios for regions in mainland China during 2000-2003

ID	Region	Area	*Coal Savings Ratios*	*Gasoline Savings Ratios*	*Electricity Savings Ratios*
01	Beijing	E	9.82	38.84	12.67
02	Tianjin	E	42.22	46.24	8.76
03	Hebei	E	44.91	0.74	14.06
04	Shanxi	C	91.78	42.30	58.83
05	Inner Mongolia	C	85.32	36.22	33.57
06	Liaoning	E	56.53	31.85	27.84
07	Jilin	C	70.90	32.88	22.57
08	Heilongjiang	C	47.40	46.11	7.59
09	Shanghai	E	0.00	0.00	0.00
10	Jiangsu	E	16.39	2.82	2.82
11	Zhejiang	E	23.65	11.29	9.50
12	Anhui	C	9.62	0.64	0.64
13	Fujian	E	0.00	0.00	0.00
14	Jiangxi	C	13.82	2.03	0.41
15	Shandong	E	0.00	0.00	0.00
16	Hennan	C	26.44	4.28	15.55
17	Hubei	C	50.73	39.82	8.62
18	Hunan	C	0.00	0.00	0.00
19	Guangdong	E	0.00	0.00	0.00
20	Guangxi	E	10.88	15.93	18.40
21	Sichuan	W	40.52	26.51	23.43
22	Guizhou	W	81.43	36.29	66.62
23	Yunnan	W	41.25	35.35	31.33
24	Shaanxi	W	55.86	46.21	41.88
25	Gansu	W	70.78	66.39	55.52
26	Qinghai	W	61.66	51.12	69.04
27	Xinjiang	W	67.08	53.39	18.05
	Area Average				
		E	18.58	13.43	8.55
		C	44.00	22.70	16.42
		W	59.80	45.04	43.70

Note: Abatement ratios are in percentage terms.

4.2 Waste of Mainland China

4.2.1 Regional Abatements Ratios for Three Industrial Wastes

This part shows the regional target abatements ratios of three industrial wastes during 2000-2003, and the average regional target abatements ratios of three industrial wastes during 2000-2003. Figures show the trends of regional target abatements ratios in the three major areas of mainland China.

4.2.1.1 Abatements Ratios for Solid Wastes Produced

As Table 18, the east area has three regions with solid waste produced abatements ratios always higher than 30% throughout the research period: Hebei (03), Liaoning (06), and Guangxi (20). The central area has eight regions with solid waste produced target abatements ratios always higher than 30%: Shanxi (04), Inner Mongolia (05), Jilin (07), Heilongjiang (08), Anhui (12), Jiangxi(14), Hennan (16), and Hubei (17), especially Shanxi (04), Inner Mongolia (05), Anhui (12), and Hubei (17) with target abatements ratios higher than 60%. The west area has five areas with solid waste produced target abatements ratios always higher than 30%: Guizhou (22), Yunnan (23), Shaanxi (24), Gansu (25) and Qinghai (26), especially Guizhou (22) and Yunnan (23), with target abatements ratios higher than 80%.

Table 18 and Figure 6 describe the 2000-2003 average solid waste produced abatements ratios in each area. The solid waste produced abatements ratios of the east area is the lowest, while the central and west areas have similarly high abatements ratios. With respect to solid wastes produced, the east, central, and west areas are the most, medium, and least efficient, respectively. The central area at one time had higher target abatements ratios than the west area.

Table 18 Actual produced and target abatements ratios of industrial solid wastes for regions in mainland China during 2000-2003

ID	Region	Area	2000		2001		2002		2003	
			Actual Produced	*Abatement Ratios*	*Actual Produced*	*Abatement Ratios*	*Actual Produced*	*Abatement Ratios*	*Actual Produced*	*Abatement Ratios*
01	Beijing	E	1139	0.03	1136	0.00	1053	0.00	1186	0.00
02	Tianjin	E	470	0.00	575	1.60	643	9.69	644	0.00
03	Hebei	E	7028	79.21	8847	78.68	8503	81.21	8975	86.96
04	Shanxi	C	7695	95.81	7211	94.94	8295	85.74	9252	85.67
05	Inner Mongolia	C	2376	87.54	2483	86.53	3044	65.80	3647	68.33
06	Liaoning	E	7563	83.18	7865	75.35	8146	81.29	8250	81.39
07	Jilin	C	1604	79.03	1635	76.38	1631	61.89	1736	53.44
08	Heilongjiang	C	2694	77.75	2925	76.42	3086	54.81	3097	58.64
09	Shanghai	E	1355	0.00	1605	0.00	1595	0.00	1659	0.00
10	Jiangsu	E	3038	14.64	3553	40.73	3796	42.23	3894	38.27
11	Zhejiang	E	1386	16.52	1603	15.28	1778	15.85	1976	14.83
12	Anhui	C	2815	69.92	3262	70.04	3415	77.32	3522	81.41
13	Fujian	E	2191	0.00	5133	0.00	4131	0.00	2981	0.00
14	Jiangxi	C	4796	86.76	4377	53.59	5850	80.90	6182	92.45
15	Shandong	E	5407	68.44	6215	69.73	6559	0.00	6786	0.00
16	Hennan	C	3625	60.10	3935	57.40	4251	68.15	4467	73.99
17	Hubei	C	2818	65.61	2694	62.24	2977	65.96	3112	71.39
18	Hunan	C	2355	0.00	2464	0.00	2434	0.00	2754	72.24
19	Guangdong	E	1694	0.02	1990	0.00	2045	0.00	2246	0.00
20	Guangxi	E	2108	37.97	2648	47.89	2535	45.71	3224	86.02
21	Sichuan	W	6019	67.44	5813	30.27	5921	77.96	6281	61.47
22	Guizhou	W	2272	90.29	2367	89.35	2879	79.76	3772	80.49
23	Yunnan	W	3187	85.52	3134	85.15	3433	82.91	3418	82.19
24	Shaanxi	W	2625	87.57	2408	82.48	2887	69.78	2948	69.27
25	Gansu	W	1704	88.65	1286	84.13	1734	66.61	2073	73.41
26	Qinghai	W	337	79.70	368	78.98	314	46.04	379	53.99
27	Xinjiang	W	718	44.40	784	51.45	1008	20.05	1087	20.94
	Area Average									
		E	3034	27.27	3743	29.93	3708	25.09	3802	27.95
		C	3420	69.17	3443	64.17	3887	62.29	4197	73.06
		W	2409	77.65	2309	71.69	2597	63.30	2851	63.11

Notes: 1. Actual produced are in 10,000 tons.
2. Abatement ratios are in percentage terms.

Among the three wastes, the solid waste produced target abatements ratios are generally the highest, implying that solid wastes produced may be the most critical task for controlling waste in mainland China.

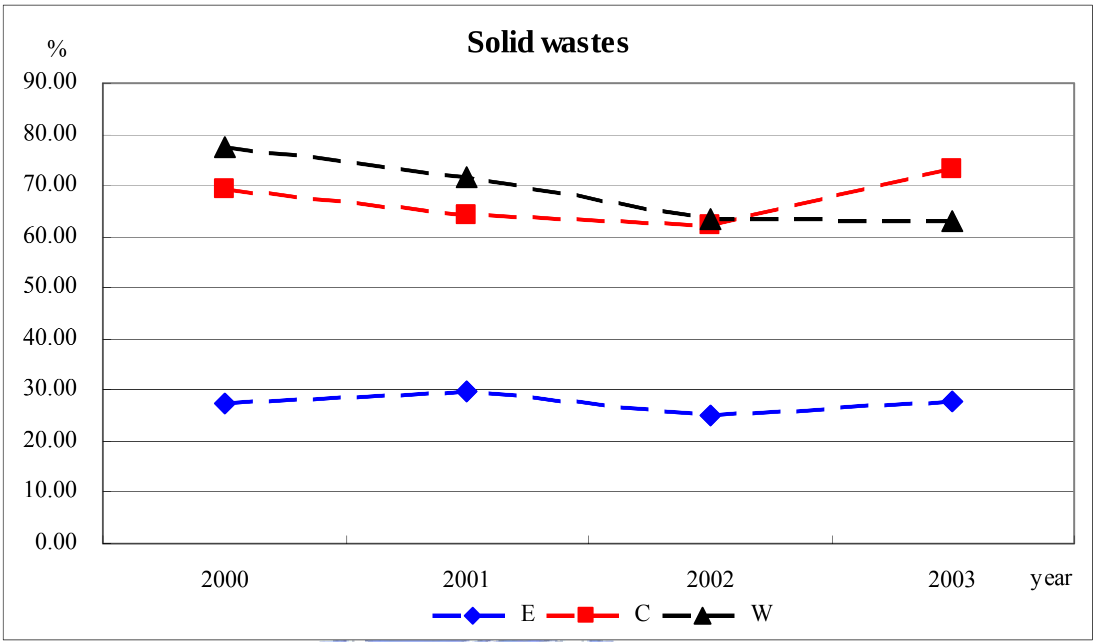

Figure 6 The average target solid waste abatements ratios in the three major areas of mainland China

Table 19 shows the Mann-Whitney test on target solid waste abatements ratios for three major areas in mainland China during 2000-2003. It presents that the target abatements ratios of west area is significantly more than east area, and which of the central area is significantly more than east area, but which of west area is not significantly more than central area. Summary of target solid waste abatement for three areas, east area is most efficient, and west area and central area are the most inefficient.

Table 19 Mann-Whitney test on target solid waste abatements ratios for three major areas

Area	Average Ratio (%)	Mann-Whitney U Statistic	Z Test	P value
Year = 2000				
East	27.27			
Central	69.17	77.5	2.127	0.017**
East	27.27			
West	77.65	70	2.853	0.002***
Central	69.17			
West	77.65	40	0.899	0.184
Year = 2001				
East	29.93			
Central	64.17	77	2.089	0.018**
East	29.93			
West	71.69	69	2.762	0.003***
Central	64.17			
West	71.69	38	0.688	0.246
Year = 2002				
East	25.09			
Central	62.29	76.5	2.051	0.020**
East	25.09			
West	63.30	63	2.218	0.013**
Central	62.29			
West	63.30	35	0.370	0.355
Year = 2003				
East	27.95			
Central	73.06	77	2.089	0.018**
East	27.95			
West	63.11	56	1.585	0.056*
Central	73.06			
West	63.11	39	0.794	0.214

Note: ***represents significance at the 0.01 level; **represents significance at the 0.05 level; *represents significance at the 0.1 level.

4.2.1.2 Abatements Ratios for Waste Water Discharged

The east area has three regions with waste water discharged abatements ratios always higher than 30% throughout the research period: Liaoning (06), Jiangsu (10), and Zhejiang (11). The central area has one region with waste water discharged target abatements ratios always higher than 30%: Hubei (17). The west area has three areas with waste water discharged target abatements ratios always higher than 30%: Sichuan (21), Shaanxi (24), and Gansu (25).

Table 20 and Figure 7 show the 2000-2003 average waste water discharged abatements ratios in each area. The east, central, and west areas have the lowest, medium, and highest waste water discharged abatements ratios, respectively. With respect to waste water discharged, the east, central, and west areas are the most, medium, and least efficient, respectively.

Although the waste water discharged abatement ranking of the east and central areas are always at the lowest and medium, their average target abatements ratios have been increasing during the research period. However, the average target abatements ratios of the west area always stayed above 30% during the 2000-2003 period, showing no significant improvement at all.

Table 21 shows the Mann-Whitney test on target waste water abatements ratios for three major areas in mainland China during 2000-2003. It presents that the target abatements ratios of the central area is not significantly more than east area, and which of west area is not still not significantly more than central area, but which of west area is always significantly more than east area. Summary of target solid waste abatement for three areas, east area is most efficient, and west area is the most inefficient.

Table 20 Actual discharged and target abatements ratios of industrial waste water for regions in mainland China during 2000-2003

ID	Region	Area	2000		2001		2002		2003	
			Actual Discharged	*Abatement Ratios*	*Actual Discharged*	*Abatement Ratios*	*Actual Discharged*	*Abatement Ratios*	*Actual Discharged*	*Abatement Ratios*
01	Beijing	E	23164	0.00	21165	0.00	18044	0.00	13107	0.00
02	Tianjin	E	17604	0.00	21250	1.60	21959	1.01	21605	0.00
03	Hebei	E	89600	7.29	103041	11.70	106772	11.91	108324	28.42
04	Shanxi	C	32406	41.01	31093	40.87	30777	32.56	30929	27.16
05	Inner Mongolia	C	21844	26.29	20960	25.12	22737	22.11	23577	17.00
06	Liaoning	E	109044	42.07	99505	40.43	92001	38.54	89186	40.64
07	Jilin	C	37386	40.65	35574	39.06	34783	23.61	31365	19.22
08	Heilongjiang	C	52644	24.83	49444	21.84	47983	7.64	50286	8.34
09	Shanghai	E	72446	0.00	68012	0.00	64857	0.00	61112	0.00
10	Jiangsu	E	201923	45.77	271029	60.05	262715	50.44	247524	46.61
11	Zhejiang	E	136433	47.38	158113	53.38	168048	44.24	168088	39.85
12	Anhui	C	63106	23.06	63229	23.20	64577	23.52	63525	31.70
13	Fujian	E	57617	0.00	69724	0.00	78511	0.00	98388	0.00
14	Jiangxi	C	41956	38.53	41507	22.23	46119	25.08	50135	38.31
15	Shandong	E	110324	10.23	115233	14.72	106668	0.00	115933	0.00
16	Hennan	C	109210	24.29	110152	24.40	114431	24.93	114224	32.58
17	Hubei	C	106733	44.40	97714	43.80	98481	32.41	96498	38.84
18	Hunan	C	112563	0.00	107175	0.00	111788	0.00	124132	59.17
19	Guangdong	E	114055	0.00	112812	0.00	145236	0.00	148867	0.00
20	Guangxi	E	81571	23.38	90512	33.69	97126	34.92	119291	74.95
21	Sichuan	W	201323	63.50	196134	58.26	197510	56.85	202133	47.27
22	Guizhou	W	20598	33.97	20812	35.82	17117	25.59	16815	24.76
23	Yunnan	W	35117	20.62	32713	23.84	33696	21.19	34655	24.71
24	Shaanxi	W	30903	37.55	28634	35.76	30496	32.34	33526	34.17
25	Gansu	W	23795	47.66	20722	45.39	19677	36.66	20899	38.57
26	Qinghai	W	4661	37.27	4385	34.64	3583	21.93	3453	23.46
27	Xinjiang	W	15365	4.20	16797	15.41	16426	12.51	16417	11.74
	Area Average									
		E	92162	16.01	102763	19.60	105631	16.46	108311	20.95
		C	64205	29.23	61872	26.73	63520	21.32	64963	30.26
		W	47395	34.97	45742	35.59	45501	29.58	46843	29.24

Notes: 1. Actual discharged are in 10,000 tons.
2. Abatement ratios are in percentage terms.

Table 21 Mann-Whitney test on target waste water abatements ratios for three major areas

Area	Average Ratio (%)	Mann-Whitney U Statistic	Z Test	P value
Year = 2000				
East	16.01			
Central	29.23	66.5	1.292	0.098*
East	16.01			
West	34.97	58	1.766	0.038**
Central	29.23			
West	34.97	35	0.370	0.355
Year = 2001				
East	19.60			
Central	26.73	63	1.025	0.153
East	19.60			
West	35.59	57	1.675	0.047**
Central	26.73			
West	35.59	41	1.006	0.157
Year = 2002				
East	16.46			
Central	21.32	57.5	0.608	0.272
East	16.46			
West	29.58	54	1.404	0.080*
Central	21.32			
West	29.58	38	0.688	0.246
Year = 2003				
East	20.95			
Central	30.26	62	0.949	0.171
East	20.95			
West	29.24	48	0.860	0.195
Central	30.26			
West	29.24	32	0.053	0.479

Note: * represents significance at the 0.1 level; ** represents significance at the 0.05 level.

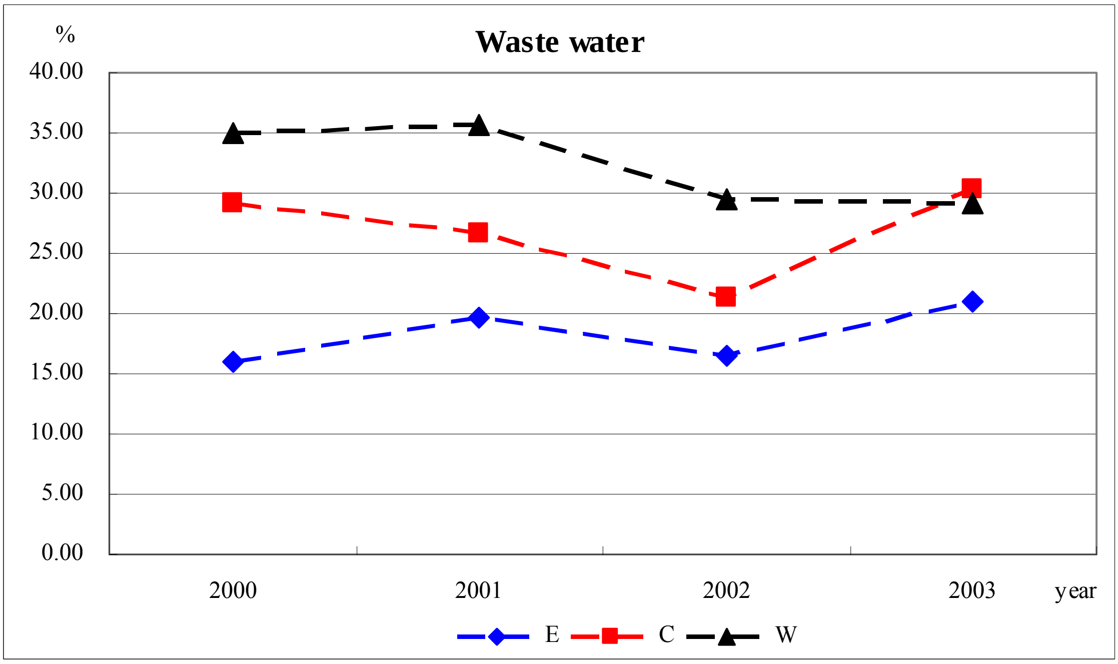

Figure 7 The average target waste water discharged abatements ratios in the three major areas of mainland China

4.2.1.3 Abatements Ratios for Waste Gas Emission

The east area has three regions with waste gas emission abatements ratios always higher than 30% throughout the research period: Hebei (03), Liaoning (06), and Guangxi (20). The central area has five regions with waste gas emission target abatements ratios always higher than 30%: Shanxi (04), Inner Mongolia (05), Jilin (07), Anhui (12), and Hennan (16), especially Shanxi (04) and Inner Mongolia (05) with target abatements ratios higher than 60%. The west area has six regions with waste gas emission target abatements ratios always higher than 30%: Sichuan (21), Guizhou (22), Yunnan (23), Shaanxi (24), Gansu (25), and Qinghai (26), especially Gansu (25) and Qinghai (26) with target abatements ratios higher than 50%.

Table 22 Actual emissions and target abatements ratios of industrial waste gas for regions in mainland China during 2000-2003

ID	Region	Area	2000		2001		2002		2003	
			Actual Emission	*Abatement Ratios*	*Actual Emission*	*Abatement Ratios*	*Actual Emission*	*Abatement Ratios*	*Actual Emission*	*Abatement Ratios*
01	Beijing	E	3227	0.00	3035	0.00	2966	0.00	3005	0.00
02	Tianjin	E	1749	0.00	2859	23.50	3677	33.24	4360	0.00
03	Hebei	E	9858	54.20	11457	54.95	12743	56.10	15768	63.41
04	Shanxi	C	6635	77.85	8027	79.97	9402	71.68	12849	75.43
05	Inner Mongolia	C	4768	73.04	4959	71.55	5998	61.44	7961	65.45
06	Liaoning	E	9432	44.08	10042	40.43	10462	39.55	12774	40.64
07	Jilin	C	3082	48.95	3237	43.51	3516	35.86	3869	34.52
08	Heilongjiang	C	4326	35.04	4617	31.36	4628	8.73	4841	11.12
09	Shanghai	E	5755	0.00	6964	0.00	7440	0.00	7799	0.00
10	Jiangsu	E	9078	14.63	13344	27.41	14286	23.59	14633	20.45
11	Zhejiang	E	6509	16.54	8530	25.46	8532	13.61	10432	21.23
12	Anhui	C	3945	31.82	4808	37.37	5119	36.81	5383	40.03
13	Fujian	E	2828	0.00	3305	0.00	3565	0.00	4189	0.00
14	Jiangxi	C	2220	26.91	2231	21.35	2612	20.83	3202	28.14
15	Shandong	E	12179	36.90	14453	41.32	14306	0.00	16139	0.00
16	Hennan	C	7436	38.80	9239	44.12	10645	47.46	11992	52.23
17	Hubei	C	5674	34.18	5820	28.24	6440	30.15	6707	34.54
18	Hunan	C	3569	0.00	3960	0.00	4190	0.00	4603	18.09
19	Guangdong	E	8326	0.00	9456	0.00	10579	0.00	11075	0.00
20	Guangxi	E	4607	56.98	5461	59.39	5693	58.38	6636	66.50
21	Sichuan	W	6687	33.19	7406	30.27	9266	33.82	8911	30.09
22	Guizhou	W	3882	77.69	3629	73.12	3515	58.77	3477	49.55
23	Yunnan	W	2749	37.75	3346	44.36	3659	39.62	4197	46.10
24	Shaanxi	W	2379	37.55	2858	40.42	3424	32.34	3861	34.17
25	Gansu	W	2800	69.57	2793	65.77	2972	51.91	4033	63.09
26	Qinghai	W	607	56.90	846	66.36	937	57.32	1002	57.75
27	Xinjiang	W	1944	26.77	2353	40.25	2512	23.76	2934	27.81
	Area Average									
		E	6686	20.30	8082	24.77	8568	20.41	9710	19.29
		C	4628	40.73	5211	39.72	5839	34.77	6823	39.95
		W	3007	48.49	3319	51.51	3755	42.51	4059	44.08

Notes: 1. Actual emissions are in 100 million m^3.
2. Abatement ratios are in percentage terms.

Table 22 and Figure 8 show the 2000-2003 average waste gas emission abatements ratios in each area. Rankings for these average waste gas emission abatements ratios are stable throughout the research period. The east, central, and west areas have the lowest, medium, and highest waste gas emission abatements ratios, respectively. With respect to waste gas emission, the east, central, and west areas are the most, medium, and least efficient, respectively.

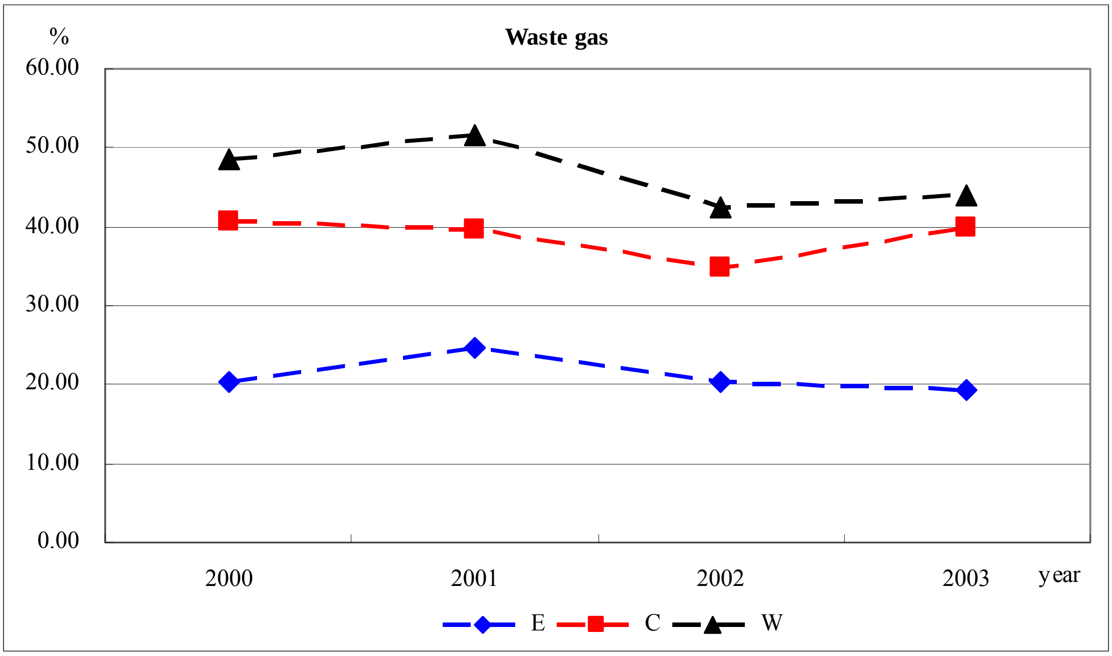

Figure 8 The average target waste gas emission abatements ratios in the three major areas of mainland China

During the 2000-2003 period, the average waste gas emission target abatements ratios in the central area was increasing, while on the contrary, in the east area and west area they were decreasing. However, the average target waste gas emission abatements ratios of the central area and west area stayed above and then around 30% during the 2000-2003 period, showing no significant improvement.

Table 23 shows the Mann-Whitney test on target waste gas abatements ratios for three major areas in mainland China during 2000-2003.

Table 23 Mann-Whitney test on target waste gas abatements ratios for three major areas

Area	Average Ratio (%)	Mann-Whitney U Statistic	Z Test	P value
Year = 2000				
East	20.30			
Central	40.73	69.5	1.519	0.064*
East	20.30			
West	48.49	62	2.128	0.017**
Central	40.73			
West	48.49	36	0.476	0.317
Year = 2001				
East	24.77			
Central	39.72	67	1.329	0.092*
East	24.77			
West	51.51	63	2.219	0.013**
Central	39.72			
West	51.51	42	1.111	0.133
Year = 2002				
East	20.41			
Central	34.77	67.5	1.367	0.086*
East	20.41			
West	42.51	61	2.038	0.021**
Central	34.77			
West	42.51	38	0.688	0.246
Year = 2003				
East	19.29			
Central	39.95	74	1.862	0.031**
East	19.29			
West	44.08	60	1.947	0.026**
Central	39.95			
West	44.08	34	0.265	0.396

Note: *represents significance at the 0.1 level ; **represents significance at the 0.05 level.

It presents that the target abatements ratios of west area is significantly more than east area, and which of the central area is significantly more than east area, but which of west area is still not significantly more than central area. Summary of target waste gas abatement for three areas, east area is most efficient, and west area and central area are the most inefficient.

4.2.2 Benchmark for Three Industrial Wastes Abatements Ratios

From Tables 18, 20, 22 and 24, the three regions in mainland China are found to always have zero target abatements ratios of three wastes, implying that their three wastes are efficient during the research period. These regions are all located in the east area: Beijing (01), Shanghai (09) and Guangdong (19). It shows that the above three regions are the benchmark for the industrial three waste abatements ratios. Hunan (18) in the central area has zero target abatements ratios for the three wastes until 2002.

4.2.3 General Comments on Three Industrial Wastes Abatements

From Table 25, the four-year average target abatements ratios of solid wastes produced for the east, central, and west areas are respectively 29.18%, 67.07%, and 68.82%. The four-year average target abatements ratios of waste water discharged for the east, central, and west areas are respectively 19.30%, 26.56%, and 32.16%. The four-year average target abatements ratios of waste gas emission for the east, central, and west areas are respectively 21.28%, 38.79%, and 46.74%.

Comparing to those cases of waste water and gas, the average target abatements ratios for solid wastes are relatively much higher in all three areas. This shows that solid waste reduction is also mainland China's most urgent task.

Table 24 Average overall technical efficiency for regions in mainland China during 2000-2003

ID	Region	Area	*2000*	*2001*	*2002*	*2003*
01	Beijing	E	1.00	1.00	1.00	1.00
02	Tianjin	E	1.00	0.98	0.99	1.00
03	Hebei	E	0.93	0.90	0.88	0.88
04	Shanxi	C	0.59	0.59	0.67	0.73
05	Inner Mongolia	C	0.74	0.75	0.78	0.83
06	Liaoning	E	0.58	0.60	0.62	0.59
07	Jilin	C	0.69	0.74	0.76	0.81
08	Heilongjiang	C	0.82	0.83	0.92	0.92
09	Shanghai	E	1.00	1.00	1.00	1.00
10	Jiangsu	E	0.85	0.84	0.86	0.87
11	Zhejiang	E	0.84	0.85	0.86	0.88
12	Anhui	C	0.77	0.77	0.77	0.75
13	Fujian	E	1.00	1.00	1.00	1.00
14	Jiangxi	C	0.73	0.79	0.79	0.75
15	Shandong	E	0.90	0.85	1.00	1.00
16	Hennan	C	0.76	0.76	0.75	0.75
17	Hubei	C	0.78	0.78	0.75	0.72
18	Hunan	C	1.00	1.00	1.00	0.95
19	Guangdong	E	1.00	1.00	1.00	1.00
20	Guangxi	E	0.85	0.86	0.87	0.85
21	Sichuan	W	0.67	0.70	0.66	0.70
22	Guizhou	W	0.66	0.64	0.74	0.75
23	Yunnan	W	0.79	0.76	0.79	0.75
24	Shaanxi	W	0.62	0.64	0.68	0.66
25	Gansu	W	0.52	0.55	0.63	0.61
26	Qinghai	W	0.63	0.65	0.78	0.77
27	Xinjiang	W	0.96	0.85	0.88	0.88

Table 25 Average annual target abatements ratios for regions in mainland China during 2000-2003

ID	Region	Area	*Solid Waste Abatement Ratios*	*Waste Water Abatement Ratios*	*Waste Gas Abatement Ratios*
01	Beijing	E	0.00	0.00	0.00
02	Tianjin	E	2.82	0.65	14.18
03	Hebei	E	81.51	14.83	57.17
04	Shanxi	C	90.54	35.42	76.24
05	Inner Mongolia	C	77.05	22.62	67.86
06	Liaoning	E	80.31	40.42	41.18
07	Jilin	C	67.68	30.63	40.71
08	Heilongjiang	C	66.91	15.68	21.57
09	Shanghai	E	0.00	0.00	0.00
10	Jiangsu	E	33.97	50.72	21.52
11	Zhejiang	E	15.62	46.21	19.21
12	Anhui	C	74.68	25.37	36.51
13	Fujian	E	17.81	11.47	0.94
14	Jiangxi	C	77.51	28.13	24.30
15	Shandong	E	34.54	6.24	19.56
16	Hennan	C	64.91	26.55	45.65
17	Hubei	C	66.30	39.87	31.78
18	Hunan	C	18.06	14.79	4.52
19	Guangdong	E	0.00	0.00	0.00
20	Guangxi	E	54.39	41.72	60.31
21	Sichuan	W	58.59	54.95	32.26
22	Guizhou	W	84.96	30.00	64.76
23	Yunnan	W	83.94	22.59	41.96
24	Shaanxi	W	77.16	35.20	36.37
25	Gansu	W	78.21	42.09	62.60
26	Qinghai	W	64.66	29.29	59.57
27	Xinjiang	W	34.22	10.98	29.66
	Area Average				
		E	29.18	19.30	21.28
		C	67.07	26.56	38.79
		W	68.82	32.16	46.74

Note: Abatement ratios are in percentage terms.

Our empirical findings of this part show that most regions with high target coal savings ratios also have high target solid wastes abatements ratios and high target waste gas abatements ratios. Because burning coal will produce the solid wastes and air pollution directly. Some regions with high target gasoline savings ratios also have high target waste gas abatements ratios.

We also find that the central and west areas have similar critical problems on the three wastes. The east area still has most of the efficient regions with respect to the three wastes, and it also has the lowest average target abatements ratios for the three wastes. The least-developed west area always has the highest average target abatements ratios for the three wastes. This implies that the most-developed east area is using environmental goods more efficiently. The last-developed areas may produce and mine using a lower grade of equipment that is highly polluting, but still they cannot afford better equipment to treat the pollutants. Better environmental performance has been accompanied with economic achievement for the more-developed east area than for the central and west areas.

Chapter 5 Concluding Remarks

In summary, this thesis employs a DEA model to analyze the targets of energy saving and waste reducing for regions in mainland China. DEA is a non-parametric method using linear programming to construct a non-parametric piecewise frontier over the data for an efficiency measurement. In order to pursue overall technical efficiency with energy and waste, this study adopts the CRS DEA model. The relative OTE for regions in mainland China from period 2000-2003 is calculated at the same time. Furthermore, both output-oriented and input-oriented CRS DEA models generate exactly the same efficiency scores, target inputs, and target outputs.

Coal, gasoline, and electricity are the three major types of energy that are inputs of industrial production. Solid waste, waste water and waste gas are the three major types of waste that are by-products of industrial production. Finding out the efficient energy savings ratios and waste abatements ratios according to the feasible Chinese production frontier is hence an important academic and policy issue. Therefore, we analyze the target abatement of individual input (including the three main types of energy and the three major types of waste) for regions in mainland China.

This thesis's main contribution is to create an input abatement index which different from the traditional DEA model. Therefore, this thesis computes the efficient energy saving targets and the efficient waste reducing targets of twenty-seven regions in mainland China during the period 2000-2003. The data envelopment analysis is used to construct the annual Chinese production frontier in each year. The values of monetary inputs and outputs such as GDP and capital are in 1996 prices. First, a single output (real GDP) and five inputs (labor, real capital stock, coal consumption, gasoline consumption, and electricity consumption) are taken into the DEA model to calculate the energy saving target. Second, a single output (real GDP) and five inputs (labor, real capital stock, solid wastes, waste water, and waste gas) are taken into the

DEA model to calculate the target waste abatement. The annual production frontier is constructed from twenty-seven Chinese regions in each year. The efficiency scores and target values of three types of energy and three types of waste for each region in each year are hence obtained by comparing to the production frontier in that year.

We establish abatement ratio by comparing the target input to the actual input further and to find the benchmark for regions in mainland China. The abatements ratios present the possible energy savings and waste abatements without reducing the maximum potential economic outputs.

Table 26 summarizes of the target energy savings ratios and waste abatements ratios for regions in mainland China. Most regions with high target coal savings ratios also have high target solid wastes abatements ratios and high target waste gas abatements ratios. Because burning coal will produce the solid wastes and air pollution directly. Some regions with high target gasoline savings ratios also have high target waste gas abatements ratios. Moreover, Shaanxi (24) and Gansu (25) have the high target abatements ratios of all energy and all waste, implying that the two regions are most inefficient among mainland China. Shanxi (04), Guizhou (22), and Qinghai (26) have high target savings ratios of three types of energy, and hence these regions could improve their efficiency by reducing consumption of coal, gasoline, and electricity. Besides, Liaoning (06) also has high target abatements ratios of three types of waste, implying that the region could reduce waste to improve its efficiency.

On the contrary, Shanghai (09) and Guangdong (19) are found to always have zero target abatements ratios of three types of energy and three types of waste. These results imply that they are producing outputs efficiently with respect to the Chinese production frontier and to be the benchmark for regions in mainland China. Moreover, Fujian (13), Shandong (15), and Hunan (18) are found to have zero target savings ratios of the three types of energy, Beijing (01) is found to have zero target abatement ratios of the three wastes.

Table 26 Summary of the target abatement for regions in mainland China

ID	Region	Area	Coal	Gasoline	Electricity	Solid Wastes	Waste Water	Waste Gas
01	Beijing	E		X				
02	Tianjin	E	X	X				
03	Hebei	E				X		X
04	Shanxi	C	X	X	X	X		X
05	Inner Mongolia	C	X		X	X		X
06	Liaoning	E	X		X	X	X	X
07	Jilin	C	X			X		X
08	Heilongjiang	C	X			X		
09	Shanghai	E						
10	Jiangsu	E					X	
11	Zhejiang	E					X	
12	Anhui	C				X		X
13	Fujian	E						
14	Jiangxi	C				X		
15	Shandong	E						
16	Hennan	C				X		X
17	Hubei	C	X	X		X	X	
18	Hunan	C						
19	Guangdong	E						
20	Guangxi	E				X		X
21	Sichuan	W					X	X
22	Guizhou	W	X	X	X	X		X
23	Yunnan	W	X			X		X
24	Shaanxi	W	X	X	X	X	X	X
25	Gansu	W	X	X	X	X	X	X
26	Qinghai	W	X	X	X	X		X
27	Xinjiang	W	X	X				

Note: X presents high target abatements ratios

For the three types of energy, target savings ratios of west area is significantly more than central area and east area, and which of central area is significantly more than east area. For the three types of waste, target abatements ratios of west area is significantly more than east area, and which of central area is significantly more than east area, but which of west area is not significantly more than central area. The results imply that east area is most efficient, and west area and central area are similar inefficient. Generally speaking, the east area performs the best in mainland China with respect to efficient for the three types of energy or the three types of waste considered. The east, central, and west areas have the lowest, medium, and highest target abatements ratios on three types of energy and three types of waste. Summary of target abatement for three areas, east area is most efficient and west area is most inefficient.

The average target coal savings ratios are relatively higher for all three areas, and the average target solid wastes abatements ratios is also relatively much higher for all three areas. These show that coal saving and solid waste reduction is mainland China's most urgent task. Mainland China should immediately engage in improving production efficiency and reducing coal consumption and recycling solid materials as its priorities.

The least-developed west area has the highest average target abatements ratios for energy and wastes. This implies that the most-developed east area is using environmental goods more efficiently. Better environmental performance has been accompanied with economic achievement for the more-developed east area than for the central and west areas. The results will provide policy suggestions for regions in mainland China to evaluate and identify their policies and programs according their income level, and to improve their overall technical efficiency by adjusting their inputs of energy and waste.

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