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Efficient saving targets of electricity and energy for regions in China

Yao-Chun Lee [a,*], Jin-Li Hu [b], Chih-Hung Kao [c]

[a] Department of Marketing & Distribution Management, Ching Yun University, 229 Chien Hsin Rd., Jung-Li 320, Taiwan
[b] Institute of Business and Management, National Chiao Tung University, Taiwan
[c] Bureau of Energy, Ministry of Economic Affairs, Taiwan

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ABSTRACT

This paper computes the three major types of efficient electricity, coal, and gasoline oil savings for 27 regions in 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 oil consumption, and electricity consumption) is used to compute the energy-saving targets of each region for each year. The efficient energy-saving ratios of each region in each year are obtained by comparing the actual energy inputs to target energy inputs. Our major findings are as follows: 1. The east area contains most of the efficient regions with respect to the three major types of energy in every year during the research period. 2. The east, central, and west areas have 2000–2003 average target saving ratios of coal consumption at 18.58%, 44.00%, and 59.80%, gasoline consumption at 13.43%, 22.70%, and 45.04%, and electricity consumption at 8.55%, 16.42%, and 43.70%, respectively. 3. Compared to the cases of gasoline oil and electricity, coal consumption saving is China's most urgent task.

1. Introduction

Energy changes and transformations make things happen. We buy energy, sell energy, eat energy, waste energy, talk a bit about conserving energy, and fight over energy. Energy, a motive force of economic activity, includes all natural resources that can be used after refining. International Energy Outlook [20] predicts that world energy consumption will increase by 60% from 1999 to 2020. Energy demand in developing Asia is projected to more than double by 2020.

Overusing energy will cause energy shortages, energy crisis, the price of energy to go up, and environment pollution. Production costs of energy rise, and this raises manufacturing costs. For the consumer, the price of energy goes higher, leading to reduced consumer confidence and spending, higher transportation costs, and general price increases. In particular, environment pollution endangers an organism's health and life indirectly through the food chain. 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., [2,4,10,24–27,40,43,44]). China, India, and other developing countries are considered the largest energy consumers and are also the largest emitters of greenhouse gases. As such, they should be involved in the efforts to solve these global problems [21].

China has abundant energy mines, but the per capita usable volume of energy is relatively low. Kambara [23] and Dorian [9] showed that the aggregate demand for energy increased correspondingly, yet the aggregate supply of energy was relatively insufficient. The inefficient energy use results from uneven mineral distribution, unbalanced regional development, and insufficient infrastructure. In order to satisfy sustainable economic development, social advancement, population growth, and increased energy demand, the energy supply must suffice the energy demand. Therefore, how to guarantee steady energy sources forms the energy topics in security, diplomacy, and trade [38].

China's energy consumption accounts for approximately 58% of East Asia's (excluding Japan) total energy consumption. All forms of energy are on the increase, and as result energy demand and use are both up. This paper presents the consumption status of the three main types of energy in China: coal, oil, and electricity. In order to avoid repeated calculation, this paper only regarded final consumptions as energy inputs.

First, coal use steadily increased in China until 1995, then declined for a few years, but now continues to rise. Coal consumption in China makes up 70% of energy use and China is the biggest consumer and producer of coal in the world. The development and production of the coal industry has provided stability in China's economic growth, but 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

* Corresponding author. Tel.: +886 3 4581196x7513; fax: +886 3 4683994.
E-mail address: yaochunlee@gmail.com (Y.-C. Lee).

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tons. A shortage of coal has limited the growth of China's steel industry, and therefore coal imports there went up to 11.09 million tons in 2003.

The major pollutants generated from coal burning are carbon dioxide and sulfur dioxide. These pollutants cause acid rain and global warming, and cause health deterioration in China's population. China's coal use discharges 19 million tons of sulfur dioxides into the atmosphere annually and impacts 30% 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, South Korea, and the Philippines have all reported acid rain originating from China's coal burning pollution.

In summary, coal burning in China is having a significant impact on the physical environment, the population in China, as well as the overall world atmosphere. Due to the rapid increase of health problems, government actions are being taken up to reduce the burning of coal and move toward cleaner technologies and renewable energies. Zhijun and Kuby [47] enhanced the model by adding investment variables for improving efficiency on coal and electricity. They found that these two energy demands in the year 2000 could be satisfied with less cost and pollution than in the supply-side-only results.

Second, China is the world's second largest oil consumer, behind the US, but its oil consumption is growing 7.5% per year, seven times faster than that of the US Growth in China's oil consumption has accelerated mainly because of a large-scale transition away from bicycles and mass transit toward private automobiles. Consequently, by the year 2010 China is expected to have 90 times more cars than in 1990. With automobiles growing at 19% a year, projections show that China could surpass the total number of cars in the US by 2030. 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 [30].

At current production rates oil is likely to last for less than two decades. In order to deal with more and more oil demand, China imported up to 95.80 million tons of crude oil in the first 8 months in 2006, up 15.3% over the same period of last year [33]. This problem has put a strain on the world's current oil contracts, and the issue has become so serious that China's president took a trip to Gabon to secure a deal for oil with Total Gabon. China's new energy plan reflects Beijing's concern about the rising cost of energy and the country's growing dependence on imported oil [34].

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

Third, total electricity consumption in China has also increased due to a growing economy and population. China's electrical power demands have increased, and the areas affected by blackouts in the future 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. 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 [32]. Increased industrial output, lower prices, and demand for high power-consuming appliances such as air-conditioners are now causing power shortages in 16 provinces. The situation has become so serious that eastern China will have electrical power shortages 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 western regions.

Steenhof [36] presented an 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 have helped increase industrial sector electricity demand between 1998 and 2002 by using decomposition analysis. Edvardsen and Førsund [11] and Jamasb and Pollitt [22] analyzed the benchmarking of the electricity industry in Europe and Northern Europe at the plant level. In summary, by 2020 projections indicate that China will be responsible for approximately 16.1% of world energy consumption. Therefore, a potential energy crisis has become a great challenge to the economic development of China.

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 to assess an economy's wealth, but it does not constitute a measure of wealth without dealing with environmental issues adequately. Although energy saving is mutually beneficial to China and the rest of the world, people may worry that a drastic reduction in energy will hamper economic growth. Therefore, given the limited availability of economically viable alternative energy sources, reducing total domestic energy use without sacrificing economic growth is an important issue for economies all over the world [8]. 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 certainly involve conflicts between environmental protection and economic growth. Therefore, energy-saving targets are very important for all economies. Efficient savings not only are feasible under China's current technology, but they also will not reduce the maximum potential economic output. Energy efficiency improvement is the key to sustainable energy management. Therefore, the main interest of this study is to address the issues related to the analysis of the targets of energy saving and the potential application and strengths of DEA for regions in China. Different from the traditional DEA model which emphasized efficiency, this thesis creates an input-saving index. It is main contribution of this paper too. This study can provide additional suggestions for the energy policies of China's economy.

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, central, and west. There is a distinct economic disparity between the coastal 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 [41].

To the best of our knowledge, the existing literature of efficient targets of energy-saving ratios does not simultaneously incorporate various types of energy. Hu and Wang [18] also indicated that China could improve its energy efficiency in various regions without reducing its potential economic growth. Hu et al. [19] find total-factor water efficiency of regions in China by the DEA. Hu and Kao [16] used the DEA approach to construct environmental-energy efficiency indicators for APEC economies. Färe et al. [12] used DEA to construct an environmental performance index focusing on pollution. In their study, energy is just one part of the inputs that are taken into account. 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. Each region's target amounts of coal consumption, gasoline oil consumption, and electricity consumption 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, the imposition of an arbitrary saving target with a developed economy's standard is avoided herein. The efficient saving ratios for each region in each year are obtained by dividing the target consumption by the actual consumption of energy.

This paper is organized as follows: Following this section, Section 2 introduces the data envelopment analysis to compute the energy-saving targets. This section also describes the data sources. Section 3 presents empirical results. Finally, Section 4 concludes this paper.

2. Method and data sources

2.1. 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 [29]. There are K inputs and M outputs for each of these N DMUs.

The envelopment of the ith DMU can be derived from the following linear programming problem:

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

where θ is a scalar representing the efficiency score for the ith DMU; λ is an $N \times 1$ vector of constants; y_i is an $M \times 1$ 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 $K \times 1$ 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 $0 \leqslant \theta \leqslant 1$, with a value of 1 indicating a point on the frontier and hence a technically efficient DMU [7]. 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 ith DMU. The weight λ serves to form a convex combination of observed inputs and outputs. It is an input-orientated measurement of efficiency.

Eq. (1) is known as the constant returns to scale (CRS) DEA model [3]. This model finds the overall technical efficiency (OTE) of each DMU. The variable returns to scale (VRS) DEA model [1] further decomposes the overall technical efficiency into pure technical efficiency (PTE) and scale efficiency (SE): OTE = PTE $\times$ SE. In order to pursue overall technical efficiency with energy, 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.

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 of our knowledge, the existing literature of efficient targets of energy-saving ratios does not simultaneously incorporate various types of energy. For example, Hu [15] used three air emissions as inputs to compute the efficient air pollution abatement ratios in China. Hu and Lee [17] found the target waste abatement of three wastes for 27 regions in China through DEA. Hu et al. [19] found total-factor water efficiency of regions in China by DEA.

2.2. Regional performance evaluation

We take the economic production function that is constructed by data envelopment analysis to analyze regional efficiencies in China. Three major types of energy (electricity, coal, and gasoline oil) 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). The target inputs and outputs for a DMU to be efficient can be computed by the DEA approach. The target saving ratios of the regions are then calculated from dividing target consumption by actual consumption.

Labor and capital are two major inputs in production. When measuring a nation's overall output, gross domestic product (GDP) is commonly used. For example, Färe et al. [13] analyzed the productivity growth of OECD countries, by considering labor and capital as inputs and GDP as an output. Chang and Luh [2] adopted similar inputs and outputs to analyze the productivity growth of ten Asian economies.

The change in income and energy is a two-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 and energy should be both taken into account in order to correct a nation's output.

The following analytical process considers coal, gasoline oil, and electricity as inputs in order to find the target input levels by the DEA approach.

2.3. 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 [28].[1] Monetary inputs and outputs such as GDP and capital stock are deflated to 1996 values. From the *China Energy Statistical Yearbook*, we establish the three types of energy dataset for 27 regions in China (24 provinces and three municipalities) during 2000–2003. Note that Chongqing became a municipality out of Sichuan in 1997 and in this study its outputs and inputs are included in Sichuan.

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 apparent economic disparity between the coastal 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 [41].

There are five inputs and one output in the DEA model to calculate the energy-saving targets. The five inputs are capital stock,

[1] The capital stock data are not available in the *China Statistical Yearbook*. In this study, the authors calculate every regional capital stock in a specific year 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 [28].

number of employed persons, and electricity consumption, coal consumption, and gasoline oil consumption. The only one output is the GDP of a specific region. These include aggregated input and output proxies. Three inputs of energy are treated as the cost of production, and they are China's three types of most important energy. To avoid the double counting problem, these three energy inputs are for final consumption. The values of monetary inputs and outputs such as GDP and capital are in 1996 prices.

Tables 1 and 2 show summary statistics of these inputs and outputs ordered by year and area, respectively. The east area has the highest GDP, capital stock, electricity consumption, and gasoline oil consumption. The central area has the largest number of employed people and the highest coal consumption. As shown in Table 3, all inputs have positive correlation coefficients with the output – that is, all inputs satisfy the isotonicity property with the output.

This paper uses the software Deap 2.1, kindly provided by Coelli [6], for computing the target inputs and outputs of each region in each year.

3. Empirical analysis

3.1. Regional saving ratios for the three major types of energy

Three major types of energy consumption (coal, gasoline oil, 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). 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 for each year. The target inputs of a DMU for a certain 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 oil consumption, and electricity consumption 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 saving target with a developed economy's standard is avoided herein. Hu and Wang [18], Hu and Kao [16], and Honma and Hu [14] constructed a total-factor energy-saving ratio index to compute how far away a region's energy input is from the efficient level. The higher the saving ratio is, the lower the total-factor efficiency will be.

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

where it is in the ith region and the tth year for kth input. As Eq. (2) shows, the saving ratio represents how far away a region's three major types of energy are from the efficient levels. The efficient targets of energy-saving ratios for each region in each year are then obtained by dividing the target energy consumption with the actual energy consumption. The actual value is always larger than or equal to the target value such that the saving ratio will always be between zero and unity.

After the DEA computation, Tables 4–6 present the regional target saving ratios of coal consumption, gasoline oil, and electricity consumption during 2000–2003. Moreover, the average regional target saving ratios of coal consumption, gasoline oil, and electricity consumption during 2000–2003 are depicted in Figs. 1–3, showing the trends of regional target saving ratios.

3.2. Saving ratios for electricity consumption

The east area has one region with electricity consumption target saving ratios always higher than 20% throughout the research period: Liaoning (06). The central area has two regions with electricity consumption target saving ratios always higher than 30%:

Table 1
Summary statistics of inputs and outputs by year.

		2000	2001	2002	2003
Inputs					
Capital stock	Mean	11,647	12,366	13,105	13,943
(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
Volume of electricity consumption	Mean	501	565	611	699
(100 million KWH)	Std. Dev.	296	366	377	448
Volume of coal consumption	Mean	5396	5624	6166	7077
(10,000 tons)	Std. Dev.	3311	3487	4077	4588
Volume of gasoline oil consumption	Mean	125	136	144	158
(10,000 tons)	Std. Dev.	64	76	81	93
Outputs					
Gross domestic product	Mean	2623	2687	2728	2848
(100 million RMB)	Std. Dev.	1833	1889	1935	2055

Notes:
1. The monetary values are in 1996 prices.
2. Data source: *China Energy Statistical Yearbook*, 2004–2005.

Table 2
Summary statistics of inputs and outputs by area.

		Area of China		
		East	Central	West
Inputs				
Capital stock	Mean	19,616	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
Volume of electricity consumption	Mean	820	471	396
(100 million KWH)	Std. Dev.	442	194	245
Volume of coal consumption	Mean	6580	7145	3870
(10,000 tons)	Std. Dev.	3973	4155	2392
Volume of gasoline oil consumption	Mean	180	126	98
(10,000 tons)	Std. Dev.	77	71	63
Outputs				
Gross domestic product	Mean	4002	2196	1385
(100 million RMB)	Std. Dev.	2070	910	1258

Notes:
1. The monetary values are in 1996 prices.
2. Data source: *China Energy Statistical Yearbook*, 2004–2005.

Table 3
The correlation coefficients between inputs and the output.

	Real capital stock	Labor	Electricity	Coal	Gasoline oil
Real GDP	0.81	0.68	0.93	0.47	0.81

Table 4
2000–2003 actual consumption and target saving ratios of electricity for regions in China.

ID	Region	Area	2000		2001		2002		2003	
			Actual consumption	Saving ratio	Actual consumption	Saving ratio	Actual consumption	Saving ratio	Actual consumption	Saving ratio
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. Saving ratios are in percentage terms.

Shanxi (04) and Inner Mongolia (05), while Shanxi (04) has target saving ratios higher than 50%. The west area has four regions with electricity consumption target saving ratios always higher than 30%: Guizhou (22), Shaanxi (24), Gansu (25), and Qinghai (26), where Guizhou (22) and Qinghai (26) have target saving ratios higher than 60%.

Table 6 and Fig. 3 show the 2000–2003 average electricity consumption saving ratios in each area. The west area always has higher target saving ratios than the others. With respect to electricity consumption, the east, central, and west areas are the most, medium, and least efficient, respectively.

During the 2000–2003 period, the average electricity consumption target saving ratio in the three areas was stable. However, the average electricity consumption saving ratio of the west area stayed around 40% during the 2000–2003 period, showing no significant improvement.

3.3. Saving ratios for coal consumption

The east area has two regions with coal consumption saving ratios always higher than 30% throughout the research period: Tianjin (02) and Liaoning (06). The central area has five regions with coal consumption target saving 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 saving ratios higher than 80%. The west area has six regions with coal consumption target saving 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 saving ratios higher than 60%.

Table 5 and Fig. 2 describe the 2000–2003 average coal consumption saving ratios in each area. The coal consumption saving ratio of the east area is the lowest, of which the central area 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 saving ratios are generally the highest, implying that coal consumption may be the most critical task for saving energy in China.

3.4. Saving ratios for gasoline oil consumption

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

Table 6 and Fig. 3 show the 2000–2003 average gasoline oil consumption target saving ratios in each area. The east, central, and west areas have the lowest, medium, and highest gasoline oil consumption saving ratios, respectively. With respect to gasoline oil consumption, the east, central, and west areas are the most, medium, and least efficient, respectively.

Table 5
2000–2003 actual consumption and target saving ratios of coal for regions in China.

ID	Region	Area	2000		2001		2002		2003	
			Actual consumption	Saving ratio	Actual consumption	Saving ratio	Actual consumption	Saving ratio	Actual consumption	Saving ratio
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	12,115	0.00	12,641	61.83	13,739	61.90	14,851	55.91
04	Shanxi	C	14,262	92.92	14,856	92.83	18,055	91.59	20,502	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	10,454	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	10,849	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	11,098	0.00	12,938	0.00	15,166	0.00
16	Hennan	C	8725	31.22	9325	18.89	10,333	30.93	11,420	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. Saving ratios are in percentage terms.

The average gasoline oil consumption target saving ratios of the east and west areas are stable throughout the research period, with the central area decreasing. However, the average target saving ratio of the west area is always above 40% during the 2000–2003 periods, showing no significant improvement at all.

3.5. Energy-efficient benchmarks

From Tables 4–6, the five regions in China are found to always have zero target saving ratios of the 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 of Hunan (18), while the 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 three major types of energy-saving ratios.

On the contrary, Shanxi (04), Guizhou (22), Shaanxi (24) Gansu (25), and Qinghai (26) have high target saving ratios of all energy types, implying that these regions are most inefficient among China. Among them, Shaanxi (04) and Shanxi (24) produce a large amount of coal, and these regions have abundant petroleum. Guizhou (22) also has abundant water resources for generating electricity.

3.6. General comments on coal, gasoline oil, and electricity consumption savings

From Table 7, the 4-year average target saving ratios of electricity consumption for the east, central, and west areas are respectively 8.55%, 16.42%, and 43.70%. The 4-year average target saving ratios of coal consumption for the east, central, and west areas are respectively 18.58%, 44.00%, and 59.80%. The 4-year average target saving ratios of gasoline oil consumption for the east, central, and west areas are respectively 13.43%, 22.70%, and 45.04%.

Our empirical findings show that the east area has most of the efficient regions with respect to the three major types of energy, while the energy consumption and the regional economic growth are out of step in the west area. The east area also has the lowest average target saving ratios for the three major types of energy. This implies that the most-developed east area is using environmental goods more efficiently. At the same time, the west area consumed the highest grade of energy, but still could not provide better living standards. This means that the least-developed west area is using environmental goods inefficiently. A better environmental performance has been accompanied with economic achievement for the more-developed east area than for the central and west areas.

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

According to our data, most of efficient energy use areas locate in China east. We think the reason is highly related the step of China's economic growth. After an open-door policy in 1978, FDI was promoted in most industries and centralized in coastal regions. In order to attract foreign firms with high technology, China's government put most resources to build up the more sufficient

Table 6
2000–2003 actual consumption and target saving ratios of gasoline oil for regions in China.

ID	Region	Area	2000		2001		2002		2003	
			Actual consumption	Saving ratio	Actual consumption	Saving ratio	Actual consumption	Saving ratio	Actual consumption	Saving ratio
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. Saving ratios are in percentage terms.

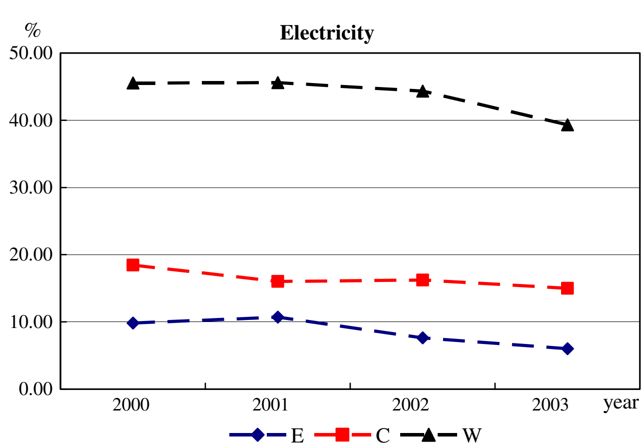

Fig. 1. The average target electricity saving ratios in the three major areas of China.

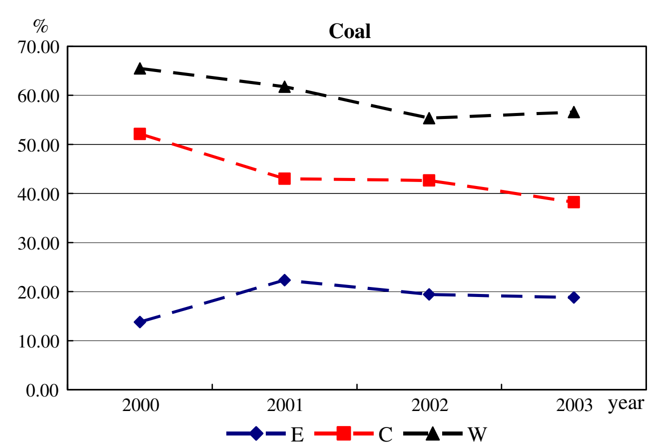

Fig. 2. The average target coal saving ratios in the three major areas of China.

infrastructure in the relatively developed provinces like Guangdong, Shandong and Fujian. The local government purchased petrochemical manufacturing equipment, pipelines, substation integration and automation systems, and automatic control system of adding pressure station with the mixed coal gas to upgrade the infrastructure and then set up the national science and industrial park [5,45,46]. According to the survey of National Bureau of Statistics of China [31], the leading industry of the relatively developed provinces focus on the Information Technology (IT), consumer electronics, communications, semiconductor, medication, and biotechnology industry.

On the other hand, many foreign firms have advanced capacity such as Surface Mount Technology (SMT) lines. Moreover, they pay more attention on conform the environment certification such as

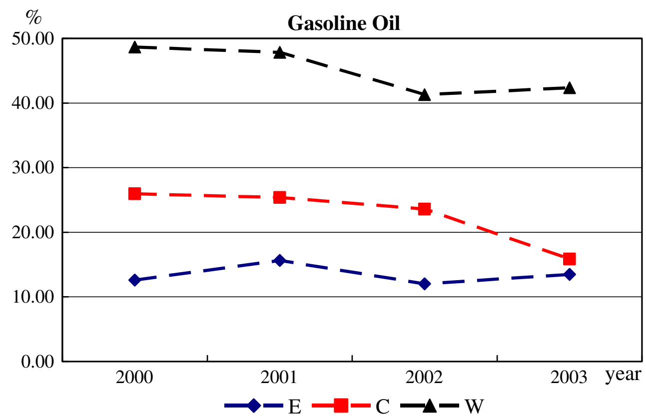

Fig. 3. The average target gasoline oil saving ratios in the three major areas of China.

Table 7
2000–2003 average annual target saving ratios for regions in China.

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

Note: Saving ratios are in percentage terms.

Waste Electrical and Electronic Equipment (WEEE) and Restriction of Hazardous Substance (RoHS), and manufacturers have to ensure that the product cannot have the substance like lead or chromium. They bring the concept of the efficient energy use and higher manufacturing performance into coastal regions [37,42]. As a result, unbalanced regional development, the gap between advanced regions and lagged regions was widening.

Furthermore, based on the Tenth Five year Economic and Social Develop Plan Codes in People Republic of China [35], the China's economic policy has been trying to upgrade the industry in order to enhance the competitiveness of China's local firms. China's government promotes the knowledge economy like the software, Integrated Circuit (IC) design, digital content and healthcare industry [39]. It also wants to change industrial structure toward the service industry such as retail, distribution and financing. They can raise GNP without more environmental goods input. These imply that the most-developed east area is using environmental goods more efficiently.

4. Conclusions and discussion

Electricity, coal, and gasoline oil are the three major types of energy that are inputs of industrial production. Finding out the efficient targets of energy-saving ratios according to the feasible Chinese production frontier is hence an important academic and policy issue.

This paper computes the efficient energy-saving ratios of 27 regions in China during the period 2000–2003. Different from the traditional DEA model which emphasized efficiency, this thesis creates an input-saving index. The data envelopment analysis is used to construct China's annual production frontiers in each year. A single output (real GDP) and five inputs (labor, real capital stock, coal consumption, gasoline oil consumption, and electricity consumption) are taken into the DEA model. The annual production frontier is constructed from 27 Chinese regions in each year. The efficiency scores and target values of three types of energy for each region in each year are hence obtained by comparing to the production frontier in that year.

Shanghai (09), Fujian (13), Shandong (15), Hunan (18), and Guangdong (19) are found to always have zero target saving ratios for the three types of energy, implying that they produce outputs efficiently with respect to China's production frontier. On the contrary, Shanxi (04), Guizhou (22), Shaanxi (24) Gansu (25), and Qinghai (26) have the highest target saving ratios of all energy types.

Generally speaking, the east area performs the best in China with respect to efficient for the three types of energy considered. The east, central, and west areas have the lowest, medium, and highest target saving ratios on the three types of energy.

We also discuss the difference of energy use from regional views. Due to China government's preferential policies on foreign investment for the east area, it built up the better infrastructure in coastal regions, especially around science and industrial parks. Foreign firms have the more efficient energy use and higher manufacturing performance than local ones. The local firms in the most-developed east area learned how to use environmental goods more efficiently in the long term. China government furthers the upgrading of industries toward knowledge economy and the service industry. It will be helpful to reduce environmental goods using and add value at the same time.

The results will provide policy suggestions for regions in China in order for them to evaluate and identify their policies and programs according to their income levels, and to improve an overall technical efficiency by adjusting their inputs of energy. For example, in the west areas, based on the experience of the east areas, build up the more sufficient infrastructure and higher manufacturing capacity will be useful to improve their efficient energy use.

The average target saving ratios for coal consumption are relatively much higher for all three areas, showing that coal saving is China's most urgent task. China should immediately engage in improving production efficiency and reducing coal consumption as its top priorities. Therefore, China could improve these regions' energy efficiency by the following policies: 1. Utilizing hi-technology to transform the traditional industry to reduce energy consumption. 2. Replacing the high-consuming energy industry with the low-consuming energy industry. 3. Developing regenerated energy to increase the energy utilization ratio. 4. Improving the proportion of coal washing, and building large-scale hydropower stations near coalmines to convert coal conveying into electricity conveying. 5. Raising the energy price and levying the energy tax in order to improve energy savings.

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