Original Research

Environmental Efficiency Evaluation in China: Application of 'Undesirable' Data Envelopment Analysis

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Abstract

Total carbon dioxide (CO_2) emission and energy consumption by mainland China in recent years has been second only to the U.S. China's environmental pollution causes about 3.5% to 8% loss of GDP every year, indicating that its domestic environmental problem has become one of the most urgent issues the government must face.

Current studies in the literature that employ data envelopment analysis (DEA) to study China's environmental issues do not consider both desirable and undesirable output or input (e.g., wastewater, CO_2) in production. Therefore, this study uses the undesirable measure DEA model to correctly calculate the impact of undesirable output and input on energy efficiency. The research herein sets up two models to analyze 27 provinces and cities in China from 2000 to 2003, and obtains various energy consumptions and pollutant reduction rates.

Keywords: China, DEA, undesirable factors, environmental performance

Introduction

In 2003 mainland China's SO_2 emissions were number one globally, 90% of which were due to coal overuse. In recent years, total CO_2 emissions ranked second only to the U.S. Though China's GDP was only 4% of the world's total in 2004, its petroleum, electricity, and coal consumption accounted for 8%, 10%, and 31% of global usage, respectively [1]. According to a China government statement, domestic petroleum demand was going to be 7% higher in 2006[1] versus 2005, with about 7 million barrels being consumed each year [2]. In fact, in 2003 and 2004 China's energy consumption grew much faster than any other year, by up to 15% growth, bringing with it higher carbon dioxide emissions. Emissions in 2004 were double that in 1990 or more. With China's economy growing at a rate above 8% on average[2], events such as hosting the 2008 Beijing Olympics are also pushing China's demand for energy to increase greatly.

The ratios of various types of energy in China in 2005 were: coal 67%, petroleum 22%, natural gas 3%, hydropower 5%, and nuclear energy 1% [3], among which the industrial sector energy demand accounted for about 70% of the total. From 1990 to 2002, domestic energy demand grew at 8% on average yearly, with 70% of electricity depending upon coal. Such a massive combustion of fossil energy (e.g., coal, petroleum, natural gas) is bound to produce environmentally harmful substances such as carbon dioxide. At present, the industrial sector accounts for about 50~60% of China's tertiary industry.

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[1]According to APEC data, China was the world's second highest petroleum-consuming country in 2006.
[2]Economic growth rates from 2000 to 2004 are 8.4%, 8.3%, 9.1%, 10%, and 10.1%, respectively.

China has attracted an enormous amount of foreign direct investment (FDI) in recent years, with average FDI flow per year from 1990 to 2002 more than U.S. $30 billion. Even more astounding is that yearly FDI flow into China in 2005 and 2006 was more than double the average FDI from 1990 to 2000. As China ranks at the top among developing countries in Asia, its FDI has brought a heavy environmental burden to the nation as well. Energy intensity per unit of GDP in 2001 was 28%, the same as in 1980, showing that its energy efficiency did not improve over nearly two decades [4]. Under such high economic growth, more and more wastes are arising from economic activities, posing adverse impacts on the environment. As pointed out in "2002 China Human Development Report" published by the UN, China's annual environmental pollution resulted in about 3.5% to 8% GDP loss.

Given the importance of China's energy efficiency improvement, this study adopts the undesirable measure DEA model proposed by Seiford and Zhu [5] to measure energy consumption and waste reduction rates more exactly and to better improve China's energy efficiency. Under the assumption of weak disposability, we consider circumstances when output or input variables might be undesirable. The study calculates the environmental performance of 27 provinces or cities in China from 2000 to 2003, helping put an order to the relative performance values of the provinces or cities each year and to present the related energy consumption and waste reduction rates.

The remainder of this paper is organized as follows: II is Literature Review, III is Research Method, IV is Empirical Results, and V is Conclusions.

Literature Review

To address environment-related issues in China, Liang et al. [6] studied energy efficiency management in the construction industry, while Cheng et al. [7] used the MM5-ARPS-CMAQ[3] model to study Beijing's air pollution. As to central air-conditioning products consuming 20% of total electricity in the country, Lu [8] proposed GB19577-2004 and GB19576-2004[4], in order to reduce energy consumption and pollutant discharges efficiently. Hao et al. [9] analyzed the feasibility of BCHP (building cooling, heating, and power) – a kind of energy efficiency technique in China – and found that BCHP can reduce about 40% energy consumption and pollutant discharges. Han et al. [10] implemented a regressive analysis to study China's coal and petroleum marginal efficiency from 1978 to 2003. Hang and Tu [1] explored China's energy price and energy intensity. Hu [11], Hu and Wang [12], Hu et al. [13], Lu and Lo [14], Liao et al. [15], and Zhang et al. [16] discussed various environmental problems in China.

Hu and Wang [12] employed the CCR-DEA model to study energy efficiency of 29 administrative regions in China from 1995 to 2002. The results indicate that total-factor energy efficiency was the best in the eastern region and the worst in the middle region. As to total-factor energy efficiency improvement in various regions, both the eastern and middle regions rose, with the middle rising greatly, while the western region had no significant improvement. Hu et al. [13] used the output-oriented CCR model and Malmquist production indicator to evaluate China's technical efficiency and productivity variation from 1997 to 2004. Hu [11] adopted the same input/output variables and employed the input-oriented DEA to evaluate China's air pollution reduction rate. The empirical results of both these articles complied with the EKC (Environmental Kuzents Curve) theory. Chien and Hu [17] employed the DEA model to analyze reclaimed energy and comprehensive efficiency of 45 countries from 2001 to 2002. In their study energy efficiency and reclaimed energy ratio in OECD countries were higher than in non-OECD countries, but the reclaimed energy ratio over energy supplied in non-OECD countries was higher than in OECD countries. These studies all adopted real GDP as a single output, without considering undesirable input or output.

When evaluating environmental performance, the earliest literature to include probable undesirable input and output variables was Pittman [18], who included pollution (e.g. particles, BOD, etc.) into the measurement. Färe et al. [19] employed the DEA model to analyze the environmental performance of OECD countries, whereby environmental performance was calculated from a distance function for desirable (good) output and undesirable (bad) output. Zhou et al. [20] suggested that when using a radial method to measure the DEA model's efficiency, there are too many DMUs whose efficiency values are 1, and hence it would sort the DMUs, resulting in an unsatisfactory model resolution. Thus, the non-radial DEA model was employed to analyze the environmental performance of 26 OECD countries from 1995 to 1997. Using a ray to measure the DEA model difference gives various weights to undesirable outputs. In a comparison of environmental performance derived from two methods, among 10 countries whose performances were 1 in 3 years by means of the radial DEA model, only two (Japan and Switzerland) had an environmental performance of 1 in the non-radial DEA model.

Zhou et al. [21] reviewed 100 studies in the literature on DEA application in the environment and energy, and found that about one quarter of them evaluated environmental performance, most of which were during 1999-2006. Of them, the fixed-scale baseline technical and ray efficiency measurement were dominant, and most employed an input-oriented model. However, in the current research of environmental performance, the output-oriented DEA model is more widely applied. The common point of the literature on the environment and energy is a consideration of both desirable output and undesirable output, and the authors believe

[3]MM5 refers to mesoscale modeling system, ARPS refers to advanced regional prediction system, and CMAQ refers to community multiscale air quality model.

[4]These are the state standards for energy efficiency in China, already implemented in March 2005. GB 19577-2004 shows the energy efficiency minimum and scales of water chillers, and GB 19576-2004 is the standard for central air conditioners.

that the environment DEA technique coupled with the directional distance function (DDF) is not a bad choice for measuring efficiency.

The research studies on China's environment primarily discuss its energy consumption reduction, pollution emission, and energy efficiency. Although pollution emission reduction can be measured, the evaluation process does not consider a probable undesirable input or output in consumption or during production. But in actual consumption or production behavior there may be undesirable inputs or outputs. Therefore, these factors that do not consider the evaluation, energy consumption, and pollution emission to decrease will fail to be accurately measured, easily resulting in underestimation or overestimation, because the normal traditional DEA model supposes input/output as strongly or freely disposable. If there is undesirable output or input, then the strong disposability theory fails to satisfy that the undesirable output or input is a negative factor, which means an output deviation.

Research Method

DEA is an efficiency measuring method first proposed by Charnes, Cooper, and Rhodes [22]. Manufacturers or industries are assumed to be at constant returns to scale (CRS), but in fact many industries are not in a CRS state. Hence, Banker, Charnes, and Cooper [23] developed variable the returns to scale (VRS) calculation model. Both CCR and BCC are radial measure methods, or in other words, input or output is adjusted by increasing or decreasing along one direction. In the actual production process, unwanted by-products may appear during input and output conversion, such as wastewater, exhaust gas, and carbon dioxide. In the traditional DEA model, if the relative inefficient DMUs have desirable and undesirable inputs/outputs to adjust, then they increase or decrease simultaneously, because they cannot just increase the desirable output yet decrease the undesirable output.

To address the above problem, we take from Seiford and Zhu [5] to apply their undesirable DEA model, which integrates weak disposal and strong disposal concepts, in order to measure a DMU's relative efficiency in a non-radial way. Hence, this situation can be improved. The output-oriented undesirable DEA model is described as follows.

Suppose there are n DMUs, Y is the output (where there are two kinds of outputs; one is the desirable (good) output Y^g and the other is the undesirable (not good) output Y^b), –*X* is the input, and the DEA data domain is Equation (1).

$$\begin{bmatrix} Y \\ -X \end{bmatrix} = \begin{bmatrix} Y^g \\ Y^b \\ -X \end{bmatrix} \tag{1}$$

In order to increase desirable output while decreasing undesirable output, Färe et al. [24] employed a non-linear planning method to solve the problem. The model is shown in Equation (2).

$$\begin{aligned} \max \quad & \Gamma \\ s.t. \quad & \sum_{j=1}^{n} z_j x_j + s^- = x_0 \\ & \sum_{j=1}^{n} z_j y_j^g - s^+ = \Gamma y_0^g \\ & \sum_{j=1}^{n} z_j y_j^b - s^+ = \frac{1}{\Gamma} y_0^b \\ & z_j \geq 0,\ j = 1,\ldots,\ n \end{aligned} \tag{2}$$

After transforming Equation (2) to the DEA model, conforming it to linearity and convexity, letting the undesirable output be non-negative, multiplying Y^b by -1, and using the transposed vector w to convert Equation (1) to Equation (3), the undesirable output becomes $\overline{y}_j^b = -y_j^b + w > 0$. Hence the original non-linear planning problem of Equation (2) can be converted to the linear planning model in Equation (4). Therefore, Equation (4) is a very linear DEA model, including desirable output and undesirable output, whereby the fittest undesirable output (y_0^b) solved is not negative.

$$\begin{bmatrix} Y \\ -X \end{bmatrix} = \begin{bmatrix} Y^g \\ \overline{Y}^b \\ -X \end{bmatrix} \tag{3}$$

$$\begin{aligned} \max \quad & h \\ s.t. \quad & \sum_{j=1}^{n} z_j x_j \leq x_0 \\ & \sum_{j=1}^{n} z_j y_j^g = h y_0^g \\ & \sum_{j=1}^{n} z_j \overline{y}_j^b = h \overline{y}_0^b \\ & z_j \geq 0,\ j = 1,\ldots,\ n \end{aligned} \tag{4}$$

The Data and Results

Data Sources

In order to measure the impact of undesirable output and input on energy efficiency correctly, this study sets up two models to analyze 27 provinces and cities in China from 2000 to 2003. Model 1 has only a single output, which is real GDP. The inputs are labor, real capital, and three undesirable inputs: electricity consumption, coal consumption, and gasoline consumption. This paper uses the above three variables as undesirable inputs because these three variables are the major consumption energy in China. Hang and Tu [13] state that petroleum, electricity, and coal consumption in China accounted for 8%, 10%, and 31% of global usage in 2004, respectively.

The output variables of Model 2 are real GDP, industrial wastewater, industrial exhaust gas, and industrial solid

Table 1. Inputs and outputs of Model 1 and Model 2.

Model 1					
Output	Input				
Real GDP	Electricity consumption	Coal consumption	Gasoline consumption	Capital	Labor
(100 million RMB)	(100 million kwh)	(10,000 tons)	(10,000 tons)	(100 million RMB)	(10,000 persons)
Model 2					
Output				Input	
Real GDP	Industrial wastewater	Industrial exhaust gas	Industrial solid waste	Capital	Labor
(100 million RMB)	(10,000 tons)	(10,000 tons)	(10,000 tons)	(100 million RMB)	(10,000 persons)

waste, among which the three kinds of industrial wastes are undesirable outputs, while labor and capital are input variables (Table 1). This paper uses the above three variables as undesirable outputs since these three undesirable outputs represent China's major pollution, which is different from the previous research by using CO_2 as an undesirable output.

The data on real GDP, labor, real capital, and discharge of three kinds of wastes are taken from 2001-2004 China Statistical Yearbook [25]. Consumption data on three kinds of energy are cited from the 2001-2004 Chinese Energy Statistical Yearbook [26].

Empirical Results and Analysis

Table 2 shows the correlation matrix of inputs and outputs, which indicates positive correlation and consistency with DEA characteristics, and the inputs and outputs vary in the same direction. Table 3 shows descriptive statistical data of input and output variables. Among the average maximum and minimum of each variable, energy consumption and waste discharge differ greatly among the provinces or cities.

Analysis of BCC Model and Undesirable DEA Model

From the BCC model and undesirable DEA model analysis results summarized in Table 4 (Model 1) and Table 5 (Model 2), we can see the relative efficiency values and standing of those provinces or cities investigated. In this study the reduction ratio calculation formula is 1- (fitness value solved by actual value) (Tables 6-8). The results are described below.

BCC Model

Using the BCC model analysis, in which all inputs/output are desirable, there are 7 provinces or cities (Tianjin, Liaoning, Shanghai, Jiangsu, Shandong, Guangdong, and Qinghai) whose efficiency values are 1 in 2000-03 (about 25.93%) for the two models. Among them, 6 provinces or cities are in the eastern region and 1 in the western region. From the efficiency score in each region every year, the eastern region is above the average overall efficiency and better than the central and western regions.

Undesirable Model

Overall in both models, there are 6 provinces or cites (Tianjin, Liaoning, Shanghai, Shandong, Guangdong, and Qinghai) whose efficiency score are 1 in 2000-03 (about 22.22%). In Model 1 there is a total of 10 provinces or cities whose 4-year efficiency values are 1, among which 6 provinces or cities are in the eastern region, while the middle and western regions have 2 provinces each. Hence, the eastern provinces or cities were developed earlier, and the greater developed those provinces or cities have become, the more they are associated with higher environmental protection technical levels and comprehensive environmental regulations and codes.

According to the analysis result of Model 1, there are 12 provinces or cities in 2000 whose efficiency values are 1, or about 44.44% efficient provinces or cities. There are 11 provinces or cities whose efficiency values are 1 each year from 2001 to 2003, or about 40.74% efficient provinces or cities.

In Model 2 there are 8 provinces or cities whose relative efficiency values are 1 from 2000 to 2003 (nearly 29.63%), among which 7 provinces or cities are located in the eastern region, while only 1 province lies in the western region. In 2000 and 2001 there are only 9 provinces or cities whose efficiency values are 1 (about 33.33%). In 2002 there are 10 provinces or cities whose efficiency values are 1 (about 37.04%). In 2003 there are 11 provinces or cities whose efficiency values are 1 (about 40.74%).

From the summary of BCC and Undesirable models, Tianjin, Shanghai, Shandong, Guangdong, and Qinghai (4 provinces or cities are in the eastern region, 1 is in the western region) are efficient in both models. As for the main coal-producing provinces of Shanxi, Inner Mongolia, Henan, Shandong, Shaanxi, and Guizhou, only Shandong has efficiency of 1 in both models, implying that compared to other provinces or cities, Shandong has better environmental protection technology and regulation.

Table 2. Correlation coefficients between inputs and output.

Model 1: GDP, Energy and Inputs						
	Real GDP	Capital	Labor	Electricity consumption	Coal consumption	Gasoline consumption
Real GDP	1					
Real Capital Stock	0.789	1				
Labor	0.683	0.450	1			
Electricity	0.952	0.729	0.687	1		
Coal	0.472	0.2477	0.485	0.6073	1	
Gasoline Oil	0.826	0.697	0.455	0.787	0.332	1
Model 2: GDP, Waste and Inputs						
	Real GDP	capital	labor	wastewater	Waste Gas	Solid Waste
Real GDP	1					
Real Capital Stock	0.789	1				
Labor	0.683	0.450	1			
Waste Water	0.830	0.733	0.757	1		
Waste Gas	0.814	0.571	0.631	0.706	1	
Solid Wastes	0.291	0.035	0.457	0.321	0.642	1

Table 3. Summary statistics of inputs and outputs by regions.

	Mean	Standard deviation	Maximum	Minimum
Real GDP	6,493.18	4,609.53	17,689.01	502.66
Real Capital Stock	1,209.10	683.53	2,920.81	321.85
Labor	2,330.31	1,530.93	6,067.24	245.11
Electricity Consumption	593.87	368.74	1,628.03	129.74
Coal Consumption	6,037.35	3,851.12	16,918.75	614.75
Gasoline Oil Consumption	140.75	77.48	336.40	16.80
Industrial Waste Water	74,879.11	59,932.52	245,797.75	4,020.50
Industrial Waste Gas	6,157.43	3,646.83	14,269.25	848.00
Industrial Solid Wastes	3,341.70	2,263.83	8,338.23	349.43

Shanxi is the largest coal mining province in mainland China and its production processes produce large coal bed gas emissions that are estimated to be about one third of the country. Because this has resulted in severe environmental pollution in Shanxi and hence affected its relative efficiency, it is believed that a full utilization of coal bed gas to generate power and issuing preferential and stimulus measures for using coal bed gas to generate power will benefit the environmental performance of the province. The Yangtze River Delta region (Shanghai, Zhejiang, and Jiangsu) has depended on coal as its main energy for a long time. To achieve the "11th Five-Year Plan" energy saving target, the region carried out universal energy saving countermeasures, such as renovating coal-burning boilers, saving and replacing petroleum, building up energy savings, optimizing energy systems, and formulating regional industry entry criteria. As a result, the industry structure was universally adjusted, so as to relieve the environmental pressure on this region [8].

Yunnan Province is now in a crucial stage of industrialization and development acceleration, where its energy demand is robust. It has adopted a chain of mechanisms in relation to an energy-saving target to achieve the "11th Five-Year Plan," including drafting an energy saving target examination method, formulating a GDP energy consumption index bulletin system, and offering education and training [27]. It believes that energy usage efficiency and an energy saving target can be achieved as soon as possible, which will benefit the environment greatly.

Table 4. Efficiency scores of Model 1.

DMU		Area	Undesirable 2000	BCC 2000	Undesirable 2001	BCC **2001**	Undesirable 2002	BCC **2002**	Undesirable 2003	BCC 2003
1	Beijing	E	0.9904	0.9155	1	0.9720	0.9834	1	0.945	1
2	Tianjin	E	1	1	1	1	1	1	1	1
3	Hebei	E	1	0.8342	0.9744	0.8670	0.9033	0.7755	0.8724	0.8086
4	Shanxi	C	1	0.7133	1	0.7673	1	0.6805	1	0.7085
5	Inner Mongolia	W	0.8854	0.7757	0.8993	0.7500	0.9191	0.7637	0.9195	0.7575
6	Liaoning	E	1	1	1	1	1	1	1	1
7	Jilin	C	0.9178	0.8445	0.9123	0.8702	0.9118	0.8241	0.9167	0.8741
8	Heilongjiang	C	1	0.8862	1	0.9962	1	0.9600	1	0.9908
9	Shanghai	E	1	1	1	1	1	1	1	1
10	Jiangsu	E	1	1	1	1	1	1	1	1
11	Zhejiang	E	0.8277	0.9255	0.8265	0.9047	0.851	0.9391	0.8729	0.9818
12	Anhui	C	0.7612	1	0.8121	1	0.8305	1	0.7995	1
13	Fujian	E	0.8332	1	0.8769	1	1	1	1	1
14	Jiangxi	C	0.7371	1	0.7572	1	0.7702	1	0.742	1
15	Shandong	E	1	1	1	1	1	1	1	1
16	Henan	C	0.7858	0.9419	0.7085	0.9669	0.7796	0.9024	0.8681	1
17	Hubei	C	0.7872	0.8962	0.7313	0.9307	0.8436	0.9101	0.9141	0.9491
18	Hunan	C	0.6718	0.9354	0.6342	0.9362	0.7251	0.9179	0.7052	0.9304
19	Guangdong	E	1	1	1	1	1	1	1	1
20	Guangxi	W	0.6664	0.8539	0.7363	0.8930	0.796	0.8592	0.7618	0.8377
21	Sichuan	W	0.9007	0.8007	0.7902	0.7929	0.8159	0.8046	0.7707	0.8174
22	Guizhou	W	0.9405	0.7318	0.9629	0.7528	0.9267	0.6096	0.9041	0.5971
23	Yunnan	W	0.7587	0.7548	0.8023	0.7964	0.858	0.7680	0.8438	0.7907
24	Shaanxi	W	0.8286	0.7314	0.8591	0.8382	0.856	0.7539	0.8311	0.7443
25	Gansu	W	1	0.9845	1	1	1	1	1	1
26	Qinghai	W	1	1	1	1	1	1	1	1
27	Xinjiang	W	1	1	0.9711	1	0.9721	1	0.9531	1
The number of efficiency scores at 1 and the %			12 (44.44%)	11 (40.74%)	11 (40.74%)	12 (44.44%)	11 (40.74%)	13 (48.15%)	11 (40.74%)	14 (51.85%)
Overall Average			**0.8997**	**0.9084**	**0.8983**	**0.9272**	**0.9164**	**0.9062**	**0.9119**	**0.9181**
Area Average		E	0.9651	0.9675	0.9678	0.9744	0.9738	0.9715	0.969	0.9790
		C	0.8326	0.9022	0.8194	0.9334	0.8576	0.8994	0.8682	0.9316
		W	0.8867	0.8481	0.8913	0.8693	0.9049	0.8399	0.8871	0.8383

E – Eastern,
C – Central,
W – Western.

There have been good performances by the provinces or cities of Tianjin, Shanghai, Fujian, and Guangdong, which adopted relative responses to the goal of the "11th Five-Year Plan." Shanghai City launched the first round of environmental protection and a three-year construction action plan in 2000, treating and controlling water, atmosphere, solid waste, afforestation, and key industry zones, in order that Shanghai's environment can be significantly improved. More rounds of environmental protection and construction action plan were launched in 2003 and 2005. During the "9th Five-Year Plan," Guangdong Province implemented environmental protection regulations like "Guangdong Green Water Program," "Guangdong Blue Sky Program," "Guangdong Pearl River Delta Water Protection Act," and "Guangdong Motor Vehicle Exhaust Emission Control Act," which targeted the urban environment, for instance, by carrying out atmosphere, water, and solid waste pollution prevention and control projects. Fujian Province guaranteed the realization of its environmental protection target by focusing on solving urban wastewater in 1996, as well as exhaust gas, noise, and solid waste pollution. During the "9th Five-Year Plan," its priority was in solving wastewater and garbage treatment and promoting clean fuel and urban fuel gas efficiency. Therefore, good performances showed up in provinces or cities that concentrated on environmental problems in their regions earlier through more comprehensive planning[5].

When we divide China into three regions, we see many different characteristics. The eastern region developed earlier and has a good agriculture basis, with better geography, labor quality, and technical level. The central region is the grain production base and rich in energy and metal and nonmetallic ores, among which coal reserves account for 80% of the country's total, leaving it with a solid heavy industry base. The western region developed later than the eastern and central regions and its economy and technical level still lag behind, but it is a large area with abundant mines and huge development potential [28]. In terms of relative efficiency, the eastern region is the best in both Model 1 and Model 2; the central region has worse relative performance in Model 1 than the western region; the central region's performances in 2000 and 2001 are worse than the western region in Model 2, though in 2002 and 2003 its performance is better than the western region.

Reduction Analysis of China's Provinces or Cities

Table 6 through Table 8 list targeted general reduction ratios for three kinds of energy consumption and three kinds of waste (Undesirable model) in each region for every year. In 2000-03 the electricity reduction ratio is 20.28%, 31.04%, 24.07%, and 27.82%; the coal reduction ratio is 44.53%, 51.04%, 39.09%, and 45.31%; the natural gas consumption reduction ratio is 27.05%, 30.35%, 21.18%, and 27.83%; the industrial used oil reduction ratio is 33.01%, 36.84%, 29.52%, and 36.47%; the industrial wastewater reduction ratio is 42.98%, 43.03%, 35.29%, and 42.21%; the solid waste reduction ratio is 131.22%, 119.25%, 75.15%, and 102.08%[6].

According to the targeted reduction ratios of the three kinds of energy consumption and three kinds of waste in each region every year, both energy consumption and waste reduction of the eastern region are less than the average overall reduction level and better than the central and western regions. The electricity consumption reduction ratios of the western region are smaller than the central region. Coal reduction is also less than the central region (except in 2003), while the natural gas consumption reduction ratios of the western region are higher than the central region (except in 2003). In terms of reduction of the three kinds of waste, the western region's reduction of wastewater and used oil is greater than the central region, except in 2002 and 2003, when the solid waste reduction ratio is less than the central region. Therefore, the western region must speed up its adjustment to the energy production and energy consumption structure.

China has primarily 10 environmental regulations for cities, including the Environment Protection Law, Atmosphere Pollution Prevention and Control Act, Water Pollution Prevention and Control Act, Solid Waste Pollution Environment Prevention and Control Act, Urban Planning Law, and Energy Saving Law. Ever since 1989, a quantitative examination has been performed on 32 key environment protected cities, and in 2003 the central government examined 47 cities directly [29]. This benefits energy application and environmental protection technology to an extent, and hence as key environment protected cities, Beijing, Tianjin, and Shanghai show good relative performance.

Overall for the Undesirable model, Table 9 summarizes the consumption reduction ratios of the three kinds of energy. From 2000 to 2003, electricity should be reduced 25.89% on average, coal should decrease 45.08%, natural gas should go down 26.60%, and used oil, wastewater, and solid waste should fall 33.96%, 40.88%, 106.93%, respectively. In the BCC model, the reduction ratios are less than that in the Undesirable model. Based on the above analysis, if we do not include undesirable factors in the model, the assessment may be overestimated or underestimated, thus resulting in input/output resource configuration error. In terms of regions, the eastern area has the best overall performance and the lowest energy consumption and average waste reduction ratio, indicating that it has better efficiency. For the central region, the consumption reduction ratios of the three kinds of energy rank first, while the reduction of the three kinds of wastes is lower than the western region, indicating that the central region still has much room to improve in technology and relevant regulations and laws.

[5]Data are excerpted from the website of the Environment Protection Administration of the People's Republic of China: www.zhb.gov.cn.

[6]Compared to the BCC model, the targeted reduction ratios for the three kinds of energy consumption and three kinds of waste are less than those in the Undesirable model.

Table 5. Efficiency score sof Model 2.

DMU		Area	Undesirable 2000	BCC **2000**	Undesirable 2001	BCC **2001**	Undesirable 2002	BCC **2002**	Undesirable 2003	BCC **2003**
1	Beijing	E	1	0.8692	1	0.8741	1	0.7783	1	0.6843
2	Tianjin	E	1	1	1	1	1	1	1	1
3	Hebei	E	0.841	0.9866	0.8288	1	0.8109	1	0.8021	1
4	Shanxi	C	0.9363	1	0.9602	1	0.9493	1	0.9525	1
5	Inner Mongolia	W	0.965	0.9040	0.9752	0.8190	0.9736	0.8668	0.9486	0.8674
6	Liaoning	E	1	1	1	1	1	1	1	1
7	Jilin	C	0.9211	0.6473	0.9519	0.7012	0.9516	0.7254	0.951	0.6743
8	Heilongjiang	C	0.9254	0.6969	0.9878	0.7966	0.9939	0.9258	1	0.8634
9	Shanghai	E	1	1	1	1	1	1	1	1
10	Jiangsu	E	0.946	1	0.9898	1	1	1	1	1
11	Zhejiang	E	0.9673	0.8405	0.9721	0.8123	0.9598	0.8309	0.9625	0.8506
12	Anhui	C	0.9608	0.6364	0.9374	0.7161	0.9226	0.8777	0.9152	0.6288
13	Fujian	E	1	0.8213	1	0.8608	1	1	1	1
14	Jiangxi	C	0.9526	0.6288	0.9841	0.5709	0.9715	0.7168	0.9562	0.7072
15	Shandong	E	1	1	1	1	1	1	1	1
16	Henan	C	0.8639	0.7793	0.8315	0.7385	0.8173	0.7918	0.8206	0.8630
17	Hubei	C	0.8608	0.7590	0.8925	0.7041	0.8636	0.7020	0.8754	0.7257
18	Hunan	C	0.9352	0.7321	0.9772	0.6593	0.9609	0.7670	0.9465	0.8050
19	Guangdong	E	1	1	1	1	1	1	1	1
20	Guangxi	W	0.7913	0.6284	0.7813	0.8818	0.7842	1	0.7431	1
21	Sichuan	W	0.8609	1	0.852	1	0.7695	1	0.8343	1
22	Guizhou	W	0.9557	0.8065	0.9671	0.6110	0.9676	0.4631	0.9618	0.4497
23	Yunnan	W	0.9395	0.4214	0.9603	0.4905	0.9503	0.6222	0.939	0.5092
24	Shaanxi	W	0.9466	0.3895	0.9704	0.5537	0.9542	0.5392	0.9396	0.4312
25	Gansu	W	0.9795	1	1	1	1	1	1	1
26	Qinghai	W	1	1	1	1	1	1	1	1
27	Xinjiang	W	1	0.8119	0.9998	0.8249	0.9912	0.8366	0.9933	0.7872
The number of efficiency scores at 1 and their %			9 (33.33%)	10 (37.04%)	9 (33.33%)	11 (40.74%)	10 (37.04%)	13 (48.15%)	11 (40.74%)	13 (48.15%)
Overall Average			**0.9426**	**0.8281**	**0.9519**	**0.8376**	**0.9419**	**0.8683**	**0.9402**	**0.8462**
Area Average		E	0.9728	0.9518	0.976	0.9547	0.9932	0.9609	0.9722	0.9535
		C	0.9181	0.7350	0.9375	0.7358	0.9253	0.8133	0.9241	0.7834
		W	0.9327	0.7735	0.939	0.7979	0.9236	0.8142	0.9208	0.7827

E – Eastern,
C – Central,
W – Western.

Table 6. Target abatement ratios of electricity and coal for regions in China (Undesirable DEA method).

DMU	Area	2000		2001		2002		2003	
		Electricity	Coal	Electricity	Coal	Electricity	Coal	Electricity	Coal
Overall Average		**20.28**	**44.53**	**31.40**	**51.40**	**24.07**	**39.09**	**27.82**	**45.31**
Area Average	E	7.64	30.98	8.00	47.38	2.82	9.98	4.60	10.78
	C	46.62	47.49	55.21	43.74	44.24	51.70	46.36	71.06
	W	34.67	56.96	36.23	61.25	29.75	60.24	37.15	60.80

Table 7. Target abatement ratios of gasoline oil and industrial waste gas for regions in China (Undesirable DEA method).

DMU	Area	2000		2001		2002		2003	
		Gasoline oil	Industrial waste gas	Gasoline oil	Industrial waste gas	Gasoline oil	Industrial waste gas	Gasoline oil	Industrial waste gas
Overall Average		**27.05**	**33.01**	**30.35**	**36.84**	**21.18**	**29.52**	**27.83**	**36.47**
Area Average	E	4.34	9.90	28.16	15.15	2.28	4.52	3.73	6.55
	C	39.01	38.55	24.94	43.55	31.37	41.60	44.36	51.53
	W	41.65	53.77	36.71	54.98	33.12	46.55	39.91	56.34

Table 8. Target abatement ratios of industrial waste water and industrial solid waste for regions in China (Undesirable DEA method).

DMU	Area	2000		2001		2002		2003	
		Industrial waste water	Industrial solid waste	Industrial waste water	Industrial solid waste	Industrial waste water	Industrial solid waste	Industrial waste water	Industrial solid waste
Overall Average		**42.98**	**131.22**	**43.03**	**119.25**	**35.29**	**75.15**	**42.21**	**102.08**
Area Average	E	19.93	46.38	30.95	51.97	11.91	11.63	10.67	11.62
	C	53.56	169.69	45.03	146.65	44.34	115.08	49.08	158.99
	W	59.17	191.30	54.67	169.66	53.22	110.23	71.16	152.00

Table 9. The average target abatement ratios of energy consumption and waste (Unit: %).

Undesirable measure DEA model						
	Electricity	Coal	Gasoline oil	Waste Gas	Waste Water	Solid Wastes
Overall	25.89	45.08	26.60	33.96	40.88	106.93
E	5.77	48.11	34.45	9.03	18.37	30.40
C	24.78	53.50	59.81	43.81	48.00	147.60
W	9.63	34.92	37.85	52.91	59.56	155.80
BCC Model						
	Electricity	Coal	Gasoline oil	Waste Gas	Waste Water	Solid Wastes
Overall	10.17	21.82	15.72	20.91	24.36	26.22
E	3.18	5.70	4.67	9.93	9.90	10.58
C	10.78	33.84	21.90	26.84	39.32	37.86
W	17.38	29.04	22.51	27.83	27.12	33.25

Conclusions

There is an abundant amount of literature on China's environmental issues, but seldom do studies consider some undesirable outputs (CO_2, wastewater, waste) that may accompany desirable output in the actual production process. The common ray Measure DEA model fails to add desirable output while not decreasing desirable output. This study has adopted the undesirable DEA model to divide output into desirable and undesirable input/output, in order to increase desirable output while reducing undesirable output.

In the traditional DEA model, if the relative inefficient DMU has desirable and undesirable inputs/outputs to adjust, then they will increase or decrease simultaneously, because one cannot only increase a desirable output yet decrease an undesirable output. However, if there are undesirable outputs, such as CO_2 or SO_2, then they will cause some environmental problems. Thus, it is important to consider undesirable output in any assessment. Unless one can divide input/outputs into desirable inputs/outputs and undesirable inputs/outputs, then there will be overestimation or underestimation.

The evaluation results of this study indicate that, Tianjin, Shanghai, Shandong, Guangdong, and Qinghai (4 provinces or cities in the eastern region, 1 in the western region) are efficient in the BCC and Undesirable models. Thus, China's Government should focus on the central area's environmental performance.

In terms of the consumption reduction ratio of the three kinds of energy, from 2000 to 2003 the BCC model needs to reduce the ratios to be lower than the Undesirable model. The general performance of the eastern region is better than the central and western regions. The energy consumption and waste reduction ratios of the eastern region are the lowest. The consumption reduction ratios of the three kinds of energy of the provinces or cities in the central region roughly lag behind the western region, but the reduction ratios of the three kinds of exhaust gases appear to be better than the western region, except in 2002 through 2003, when the solid waste reduction ratio is higher than the western region. Therefore, China's Government is better to reduce energy consumption in the central and western regions.

China is the second largest energy consumption and carbon dioxide emission country in the world, second to the U.S., and about 70% of its energy is consumed by the industrial sector. China's acid rain formed by SO_2 and soot from burning coal is estimated to fall on about 30% of domestic land. Since energy consumption still heavily depends on coal, SO_2 emission was number one in the world in 2003. Because China's domestic economy has grown quickly, it has brought tremendous crisis to the environment. China's government not only has adopted domestic policies to tackle its increasingly serious environmental problem, (e.g. 9th Five-Year Plan, 10th Five-Year Plan, Cleaner Production Promotion Law, 11th Five-Year Plan), but also cooperates with the world (e.g. Global Environment Fund (GEF), APEC). The adoption of these measures has no other target but to enhance energy application efficiency and to reduce waste output of each province or city so as to improve the domestic environmental problem.

As China's energy demand increases, its energy production has grown quicker, of which coal has increased the most. The problem is that the production and consumption processes have resulted in much waste and pollution to the environment, such as SO_2, fume, dust, and carbon dioxide emissions. Hence, in many of the aforementioned coal-producing or coal-based energy consumption provinces, their relative performances will be worse. Thus, an important topic is how to develop cleaner production energy technology and curb energy consumption waste. In addition, China's government should support new technology in order to replace old production processes, increase energy efficiency and reduce the undesirable inputs and outputs.

While there is a balancing act for the provinces or cities in terms of economic development and the environment, when addressing various environmental issues, China should strengthen the formulation of relevant environmental regulations, tighten their execution, be active in changing the country's energy structure and energy consumption behavior, and enhancing energy application efficiency, in order to solve the environmental pollution problem fundamentally.

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