Total Energy Consumption Control based on Environmental ZSG-DEA

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Abstract
This paper designs a new model to solve the problem of allocation for total energy consumption between provinces in China, based on the environmental production technology and ZSG-DEA method, comprehensively considering the input/output variables of energy, capital, labor, desirable and undesirable output. The results show that: Through the ZSG-DEA allocation of energy quotas, the efficiency in energy use will be promoted obviously; The average general regulation cost will reduce 94.472%, and average strict regulation cost will reduce 75.111%, but generate the control cost for energy consumption 116.946 billion RMB (deflated to 1952 price); ZSG-DEA allocation will reduce the environmental regulation cost, and generate cost for controlling energy consumption; The ZSG-DEA allocation will cause the equity losses. However, it will cause the slight influence on the carbon emission intensity, and make the energy quotas allocation compatible with the emissions reduction target.
Key words: TOTAL ENERGY CONSUMPTION CONTROL, ENVIRONMENTAL ZSG-DEA, ENVIRONMENTAL REGULATION COST, COST OF TOTAL ENERGY CONSUMPTION CONTROL

Introduction

Total energy consumption control is the prerequisite for the feasibility of energy saving and emission reduction plan. The cost of energy saving and emission reduction can be effectively calculated only after total energy consumption is ascertained. Then the market-based trade of energy consumption quota can be possible and the minimum cost of total control be realized. However, at the present stage, central government's evaluation mechanism of energy saving for regional government takes energy consumption per unit of gross regional product (GRP) as a benchmark, which may result in problem of uncontrollable total energy consumption owning to uncertainty of GRP growth expectations. Therefore, models and methods need to be innovated to fulfill transition from intensity control to total control. In taking full account of the allocation of total energy consumption and energy consumption demand in each province, the problem of how to realize optimal output efficiency after energy consumption allocation needs further investigation in the meantime.

Literature Review

Studies on energy consumption quota have not been paid much attention both at home and abroad for it is a relatively new issue. At present, only the target decomposition of renewable energy in European Union[1] and CO2 emission trading scheme supported to energy savings certificates[2] are concerned to this issue. By contrast, studies on allocation of carbon emission quota under total control have been intensively studied both at home and abroad. After the adoption of Kyoto Protocol, scholars from different countries have been advocating various methods on allocation of carbon emission quota, among which the convergence method, multi-sector convergence, multiple periods method by Netherland National Institute for Public Health and the Environment, alternative scheme based on reduction of carbon emission intensity by America, dual intensity target by Korean scholars, sustainable development policy and measures by South Africa and gradual participation by Newell et al[3,4]. All these methods have provided inspiration on allocation of energy consumption quota. As Svendsen et al[5] suggested, total control is the principle method to achieve targets of pollutant emission reduction for each country while allocation of initial emission permits is the key issue involved. Specific to China's regional allocation of energy saving index, institutions like United States Department of Energy, Energy Department of National Development and Reform Commission (China), Development Research Center of the State Council (China) have done some work. However, most of the studies are focusing on direct analysis of energy intensity index. Investigation on energy quota under total energy control target is obviously insufficient. In conclusion, studies on regional allocation of energy-saving index have made great achievement. Relationship of energy-saving index between total energy consumption and energy intensity is further cleared. However, while it is recognized that regional allocation of energy-saving index has a ZSG feature under total energy consumption constraint, there is little study on regional allocation of energy saving and emission reduction based on ZSG efficiency model. The employment of ZSG efficiency perspective will provide a quantitative basis for the scientific and economic implementation of the country's overall target on energy saving and emission reduction. In addition, the improvements on ZSG model will also enrich the methodology system of energy and environment policy analysis.

ZSG-DEA Method based on Environmental Production Technology

Input (or output) variable in classic DEA model (CCR, BCC etc.) has relative high degree of freedom, while that adopted in resource allocation domain is often restricted to total sum as constant and constrained by ZSG. Increase (or decrease) of any DMU input (or output) variable corresponds to decrease (or increase) of other DMU input (or output) variable. Lins[6] first developed the ZSG-DEA model. Through redistribution of input (or output) variables by ZSG-DEA, efficiency value of every DMU is readjusted. All the DMU technology efficiency value reaches 1 and a new production frontier (ZSG-DEA production frontier) is formed. However, due to constraint of DEA efficiency model, traditional ZSG-DEA can only conduct efficiency calculation and quotas allocation on single input (or output). For example, in study initial allocation of CO2 emission right, Gomes[7] set CO2 as the only input variable, while population, energy consumption and GRP are set as output. Although this method is common in dealing with undesirable output, it violates the actual production process where energy consumption is taken as output variable and undesirable output as input variable. This paper attempts to improve the traditional ZSG-DEA method and sets CO2 as output variable (and add undesirable output constraint[8,9]) according to production theory while still sets energy consumption as input variable. It also aims to restructure the traditional single input/output ZSG-DEA Model (uni-input/output ZSG-DEA Model) based on non- parameter distance function and form environmental multiple input/output ZSG distance function model so to meet the requirement of single variable value distribution under multi inputs and outputs. Considering the constraints of total energy consumption control, this paper uses energy input oriented distance function:

$$D_e(E,K,L,Y,C) = \sup\{\lambda : (E/\lambda, K, L, Y, C/\lambda) \in T\} \quad (1)$$

Equation (1) denotes: given production technology (T), capital (K), labor (L), GRP (Y), and CO2 (C), energy consumption should be reduced as much as possible. Equation (1) can be formulated as piecewise linear function:

$$[D_e(E,K,L,Y,C)]^{-1} = \min \tilde{\theta}$$

$$\begin{aligned} s.t. \sum_{k=1}^{K} \lambda_k E_{km} &\le \tilde{\theta} E_{om},\ m = 1,2,\cdots,M \\ \sum_{k=1}^{K} \lambda_k K_{kn} &\le K_{on},\ n = 1,2,\cdots,N \\ \sum_{k=1}^{K} \lambda_k L_{kl} &\le L_{ol},\ l = 1,2,\cdots,L \\ \sum_{k=1}^{K} \lambda_k Y_{ki} &\ge Y_{oi},\ i = 1,2,\cdots,I \\ \sum_{k=1}^{K} \lambda_k C_{kj} &= \tilde{\theta} C_{oj},\ j = 1,2,\cdots,J \\ \lambda_k &\ge 0,\ k = 1,2,\cdots,K \end{aligned}$$

(2)

The variables in model (2) share the same definitions in model (1). It is different from traditional energy input oriented Shephard distance function lies in the addition of energy structure carbon intensity (CO2 emission per unit of energy consumption[10]) constraint. Based on model (2), total energy consumption constraint is added as well:

$$D_e(E,K,L,Y,C) = \sup\{\lambda : (E/\lambda, K, L, Y, C/\lambda) \in T, \sum_{k=1}^{K} E_k/\lambda_k = \sum_{k=1}^{K} E_k\}$$

(3)

Equation (3) can be formulated as piecewise linear function:

$$[D_e(E,K,L,Y,C)]^{-1} = \min \theta$$

$$\begin{aligned} s.t. \sum_{k=1}^{K} \lambda_k E_{km} \left| 1 + \frac{E_{om}(1-\theta)}{\sum_{k\ne o} E_{km}} \right| &\le \theta E_{om},\ m = 1,2,\cdots,M \\ \sum_{k=1}^{K} \lambda_k K_{kn} &\le K_{on},\ n = 1,2,\cdots,N \\ \sum_{k=1}^{K} \lambda_k L_{kl} &\le L_{ol},\ l = 1,2,\cdots,L \\ \sum_{k=1}^{K} \lambda_k Y_{ki} &\ge Y_{oi},\ i = 1,2,\cdots,I \\ \sum_{k=1}^{K} \lambda_k C_{kj} &= \tilde{\theta} C_{oj},\ j = 1,2,\cdots,J \\ \lambda_k &\ge 0,\ k = 1,2,\cdots,K \end{aligned}$$

(4)

As shown above, Model (4) has characteristics of both environmental production technology and ZSG-DEA, and also can be use to solve the problem of optimal energy allocation under total consumption constraint. Assign the excessive energy input of province *i* to other provinces by using $E_{im}(1-\theta_i)/\sum_{k\ne i} E_{km}$. At the same time, because model (4) is nonlinear programming, the quantitative relation of technology efficiency θ_i and $\tilde{\theta}_i$ in model (4) and model (2) can be established through linear transformation:

$$\theta_i = \tilde{\theta}_i \left(1 + \frac{\sum_{j\in W} E_j (1 - \phi_{ji}\theta_i)}{\sum_{j\notin W} E_j} \right) \quad (5)$$

In model (5), DMUs whose technology efficiency $\tilde{\theta}_i$ is not 1 in model (2), make up cooperation set W. Equation $\phi_{ji} = \tilde{\theta}_j / \tilde{\theta}_i$ denotes proportional relation of technology efficiency between DMU *j* and DMU *i*. θ_i expresses ZSG-DEA technology efficiency of each DMUs.

Cost of Environmental Regulation and Total Energy Consumption Control

The very important characteristic of environmental production technology is its concern to environmental regulation cost. Zhou et al[11] and Färe[12] studied the environmental regulation cost under weak disaposibility constraint of undesirable output. They assume that undesirable output is unavoidable in production process. The existance of undesirable output determins that desirable output is impossible to achieve the optimal value under weak disaposibility constraint. The gap between target value of undesirable output under weak disaposibility constraint and that without such contraint is cost of environmental regulation[13,14]. It can be formulated as model (6):

$$\vec{D}\left(E,K,L,Y,C;-g_E,g_y,-g_u\right) = \sup\left\{ \beta : \left(E+\beta g_E, K, L, Y+\beta g_y, C+\beta g_u\right) \in T \right\} \quad (6)$$

where, $g = \left(-g_E, g_y, -g_u\right)$ is direction vector. The different choice of direction vector may bring about four environmental regulations. General regulation is $g = (0, Y, 0)$. Strict regulation is $g = (0, Y, -C)$. Adjustment of undesirable output only, is $g = (0, 0, -C)$. Direction vector without environmental regulation, undesirable output in assumption of strong disposability, is $g = (0, Y, 0)$. Under general regulation, the maximum potential desirable output of a certain DMU is at point F. Without environmental regulation, its desirable output is at point G. The distance between F and G is the cost of environmental regulation after addition of undesirable output under weak disposability constraint. Under strict regulation, the maximum potential desirable output of certain DMU is at point K. The environmental regulation cost can be represented by distance between point K and I. As shown in figure 1, cost of KI under strict regulation is higher than that of FG under general regulation.

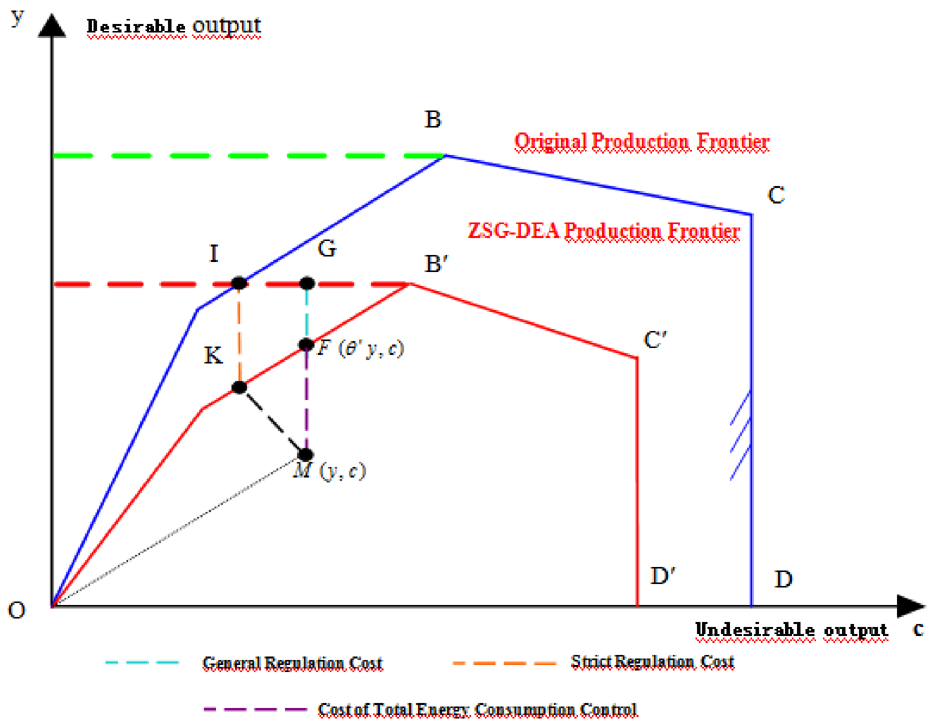

Figure 1. Cost of Environmental Regulation and Total Energy Consumption Control

There is opportunity cost under total energy consumption control. That is, a DMU can choose to be out of the energy consumption quota allocation. It promises to meet efficiency requirements of ZSG-DEA (not involve itself in reference technology) by improving desirable output so to prevent itself from being deprived of energy consumption quota. This paper defines it as cost of total energy consumption control. In order to measure the target value of desirable output under alternative plan, Shephard output distance function is defined as follows:

$$D_y(E,K,L,Y,C) = \inf\{\lambda' : (E,K,L,Y/\lambda',C) \in T'\} \quad (7)$$

Where

$$T' = \{(E,K,L,Y,C) : (E_o,K_o,L_o,Y_o,C_o) \notin T\} \quad (8)$$

The difference between production feasible set T' and T is that, T' is exclusive of target DMUs and it only aims to allocate ZSG-DEA energy consumption quota among other DMUs. Total energy consumption remains unchanged after allocation. Details equation (7) in form of DEA model is as follows:

$$[D_y(E,K,L,Y,C)]^{-1} = \max \theta'$$

$$\begin{aligned} s.t. \ & \sum_{k=1,k\neq o}^{K} \lambda_k \theta_k E_{km} \le E_{om},\ m=1,2,\cdots,M \\ & \sum_{k=1,k\neq o}^{K} \lambda_k K_{kn} \le K_{on},\ n=1,2,\cdots,N \\ & \sum_{k=1,k\neq o}^{K} \lambda_k L_{kl} \le L_{ol},\ l=1,2,\cdots,L \\ & \sum_{k=1,k\neq o}^{K} \lambda_k Y_{ki} \ge \theta' Y_{oi},\ i=1,2,\cdots,I \\ & \sum_{k=1,k\neq o}^{K} \lambda_k \tilde{\theta}_k C_{kj} = C_{oj},\ j=1,2,\cdots,J \\ & \lambda_k \ge 0,\ k=1,2,\cdots,K \end{aligned} \quad (9)$$

In model (9), θ means technology efficiency of ZSG-DEA determined by model (4) which takes T as reference technology. θE means energy consumption of every province after ZSG-DEA allocation of model (4). $\tilde{\theta}C$ means CO2 emission of every DMU after allocation of model (2). $\theta' Y$ means desirable output under ZSG-DEA constraints. $(\theta'\text{-}1)Y$ means cost of total energy consumption control (distance between point M and F in figure 1).

Data Source and Treatment

We estimate total GDP in 2015 will be 63119.7 billion RMB (2010 constant price). The total energy consumption will be 4329.75 million tons of standard coal and the energy consumption per unit of GDP will be 0.686 tons of standard coal per 10,000 RMB (2010 constant price). In estimating GRP, CO2, energy consumption, capital stock and labor force input of every province in 2015, we make allocation among provinces according to proportion of each province's portion to national total on base year. National total CO2 emission is calculated according to 12th FYP emission reduction target. For sake of consistency with the quantity of value of capital stock, this paper transforms all the GRP-related data to 1952 constant price. On provincial CO2 emission calculation, it is estimated according to final energy consumption.

Allocation of ZSG-DEA energy consumption quota

By allocating each province's energy consumption quota based on model (4) and making comparison between traditional technology efficiency and ZSG-DEA technology efficiency, potential amount of energy saving before and after allocation can be calculated as shown in table 1:

Table 1. Comparison between traditional DEA efficiency and ZSG-DEA allocation efficiency at provincial level in 2015

Province	Traditional energy consumption	Traditional DEA efficiency	Potential energy saving	ZSG-DEA energy consumption quota	Efficiency after allocation	ZSG-DEA energy saving
	(Ten thousand tons)		(Ten thousand tons)	(Ten thousand tons)		(Ten thousand tons)
Beijing	7963.359	1.000	0.000	10880.230	1.000	-2916.871
Tianjin	7119.485	1.000	0.000	9727.256	1.000	-2607.771
Hebei	30807.973	0.427	17644.652	17984.867	1.000	12823.105
Shanxi	18878.079	0.338	12504.146	8708.618	1.000	10169.461
Inner Mongolia	18596.625	0.370	11714.211	9403.349	1.000	9193.276
Liaoning	23163.930	1.000	0.000	31648.563	1.000	-8484.634
Jilin	9329.821	0.586	3865.542	7465.771	1.000	1864.050
Heilongjiang	12685.807	0.637	4604.144	11041.868	1.000	1643.940
Shanghai	12565.426	1.000	0.000	17167.971	1.000	-4602.545
Jiangsu	28736.020	0.930	2020.638	36500.865	1.000	-7764.845
Zhejiang	18867.324	1.000	0.000	25778.169	1.000	-6910.845
Anhui	10781.973	1.000	0.000	14731.264	1.000	-3949.291
Fujian	10806.889	1.000	0.000	14765.306	1.000	-3958.417
Jiangxi	7044.892	0.761	1683.818	7324.764	1.000	-279.872
Shandong	39293.840	0.643	14010.403	34544.418	1.000	4749.423
Henan	23938.813	0.603	9511.467	19711.888	1.000	4226.926
Hubei	16614.080	1.000	0.000	22699.593	1.000	-6085.513
Hunan	16157.436	0.722	4493.353	15936.479	1.000	220.957
Guangdong	29880.668	1.000	0.000	40825.552	1.000	-10944.884
Guangxi	8574.968	0.777	1909.159	9107.404	1.000	-532.436
Hainan	1493.834	1.000	0.000	2041.006	1.000	-547.171
Chongqing	8520.252	0.681	2720.521	7924.094	1.000	596.158
Sichuan	19782.217	0.722	5495.992	19519.075	1.000	263.142
Guizhou	9170.512	0.326	6178.610	4087.795	1.000	5082.717

Yunnan	9734.986	1.000	0.000	13300.780	1.000	-3565.794
Shannxi	9748.971	0.694	2985.581	9240.728	1.000	508.243
Gansu	6643.785	0.371	4177.104	3370.194	1.000	3273.592
Qinghai	2846.024	0.338	1884.493	1313.726	1.000	1532.298
Ningxia	4105.891	0.263	3027.600	1473.254	1.000	2632.637
Xinjiang	9121.096	0.381	5644.422	4750.132	1.000	4370.963

After ZSG-DEA allocation, technology efficiency value of every province reaches 1. And Pareto optimality of energy allocation is realized under technology efficiency perspective. Eastern provinces like Guangdong, Liaoning, Jiangsu, Zhejiang, Hubei, Shanghai and Fujian, with higher traditional DEA efficiency, get more energy consumption quota after ZSG-DEA allocation. On the contrary, due to lower energy efficiency, most western provinces get less energy consumption after ZSG-DEA allocation comparing with original energy consumption. In particular, the total energy consumption of Shandong, Guizhou, Inner Mongolia, Shanxi and Hebei province would be decreased and accounts for 67% of the entire available transferable quotas. Consequently, the five provinces above are facing stronger energy constraint, which tally with the actual situation. Official data in *China statistical yearbook, 2011* shows that provinces like Hebei, Inner Mongolia, Shanxi and Guizhou are at the end of the national energy efficiency ranking. Although Shandong province ranks eleven, in the middle of the ranking, its energy consumption is on the top. Therefore, it needs to reduce large amount of energy consumption in course of energy efficiency improvement. Original input and output combination of Jiangxi and Hunan province is closest to requirements of ZSG-DEA production frontier. As a result, the two provinces do not have much change after allocation of energy quota. This also explains that the input/output efficiency benchmark under ZSG-DEA allocation is in accordance with reference system of the two provinces' traditional technology efficiency (Both provinces, located in central China, represent regions of moderate level of economic development. It is appropriate to take the two provinces as benchmark.). After ZSG-DEA allocation, provinces with higher efficiency can get extra energy consumption quota, while provinces with lower energy efficiency are deprived certain amount of energy consumption quota. On the model, it can be illustrated that ZSG-DEA production frontier shrinks further comparing to the original production frontier. Therefore, a new production frontier enfolded by original production frontier comes into being. Provinces are distributed on the newly formed ZSG-DEA production frontier and national optimal energy efficiency is realized.

Table 2. Comparison on energy intensity, CO_2 emissions intensity and carbon intensity of energy structure before and after ZSG-DEA allocation at provincial level in 2015

Province	E/GRP (before allocation)	E/GRP (after allocation)	CO_2/GRP (before allocation)	CO_2/GRP (after allocation)	CO_2/E (before allocation)	CO_2/E (after allocation)
	(ton/10,000 RMB)	(ton/10,000 RMB)	(ton/10,000 RMB)	(ton/10,000 RMB)	(ton/ton)	(ton/ton)
Beijing	2.362	3.227	5.394	5.394	2.284	1.672
Tianjin	3.231	4.414	8.283	8.283	2.564	1.877
Hebei	6.323	3.691	15.802	6.752	2.499	1.829
Shanxi	8.589	3.962	18.441	6.226	2.147	1.572
Inner Mongolia	6.669	3.372	14.575	5.394	2.185	1.600
Liaoning	5.253	7.178	11.668	11.668	2.221	1.626
Jilin	4.506	3.606	11.144	6.527	2.473	1.810
Heilongjiang	5.121	4.458	9.963	6.347	1.945	1.424

Shanghai	3.064	4.186	6.729	6.729	2.196	1.607
Jiangsu	2.904	3.688	7.070	6.573	2.435	1.782
Zhejiang	2.849	3.892	7.506	7.506	2.635	1.928
Anhui	3.652	4.989	9.463	9.463	2.591	1.897
Fujian	3.070	4.194	7.895	7.895	2.572	1.883
Jiangxi	3.120	3.244	7.088	5.394	2.272	1.663
Shandong	4.199	3.692	10.651	6.854	2.537	1.857
Henan	4.339	3.573	10.371	6.250	2.390	1.749
Hubei	4.355	5.951	11.440	11.440	2.627	1.922
Hunan	4.217	4.159	9.877	7.131	2.342	1.714
Guangdong	2.718	3.714	6.243	6.243	2.297	1.681
Guangxi	3.751	3.984	9.835	7.645	2.622	1.919
Hainan	3.029	4.138	6.537	6.537	2.158	1.580
Chongqing	4.500	4.185	10.141	6.903	2.254	1.649
Sichuan	4.818	4.754	9.292	6.711	1.928	1.411
Guizhou	8.341	3.718	19.217	6.270	2.304	1.686
Yunnan	5.641	7.707	14.150	14.150	2.509	1.836
Shaanxi	4.031	3.821	8.349	5.792	2.071	1.516
Gansu	6.749	3.423	16.209	6.018	2.402	1.758
Qinghai	8.822	4.072	17.880	6.041	2.027	1.483
Ningxia	10.172	3.650	23.343	6.130	2.295	1.680
Xinjiang	7.022	3.657	15.310	5.836	2.180	1.596
Average	4.914	4.210	11.329	7.203	2.332	1.707
Variance	4.259	1.082	20.031	4.046	0.042	0.022

Table 2 depicts energy utilization efficiency and CO_2 index changes after ZSG-DEA allocation. The mean value and variance of each province's energy intensity, CO_2 emission intensity and carbon intensity of energy structure after ZSG-DEA allocation is remarkably smaller than the value before allocation. The convergence effect of ZSG-DEA to CO_2 emission intensity index is particularly noticeable. This indicates, to a certain extent, that ZSG-DEA allocation has obvious target steering function in narrowing differences of energy intensity, CO_2 emission intensity and carbon intensity of energy structure. Moreover, energy saving after ZSG-DEA allocation and energy saving potential are consistent in distribution (see figure 2). It is strictly allocated according to each province’s energy saving potential.

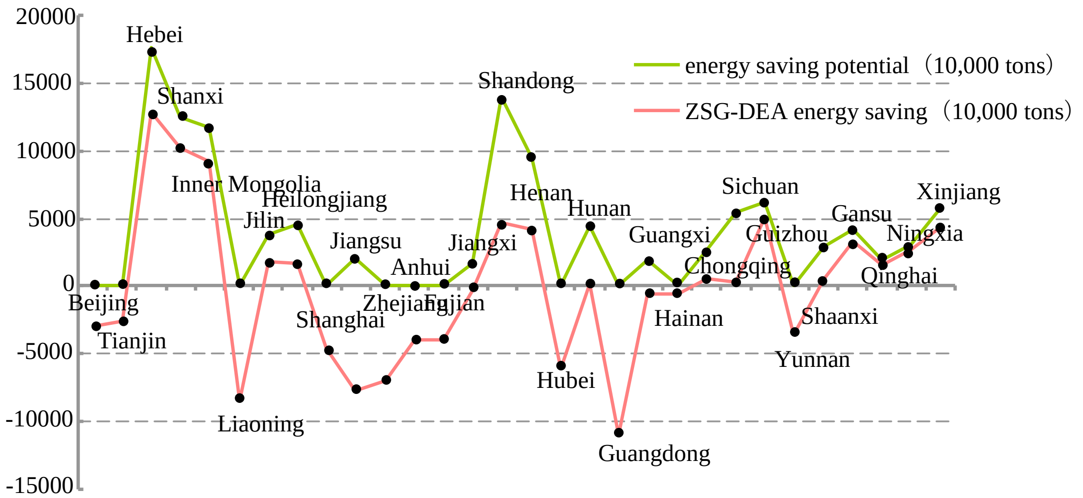

Figure 2. Potential energy saving and energy saving under ZSG-DEA constraint at provincial level in 2015

Comparing with traditional DEA, ZSG-DEA has constraint condition of total energy consumption. Double constraint of environmental regulation (mainly from weak disposability of undesirable output) and total energy consumption control (mainly from opportunity cost of energy consumption constraint) would be given. Based on formula from (6) to (9), this paper further considers cost of double constraint.

Table 3. Cost of environmental regulation and total energy consumption control at provincial level in 2015

Province	Environmental regulation cost before ZSG-DEA allocation		Environmental regulation cost after ZSG-DEA allocation		Total energy consumption control cost
	General environmental regulation cost	Strict environmental regulation cost	General environmental regulation cost	Strict environmental regulation cost	
	(100 million RMB)	(100 million RMB)	(100 million RMB)	(100 million RMB)	(100 million RMB)
Beijing	0.000	0.000	0.000	0.000	0.000
Tianjin	0.000	345.220	0.000	345.220	1180.250
Hebei	6945.810	7627.430	0.000	156.670	1226.180
Shanxi	5455.880	5637.550	161.610	343.280	339.060
Inner Mongolia	5085.430	5085.430	125.610	125.610	0.000
Liaoning	269.560	3776.850	269.560	3776.850	5128.680
Jilin	1444.930	1682.910	0.000	46.230	434.670
Heilongjiang	2456.450	2693.070	507.050	743.670	437.700
Shanghai	204.820	767.900	204.820	767.900	1014.490
Jiangsu	108.160	1295.770	0.000	440.230	2162.270
Zhejiang	0.000	281.510	0.000	281.510	2592.730
Anhui	0.000	803.870	0.000	803.870	2227.200
Fujian	0.000	392.450	0.000	392.450	1632.250
Jiangxi	724.930	724.930	12.010	12.010	0.000
Shandong	4747.930	6164.520	0.000	232.500	2531.540
Henan	3743.330	4213.370	0.000	186.200	875.690
Hubei	0.000	1849.870	0.000	1849.870	4275.200
Hunan	1776.370	2478.500	0.000	576.010	1233.290
Guangdong	0.000	857.250	0.000	857.250	1729.920
Guangxi	390.280	949.730	0.000	141.390	954.160
Hainan	34.750	92.030	34.760	92.030	104.530
Chongqing	1184.450	1481.760	32.580	329.890	529.640
Sichuan	3268.300	3823.760	941.290	1496.750	1001.950
Guizhou	2604.910	2700.830	0.000	84.800	178.450
Yunnan	0.000	1622.790	0.000	1622.780	2801.410
Shaanxi	1530.760	1623.180	266.660	359.080	178.490
Gansu	1714.720	1774.750	0.000	6.150	113.840
Qinghai	843.720	864.150	45.830	66.260	38.670
Ningxia	1279.700	1309.000	0.000	27.110	55.090
Xinjiang	2456.560	2511.820	66.710	121.960	106.320
Average	1609.058	2181.073	88.950	542.851	1169.456

Variance	48271.750	65432.200	2668.490	16285.530	35083.670

Table 3 shows cost of environmental regulation is remarkably reduced after ZSG-DEA allocation. Provincial general environmental regulation cost is reduced from 4827.175 billion RMB before allocation to 266.849 billion RMB after allocation, while strict environmental regulation cost is reduced an outstandingly 75% from 6543.220 billion RMB to 1628.553 billion RMB. Before allocation, Hebei, Shandong, Shanxi and Inner Mongolia has higher general and strict environmental regulation cost. Yet, the problem disappears after allocation. Liaoning province has higher cost of total energy consumption control, which is related to the characteristic of its industrial structure. Liaoning province is highly reliable to resources and petrochemical industry, which make great contribution to its GRP. If strict control of total energy consumption comes into practice, it will have significant influence to its economic output. Comparing cost of total energy consumption control and environmental regulation, total cost of total energy consumption control is higher than that of strict environmental regulation. This implies that total energy consumption control can reduce cost of environmental regulation effectively. Meanwhile, opportunity cost under energy consumption control will be generated by ZSG-DEA allocation, which may influence the potential economic growth of each province.

By comparing energy intensity reduction target of each province in *12th FYP energy saving target decomposition scheme (draft)*, it shows that:

Table 4. Comparison on ZSG-DEA energy consumption per unit of GRP and planning target in 12th FYP at provincial level in 2015

Province	Energy intensity in 2010	ZSG-DEA energy intensity in 2015	Energy intensity reduction in 12th FYP	Planning target	Difference
	(ton/10,000 RMB 1952 constant price)	(ton/10,000 RMB 1952 constant price)	(%)	(%)	(%)
Beijing	2.810	2.630	6.406	17.000	-10.594
Tianjin	3.850	3.250	15.584	18.000	-2.416
Hebei	7.530	4.680	37.849	17.000	20.849
Shanxi	10.220	4.380	57.143	16.000	41.143
Inner Mongolia	7.940	7.620	4.030	15.000	-10.970
Liaoning	6.250	5.850	6.400	17.000	-10.600
Jilin	5.360	5.480	-2.239	16.000	-18.239
Heilongjiang	6.100	4.870	20.164	16.000	4.164
Shanghai	3.650	3.080	15.616	18.000	-2.384
Jiangsu	3.460	2.870	17.052	18.000	-0.948
Zhejiang	3.390	2.860	15.634	18.000	-2.366
Anhui	4.350	4.440	-2.069	16.000	-18.069
Fujian	3.650	3.740	-2.466	16.000	-18.466
Jiangxi	3.710	3.800	-2.426	16.000	-18.426
Shandong	5.000	4.680	6.400	17.000	-10.600
Henan	5.170	3.850	25.532	16.000	9.532
Hubei	5.180	5.300	-2.317	16.000	-18.317
Hunan	5.020	4.100	18.327	16.000	2.327
Guangdong	3.240	2.730	15.741	18.000	-2.259
Guangxi	4.470	4.290	4.027	15.000	-10.973

Hainan	3.610	3.500	3.047	10.000	-6.953
Chongqing	5.360	4.260	20.522	16.000	4.522
Sichuan	5.740	4.980	13.240	16.000	-2.760
Guizhou	9.930	4.880	50.856	15.000	35.856
Yunnan	6.720	6.440	4.167	15.000	-10.833
Shannxi	4.800	4.420	7.917	16.000	-8.083
Gansu	8.030	4.680	41.719	15.000	26.719
Qinghai	10.500	3.730	64.476	10.000	54.476
Ningxia	12.110	11.620	4.046	15.000	-10.954
Xinjiang	8.360	8.110	2.990	10.000	-7.010

Changes of energy intensity at provincial level under ZSG-DEA allocation are quite different from the 12th FYP planning target. The reason is that the planning targets are determined by trend extrapolation according to each province's historical data. Along with adjustment of desirable economic growth, this may neglect the ZSG condition among provinces caused by fixed total energy consumption. Due to higher traditional DEA efficiency, the 11 provinces of Beijing, Tianjin, Liaoning, Shanghai, Zhejiang, Anhui, Fujian, Hubei, Guangdong, Hainan, and Yunnan can get more energy consumption quota after ZSG-DEA allocation. The reduction of their energy intensity is lower than the planned reduction target. On the other hand, provinces with lower traditional DEA efficiency like Hebei, Shanxi, Guizhou, Gansu and Qinghai are deprived of energy consumption quota. Therefore, these provinces confront to stronger energy consumption constraint and have sharp reduction of energy intensity. The reason is that ZSG-DEA allocation is based on total-factor energy efficiency (comprehensively consider capital, labor, desirable and undesirable output). For convenience of analysis, humanities indicator (like total population, regional GDP per capita etc.) concerned with fairness is not involved. Tianjin, Shanghai, Jiangsu, Zhejiang and Guangdong are less sensitive to the control mode of total energy consumption. The gap between their energy intensity reduction and that of 12th FYP target is about 2%. This is because the above mentioned five provinces have higher energy efficiency. According to technical efficiency, they get more energy consumption quota. In addition, they have higher energy consumption, quota allocation has less influence to them.

In the *Consultative draft*, CO_2 reduction target falls into seven categories. Hereby, compare CO_2 emission intensity and reduction target in 12th FYP under validity of ZSG-DEA technical efficiency:

Table 5. Comparison on ZSG-DEA CO_2 emissions intensity and planning target in 12th FYP at provincial level in 2015

Province	carbon emission intensity in 2010	ZSG-DEA carbon emission intensity in 2015	Carbon emission intensity reduction in 12th FYP	Planning target	Difference
	(ton/10,000 RMB 1952 constant price)	(ton/10,000 RMB 1952 constant price)	(%)	(%)	(%)
Beijing	6.500	5.390	17.077	17.000	0.077
Tianjin	9.980	8.280	17.034	18.000	-0.966
Hebei	19.040	10.490	44.905	17.000	27.905
Shanxi	22.220	7.730	65.212	16.000	49.212
Inner Mongolia	17.560	14.580	16.970	15.000	1.970

Liaoning	14.060	11.670	16.999	17.000	-0.001
Jilin	13.430	11.140	17.051	16.000	1.051
Heilongjiang	12.000	7.790	35.083	16.000	19.083
Shanghai	8.110	6.730	17.016	18.000	-0.984
Jiangsu	8.520	6.960	18.310	18.000	0.310
Zhejiang	9.040	7.510	16.925	18.000	-1.075
Anhui	11.400	9.460	17.018	16.000	1.018
Fujian	9.510	7.900	16.930	16.000	0.930
Jiangxi	8.540	7.090	16.979	16.000	0.979
Shandong	12.830	10.650	16.991	17.000	-0.009
Henan	12.500	7.560	39.520	16.000	23.520
Hubei	13.780	11.440	16.981	16.000	0.981
Hunan	11.900	7.890	33.697	16.000	17.697
Guangdong	7.520	6.240	17.021	18.000	-0.979
Guangxi	11.850	9.840	16.962	15.000	1.962
Hainan	7.880	6.540	17.005	10.000	7.005
Chongqing	12.220	7.890	35.434	16.000	19.434
Sichuan	11.200	7.890	29.554	16.000	13.554
Guizhou	23.150	9.840	57.495	15.000	42.495
Yunnan	17.050	7.710	54.780	15.000	39.780
Shannxi	10.060	7.520	25.249	16.000	9.249
Gansu	19.530	9.840	49.616	15.000	34.616
Qinghai	21.540	6.540	69.638	10.000	59.638
Ningxia	28.120	23.300	17.141	15.000	2.141
Xinjiang	18.450	15.310	17.019	10.000	7.019

Table 5 demonstrates that the difference between changes of carbon emission intensity at provincial level under ZSG-DEA allocation and 12th FYP planning target is smaller than energy intensity difference. The reason lies in that, in researching process, this paper does not put constraint of CO2 emission. CO2 emission under ZSG-DEA allocation of each province depends on their traditional DEA efficiency value. Other provinces' influence to a certain province's CO_2 emission is out of consideration. However, under ZSG-DEA allocation, CO_2 emission intensity in Shanxi, Guizhou, Yunnan, Gansu And Qinghai province still decreases noticeably. In this paper, we considered the restriction of fixed parameter between energy and CO_2 emission. In adjustment process according to traditional energy efficiency, although allocation of energy consumption quota is not involved, sharp changes of energy consumption brings about sharp changes of CO_2 emission. Therefore, CO_2 emission intensity reduces dramatically. The gap between reduction target of CO_2 emission intensity and planning target in the 16 provinces of Beijing, Tianjin, Inner Mongolia, Liaoning and etc. is controlled within 2%. This implies that ZSG-DEA, in effective allocation of energy quota, has little interference to reduction target of CO_2 emission intensity. It can be policy compatible with implementation of planned target of CO_2 emission intensity. Although CO_2 emission intensity declines dramatically in Hebei, Shanxi, Guizhou, Gansu And Qinghai province, reduction target is not out of the reasonable range through comparison. Hebei's reduction target of CO_2 emission intensity in 2015 is about 10 ton/ 10,000 RMB, similar to Shaanxi's CO_2 emission intensity in 2010. Qinghai' s reduction target of CO_2 emission intensity in 2015 is about 7.8 ton/ 10,000 RMB, similar to Hainan's CO_2 emission intensity in 2010. Guizhou and Gansu's reduction target of CO_2 emission intensity in 2015 is about 9.8 ton/ 10,000 RMB, similar to Tianjin's CO_2 emission intensity in 2010. Shanxi's reduction target of CO_2 emission intensity is slightly higher, similar to Guangdong's CO_2 emission intensity in 2010. On the one hand, this demonstrates severe imbalance of energy input and output in Shanxi. Economic development pattern under "resource curse" has caused excessive reliance on energy input. On the other hand, the country should provide Shanxi with reasonable subsidy to improve total factor productivity and comprehensive output efficiency.

Conclusions

This paper proposes a ZSG-DEA method based on environmental production technology, which having been improved by adopting non-parametric distance function, breaks single input or output restrictions of Gomes model. Through comprehensive consideration of allocation and substitution utility among factors of energy, capital and labor, efficient allocation of energy consumption quota under total factor perspective is achieved. Meanwhile, this paper pays more attention to influence of undesirable output to production efficiency and allocation plan. This enables the model to have a overall consideration to influence of environmental regulation during process of energy consumption quota. By applying ZSG-DEA model to study of "12th FYP" total energy consumption control, its result demonstrates: (1) After ZSG-DEA allocation of total energy consumption, technology efficiency in every province is realized. Allocation of the amount of energy saving is also basically in accordance with each province's energy saving potential. (2) After allocation of ZSG-DEA energy consumption quota, environmental regulation cost is effectively reduced. Problem of total energy consumption control cost comes into being at the same time. (3) Allocation of energy consumption quota based on standard of ZSG-DEA technical efficiency is out of consideration on fairness. This explains why each province's total energy consumption control target after ZSG-DEA adjustment is not consistent with the planning target. However, constraint of ZSG-DEA total energy consumption control has little influence on planning reduction target of CO_2 emission intensity, which realizes the compatibility between energy saving and emission reduction policy to certain extant. In subsequent study, this paper will concentrate on how to realize consistency of total control target and energy intensity reduction target as well as the inter-temporal allocation based on time dimension.

In modeling process, this paper lays stress on environmental DEA efficiency standard and takes energy, capital, labor input and effective relationship of desirable and undesirable output as standard for allocation of energy consumption quota. Due to the fact that provinces are heterogeneous individuals, who hold different features in industrial structure, economic development level, natural endowments, weather condition as well as energy utilization. It is not appropriate to simply compare each province's energy efficiency and calculate their energy saving potential from efficiency analysis perspective. In the future, this paper will make more effort to study the heterogeneous feature of each province's energy utilization in process of efficiency analysis.

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