World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:6, No:8, 2012

Research on Regional Energy Saving Potential Based on Nonparametric Radial Adjustment and Slack Adjustment

Donglan Zha, Ning Ding

***Abstract*—**Taking the provincial capital, labor and energy as inputs, regional GDP as output from 1995 to 2007, the paper quantifies the vertical and lateral energy saving potential by introducing the radial adjustment and slack adjustment of DEA. The results show that by the vertical, the achievement of energy saving in 2007 is better than their respective historical performances. By horizontal, in 2007 it can be found that Tianjin, Liaoning, Shanghai and Yunnan do better in energy saving than other provinces. In national wide, the higher of energy efficiency, the larger of per capita GDP and the proportion of the tertiary industry in the national economy, the more open to the outside, the lower the energy saving potential demonstrates, while the energy endowment has negative effect on energy saving potential.

***Keywords*—**radial adjustment; slack adjustment; regional disparity; energy saving potential

I. Introduction

SINCE the exploration of oil crisis in the 1970s and a growing environmental awareness among societies, a rapid development of energy-saving technologies has been induced. The uptake of these technologies is to reduce the amount of energy required to provide products and services more than reducing energy use. It is, therefore, an important measure to mitigate the depletion of fossil fuels and carbon emissions while give consideration to keep a stable economy growth, especially for the developing countries. The developed countries have taken a large number of measures on energy saving which have swept the profession. Basically, in the past about forty years, the focus of energy saving have experienced three periods: energy saving by living economically, energy storing and improving energy efficiency. According to the International Energy Agency, improved energy efficiency in various sectors could reduce the world's energy needs in 2050 by one third, and help control global emissions of greenhouse gases[1].

In China since the introduction of reform and opening up policies in 1978, China's economic growth rate has averaged almost 10.01% per annum during 1980-2009. However, the rapid economic growth has been largely supported by the energy consumption, with average growth rate of 5.74% during those thirty years. It grew even faster attaining 8.2% at the fist ten years of this century. The global shares of primary energy consumption were only 6.3% for China and as high as 28.6% for the USA in 1978. By 2010, China's global share soared to 20.3% while the USA's global share decreased dramatically to 19%, which means that China overpasses USA in energy consumption and has been the largest energy consumer in the world[2]. Although there are differences of the statistic standards, that China is a big country in energy consumption has no dispute. Some projections suggest an even higher growth rate of energy consumption for China. Thus, the energy and the emerging environment issues are especially prominent and vital to China sustainable development.

Nevertheless, China's energy efficiency is still much lower than many developed countries, even the average level of the world. In 2008 energy intensity (energy consumption per unit of gross domestic production) was 0.72 TPES/GDP (toe/thousand 2000 USD) in China compared to 0.20 in USA, 0.10 in Japan and 0.31 in the word (IEA 2011). How to improve energy efficiency has become an urgent issue that China has to face. The Chinese government has launched a series of vigorous programme. Over the past Eleventh Five Year (2006–2010), China successfully attained the goal of 20% drop on energy intensity. For the next Twelfth Five Year (2011–2015), energy intensity and CO_2 emission are set to decrease by 16% and 17% respectively. The central goals have been assigned to 34 provinces, autonomous regions and municipalities (Tai Wan, Macao and Hong Kong excluded)[3], see Table 1. The objectives to reduce energy intensity are classified into five categories. The four regions set for reducing 18% are from the highly developed eastern coastal area of China and the industry added value take a large proportion to their GDP (Tianjin 52.71%, Shanghai 43.47%, Jiangsu 50.57%, Shandong 48.43% in 2007). Conversely, the minimum goal of 10% is set for the least developed regions. For example, in 2007 the average GDP per capita for Hainan, Tibet, Qinghai, Xinjiang are 14477, 12049, 14196 and 16817 RMB at current price respectively, much lower than 21215 RMB of the national average level. There is an underlying issue whether the local places can achieve the goal, which seems largely depend on their individual PES. Therefore, it's necessary to measure the PES for individual regions.

This remainder of the paper is organized as follows. Section 2 reviews previous studies on PES. Section 3 outlines the method to be used to estimate the PES. Section 4 presents the vertical and horizontal PES. Section 5 reports determinants on region PES and the final Section conclude.

Donglan Zha is with Institution Nanjing University of Aeronautics and Astronautics, China, E-mail zdl@nuaa.edu.cn Tel.: +86 25 84893951; Fax: +86 25 84892751

[1] Data source: Sophie Hebden (2006-06-22). "Invest in clean technology says IEA report". Scidev.net.http://www.scidev.net/News/index.cfm?fuseaction=readNews&itemid=2929&language=1. Retrieved 2010-07-16

[2] Data source: BP Statistical Review of World Energy June 2011.

[3] We call province for short in the following sections.

TABLE I
THE ENERGY INTENSITY GOAL FOR INDIVIDUAL PROVINCE IN THE TWELFTH FIVE YEAR (2011–2015)

Provinces (Autonomous regions, municipalities)	Energy intensity decrease goal (2011-2015)
Tianjin, Shanghai, Jiangsu, Zhejiang	18%
Beijing, Hebei, Liaoning, Shandong	17%
Shanxi, Jilin, Heilongjiang	16%
Inner Mongolia, Guangxi, Guizhou, Yunnan, Gansu, Ningxia	15%
Hainan, Tibet, Qinghai, Xinjiang	10%

II. LITERATURE

As noted above, extensive literatures have devoted to explore the driving forces of economy-wide energy efficiency and try to improve it. The widely used index decomposition analysis (IDA) technique is a good way of this practice, which can decompose the predefined effects. For example, it can differentiate efficiency and structure drivers of energy consumption, energy efficiency and carbon intensity. The Logarithmic Mean Divisia Index method (LMDI) proposed by Ang (2004) is a perfect decomposition in energy efficiency accounting framework using the IDA approach [1]. It is widely used to decompose energy consumption, energy efficiency or carbon emission at the national level or sector applications. A detailed comparison about the existing IDA-based energy efficiency accounting systems can be found in the recent study from [2].

The literature on PES is thin, primarily on specific sector. Some researchers presented PES for residential sector [3], [4]. [5] estimated the electric energy saving potential by substitution of domestic refrigerators. For China, [6] calculated the energy-saving potential of the regions in China by comparing their energy efficiency with the highest one, and she found the PES are 38% for the eastern, 29% for the central and 48% for the western of China. The method applied is easy to use, however, the diversities of industrial structure and resource endowments are not fully considered when give the assumption that the energy efficiency of each region can convergent. It seems unrealistic that in the future all the regions would have the same energy efficiency with no consideration of capital and labor inputs which equally contribute to GDP. [7] identified the effects of investment ratio, energy price and technological progress on energy demand by building an energy-economy model, and based on some possible economic growth scenarios they forecasted China's energy demand and saving potential during 2006-2010. Their results of PES are based on the forecasts of energy efficiency improvement. [8] analyzed the contribution of technical progress and industrial structure to energy saving from 1995 to 2007 by Laspeyres index decomposition model, and the energy-saving potential of the Yangtze River Delta were compared. Actually, their main contribution is that they detected the driving forces of energy efficiency. The present paper extends and reinforces the previous literature.

III. METHOD

Recently, data envelopment analysis (DEA) has become more commonly adopted in the energy efficiency and environment literature ([9] for a review). It is a well established nonparametric frontier analysis technique on efficiency evaluation, developed by [10], which only requires the observed quantities of inputs and outputs. In traditional DEA framework, DEA can derive the efficient decision making units (DMUs) from multiple inputs and outputs, and the non-efficient DMU can move to the efficient one by linear programming. If the DMU is not efficient, several efficient DMUs are designated as ‘‘a reference set’’ and the efficiency score of DMU is calculated based on the distance between the DMU and a production process possibility frontier constructed by the reference set.

To do further analysis, we assume that there are two types of inputs: energy and non-energy. When the outputs are fixed and the inputs are to be minimized, it can be showed as Fig. 1. Point A and B are the observed inputs and are not in the efficient surface. The efficiency of DMUA and DMUB are OA′/OA and OB′/OB and they are expected to move to points A′ and B′ by radial adjustment. Moreover, they continue to move their position and are stopped at point C by slack adjustment, which happen under the assumption that production surface is not smooth and segmented. More specially, the primary points A and B run as the existence of non-efficiency loss, which incorporate two parts. One part is about excessive inputs of factors because of the technology inefficiency, they are AA′ and BB′. The other part stems from the inappropriate allocation of factors, which leads to the slack quantities those are A′C and B′C. Therefore, AC (AA′+A′C) and BC (BB′+B′C) are the possible quantities of energy saving. PES is measured by comparing them with their initial values. The larger is the gap, the larger is the PES. When the value is zero, it reflects the best usages of energy.

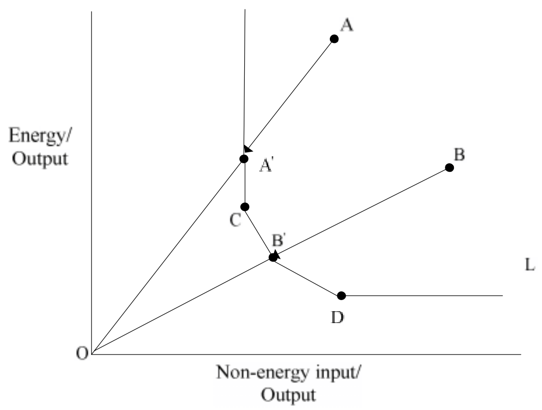

Fig. 1 The radial and slack adjustments of DEA under constant returns to scale

IV. THE VERTICAL AND HORIZONTAL PES

A. Data

Due to lack of availability of longer time series of energy data for provinces, the time period for the study is limited to 1995-2007 only. Xizang and Hainan are excluded because of their incomplete data and Chongqing is added to Si Chuan, and the panel sampling is 28[4], giving us a panel database with a total of 364 observations. The data retrieved for the study come from (1) China Statistical Yearbook as published by China's National Bureau of Statistics [11], (2) various years of China Energy Yearbook as published by China's National Bureau of Statistics [12]. Our panel data study is based on three inputs (capital stock, labor and aggregated energy) and one output (GDP) in various provinces.

The fundamental issue is how to accurately measure capital (K) which is the most controversial. Theoretically, capital is composed of direct and indirect stocks that can form the production capability. Both fixed and current assets are involved, together with all kinds of services and welfare facilities. However, these data are not ready. We try to calculate the capital stock by the perpetual inventory method where $K=K_{t-1}(1-\delta)+I_t$ [13]. Here, K_{t-1} is capital stock for year t-1. I_t is the additional capital investment for year t and here we assign Total Investment in Fixed Assets to represent it. δ is the capital depreciation rate. The total capital stock comes from [14] at constant prices of 1952 and we make an update with the capital stock series mentioned above. With respect to labor input (L), theoretically, it should reflect both the quantity and the quality of labors. Nonetheless, the quality of labors is hard to measure and there are no published data at the provincial level. We denote the average value of number of employed persons at year-beginning and year-end from CNBSa as L[5]. The primary energy (E) is aggregated by coal, oil, natural gas and electricity by converting them into the same unit (ten thousand standard coals). Total output (Y) is represented by region GDP at constant prices of 1952.

We present a summary description of the four indicators for the whole country. It's easy to find that the trend of capital is similar with that of GDP, which experienced mainly two segments, 1995-2001 with a slight drop in growth rate and 2002-2007 with a stable rise. For the whole period, the growth rate of capital shows larger than that of GDP, which demonstrates that the economy of China is partly driven by the capital contribution. With reference to energy, it can be seen that the growth rate of energy series cannot be trend-stationary in particular. Since 1998, it keeps a powerful rise reaching the peak with 21.94% in 2004 and onwards it shows a vigorous decline. This can be explained by the excessive investment of energy intensive industries, such as steel, metallurgical, chemical power, and building materials industries since 2002. The growth rate of labor fluctuates in the period 1995-2002 and since 2003 it shows small rise which is to satisfy the demand of fast economy development (average 11.66% growth rate of GDP in 2003-2007). It should be noticed that in years 1998 and 1999, the growth rates of labor are negative.

[4] Chongqing was approved by the State Council on 18 April 1997 and formerly it was a sub-provincial city within Sichuan Province. With a view to the consistent statistic standard, in the present paper Chongqing is combined with Sichuan.

[5] Before 2002, there is no term named Total Investment in Fixed Assets in CSY and it is constituted by Capital Construction and Newly-increased Investment two items.

This may be influenced by the Asian finance crisis and accompanying the industrial restructuring.

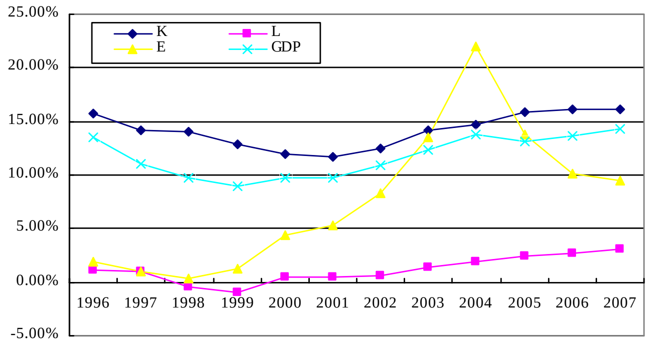

Fig. 2 The trend of growth rate of input and output indicators

B. Vertical PES of regions

We concern ourselves first on vertical PES. It is to detect that in which year each province can use energy more efficiently by comparing its own history performances, which can be finished by radical adjustment in DEA. The computational process was run by DEAP2.1. As can be observed in Table 2, compared to the history series, PES in 2007 is the smallest for all the 28 provinces. It can be explained by the perspective of energy efficiency. The statistical data show that the energy efficiency in 2007 is the highest one in the period studied for all the provinces (CNBSb). Among them, the largest decline of energy intensity is seen in Beijing, with 6.04% drop compared to that in 2006. Even the smallest decrease rate of energy intensity can get to 2.2% for Qinghai in 2007. These performances are associated with the important steps in promulgation an implementation the Eleventh Energy Plan at the beginning of 2007 by National Development and Reform Commission, and printing and issuing the comprehensive working programme of energy saving and carbon reduction by the State of Council. The related policies put forward clear goals and ascertained the responsibilities of cutting energy consumption for each province.

More specifically, taking Beijing as sample, its PES experiences a stable downward trend, which reveals that Beijing can use energy more efficiently as time goes on. While the PES of most of the provinces are unstable, which mean they fail to use the energy efficiently at the present technology.

C. Horizontal PES of regions

Focusing further on horizontal PES by slack adjustment in DEA, it is hypothesized that the technology of provinces can convergent. Taking the new data of 2007 as sampling, and the results of horizontal PES are showed in Table 3. As can been seen, in 2007 Tianjin, Liaoning, Shanghai and Yunnan are energy efficient compared to other regions. Then comes with Fujian, Zhejiang and Jiangsu provinces, the horizontal PES is smaller than 30%. The largest PES is from Qinghai with 128.36%, followed by Ningxia and Guizhou with 91.98% and 76.6%.

TABLE II
THE VERTICAL PES OF PROVINCES

Provinces	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Beijing	0.5071	0.4831	0.4586	0.4177	0.3699	0.3382	0.2780	0.2288	0.1814	0.1444	0.1094	0.0604	0
Tianjin	0.1486	0	0.0059	0.0426	0.0475	0.0445	0.0384	0.0336	0.0316	0.0049	0	0	0
Hebei	0	0	0	0	0.0036	0.0025	0	0	0	0.0128	0.0137	0	0
Shanxi	0.3233	0.0772	0	0	0.0030	0	0.0334	0.0361	0.0303	0	0.0011	0	0
Inner Mongolia	0	0	0.0999	0	0.0918	0	0	0	0	0	0.0227	0	0
Liaoning	0.3959	0.3485	0.2707	0.1783	0.1371	0.1806	0.0978	0	0	0	0.0198	0	0
Jilin	0.3255	0.2452	0.2058	0	0	0	0	0	0	0	0	0	0
Heilongjiang	0.1080	0.0044	0	0.0257	0.0384	0.0394	0.0386	0.0296	0.0192	0.0043	0	0	0
Shanghai	0	0.0735	0.0990	0.1177	0.1173	0.1016	0.0883	0.0756	0.0546	0.0257	0.0556	0.0201	0
Jiangsu	0	0.0116	0	0	0.0001	0.0034	0	0	0	0	0.0754	0.0430	0
Zhejiang	0	0.0017	0	0	0	0	0	0	0.0015	0.0516	0.0505	0.0351	0
Anhui	0.1854	0.1345	0	0.0057	0.0075	0.0143	0.0095	0	0	0	0.0041	0	0
Fujian	0	0.0207	0	0	0.0036	0	0	0	0	0.1548	0.1212	0	0
Jiangxi	0	0	0	0	0	0	0	0	0.0101	0.0901	0.0712	0	0
Shandong	0	0	0	0	0	0	0.0037	0	0	0	0.0395	0	0
Henan	0	0	0	0.0127	0.0153	0.0167	0.0099	0	0	0	0.0107	0	0
Hubei	0	0	0	0	0.0037	0.0098	0	0.0088	0.0145	0.0250	0.0176	0	0
Hunan	0	0.0638	0	0	0	0	0.0045	0.0009	0	0.0233	0.0449	0.0390	0
Guangdong	0	0.0104	0	0	0.0022	0.0011	0	0.0003	0.0015	0.0026	0.0198	0.0239	0
Guangxi	0	0.0027	0	0	0	0	0.0185	0	0	0.0046	0.0352	0	0
Sichuan	0.3564	0	0	0.0276	0.0293	0.0349	0	0.0145	0.0397	0.0688	0.0587	0.0324	0
Guizhou	0	0	0	0	0	0.0088	0.0086	0	0.0623	0.0566	0.0427	0.0248	0
Yunnan	0	0	0.1142	0.0287	0.0250	0	0.0065	0.0052	0	0.0098	0.0433	0	0
Shaanxi	0.1811	0.1977	0	0.0035	0	0	0.0055	0	0.0045	0.0001	0.0045	0	0
Gansu	0.0818	0	0	0	0	0.0026	0	0	0.0312	0.0372	0.0410	0	0
Qinghai	0	0.0034	0.0221	0	0.1406	0.0200	0.0026	0	0	0.0245	0.0513	0.0250	0
Ningxia	0.1654	0.0660	0	0	0	0	0	0	0.3634	0.1675	0.1048	0	0
Xinjiang	0	0.0837	0	0.0045	0	0	0	0	0	0.0392	0.0480	0.0322	0

TABLE III
THE HORIZONTAL PES OF PROVINCES

Provinces	Energy input (ten thousand ton)	Radial adjustment	Slack adjustment	PES	Provinces	Energy input (ten thousand ton)	Radial adjustment	Slack adjustment	PES
Beijing	6285.04	-2144.29	0	0.3412	Henan	17841.00	-10258.74	0	0.5750
Tianjin	4944.49	0	0	0	Hubei	11860.59	-5011.40	0	0.4225
Hebei	23489.86	-10881.94	0	0.4633	Hunan	10796.51	-5199.23	0	0.4816
Shanxi	14619.76	-9470.59	-298.35	0.6682	Guangdong	21912.11	-9008.19	0	0.4111
Inner Mongolia	12723.24	-7966.79	-191.79	0.6412	Guangxi	6136.67	-2252.96	0	0.3671
Liaoning	17379.47	0	0	0	Sichuan	18902.02	-8199.13	0	0.4338
Jilin	7346.11	-3308.50	0	0.4504	Guizhou	7691.96	-5891.94	0	0.7660
Heilongjiang	9374.49	-4326.41	0	0.4615	Yunnan	7173.26	0	0	0
Shanghai	9767.75	0	0	0	Shaanxi	6639.48	-3333.96	0	0.5021

Jiangsu	20604.43	-5718.43	0	0.2775	Gansu	5100.00	-2688.91	0	0.5272
Zhejiang	14532.91	-3182.32	0	0.2190	Qinghai	2094.89	-2688.91	0	1.2836
Anhui	7752.06	-3238.48	0	0.4178	Ningxia	3047.00	-2688.91	-113.72	0.9198
Fujian	7574.16	-527.78	0	0.0697	Xinjiang	6575.73	-4407.07	0	0.6702
Jiangxi	5053.76	-2974.61	0	0.5886	Henan	6575.72	-4407.0674	0	0.6702
Shandong	28554.40	-10695.58	0	0.3746					

Furthermore, we classify the provinces into six regions according to their geographical position. The inputs and output in 2007 are treated as observations and the horizontal PES at the region level is estimated. As shown in Table 4, the largest PES witnesses 43.94% in the northwestern area, coming with the southwest and the central-south.

Looking forward, the central-south has the largest radical adjustment which suggests that there is much room to process the energy utilization technology. At the same time, there are slack adjustments for southwester and central south areas. It addresses the issue that to improve the allocation efficiency in these two areas is necessary.

TABLE IV
ANALYSIS ON HORIZONTAL PES BY REGIONS

Region	Energy input (ten thousand ton)	Radial adjustment	Slack adjustment	PES
North China	62062.39	-3396.89	-6962.92	0.1669
Northeast	34100.07	0	0	0
East China	93839.48	0	0	0
Central South	68546.88	-18644.42	0	0.2720
Southwest	33767.24	-9054.57	-3654.68	0.3764
Northwest	23457.10	-10307.11	0.00	0.4394

V. THE DETERMINANTS ON PES

As illustrated above, there is large PES both at the provincial and region level. The question arises as to how to explore the potentials and reduce energy consumption. Therefore, an insight into identifying the factors that may influence PES is necessary.

To get the value of dependent variable, we estimate the horizontal PES for each year to capture the year-to-year change (Section 4.3 is only for 2007). And based on the previous literatures, we choose energy efficiency, living standard, industry structure, energy resource endowment and opening degree as independent variables. Table 5 provides descriptive statistics of these variables for the data set.

TABLE V
THE STATISTIC DESCRIPTION OF DEPENDENT VARIABLES

Variables	Definition	Observations	Average	Standard errors	maximum	minimum
Energy Efficiency (EE)	GDP/Energy consumption (ten thousand/ton standard coal)	364	0.1958	0.1063	0.5586	0.0379
living standards (AGDP)	Average GDP (ten thousand/capita 1952 RMB)	364	0.3160	0.3729	0.2937	0.0390
Industry Structure (STR)	The added value of the tertiary industry/ the second industry	364	0.8200	0.2400	2.6900	0.4900
Energy Resources Endowments (ENP)	Energy production (ten thousand ton standard coal)	364	0.5539	0.7149	0.5463	0.0194
Openness degree (OP)	Investment from foreign enterprises/ GDP	364	0.5300	0.5100	2.7400	0.0200

Note: the quantity of energy production is obtained by multiplying the fuel by their coefficient of converting to coal. Investments from foreign enterprises are converted into RMB by exchange rate at that very year.

$$PES_{i,t} = \alpha_0 + \beta_1 EE_{i,t} + \beta_2 AGDP_{i,t} + \beta_3 STR_{i,t} + \beta_4 ENP_{i,t} + \beta_5 OP_{i,t} + \mu_{i,t} \quad (1)$$

Where, $PES_{i,t}$ is the PES for the i_{th} province in the t year. α_0 is the intercept variable and $\beta_1 \sim \beta_5$ are the parameters to be estimated. $\mu_{i,t}$ represents random disturbance term.

With a view to the region divergence of driving forces to the PES, we do the regression analysis both at the national level and by grouped the eastern, central and western regions. In a panel context, we fist judge the model types (fixed effect or random effect) by the Hausman test. The values of Chi-Sq statistic show that the models for the nation and the central area fit the fixed effect, while that for the eastern and western regions are appropriate to random effect. The regression results are reported in Table 6. From the table, we can find the four models have strong explanation power which means the choosing of driving forces is reasonable. When the t-values of variables are not significant at the at the 10% level, we reject them and do regression again. Fortunately, this step only refers to the model for the eastern area.

From the results, it is observed that no matter the aggregated or by region, the higher is the energy efficiency, the smaller is the PES. It reflects when the region can efficiently use energy, the PES is obviously small. With respect to average GDP, the larger is it for the eastern and the western areas, the larger is their PES, while in the central the relation is the opposite. The reasons are firstly, the economies in the eastern and the western areas are partly driven by energy consuming. While, the central is comparatively lack of energy and constrained by the resources and the capital, labor have been the major input factors. On the other end, because they are short of energy, how to use it more efficiently is paid more attention to.

With the exception of the central area, the nation and the other regions present negative relations between industry structure and PES. Generally, the tertiary industry is less energy consuming compared to the industry and it can use energy more efficiently. The eastern area has the highest share of tertiary industry, and the degree of influence of industry structure is not as large as expected. It is clear that different driving forces on PES can be found across the studies.

The regions with fluent energy have larger PES, as the central and the east, which suggests that the waste of energy in these areas do exist. In the west the results turn out to be the very reverse of the others. The reasoning is involved that the western is relatively short of energy and can use them more efficiently as noted above. Besides, the western has improved their energy efficiency with the help of technology spilling from the east and the foreign investment.

We observe that when one place has high opening degree, its PES is small. This rule is true for the central and the western of China. However, the eastern runs the opposite. One possibility is that the eastern is the first to put forward and implement the reform and opening-up, and these policies have been relatively mature and the effects on PES are not so prominent.

TABLE V I
THE REGRESSION ANALYSIS OF THE DETERMINANTS ON PES

Variables	Country	East	Central	West
EE	-0.5611 (-2.6805)**	-0.7367 (-5.9727)***	-0.7398 (-4.8008)***	-1.4999 (-1.8623)*
AGDP	-0.1578 (-3.3724)***	0.7322 (3.4913)***	-0.1256 (-2.2328)**	1.1883 (4.0670)***
STR	-0.0878 (-1.7788)*		-0.000076 (-7.9599)***	-0.2735 (-1.7038)*
ENP	0.1227 (8.7438)***	0.5233 (1.6869)*	0.4664 (8.7515)***	-0.2065 (-3.3777)**
OP	-0.0749 (-2.5206)**		-0.0659 (-1.6921)*	-0.2102 (-1.6752)*
Constants	1.5434	0.3195	0.5771	0.8452
R^2	0.8419	0.4627	0.8581	0.6511
Observation	364	130	104	130
Chi-Sq Statistic	7.5293	0.6264	79.9504	3.683

Note: Figures in parentheses are t-statistics * Significant at the 5%-level. ** Significant at the 1%-level

VI. CONCLUSION

Energy saving and carbon reduction have been the focus of the government and the society in China. We concern ourselves at the provincial lever in time series 1995-2007, and apply the radiation and slack adjustment of DEA to explore the PES both on vertical and horizontal levels.

The results demonstrate that compared to the historical performance, the use of energy shows the most efficiently in 2007 during the times studied. With regard to horizontal level, in 2007 Tianjin, Liaoning, Shanghai and Yunnan performs best in energy use. The radial adjustment suggests there is much room to improve energy-saving technology in Hebei, Shandong and Henan, while Shanxi, Inner Mongolia run the inappropriate allocation on energy.

When dividing the country into six regions, the northeast and east China appear to be highly plausible in energy use. Turing to the determinants of PES, it is found that the average GDP, the tertiary industry/ the second industry and opening degree have negative effect on PES, while the energy endowment take the positive effect. China has given high priority to save energy and protect environment. But it doesn't mean the PES can be filled up in short time. There are many ways to save energy-stage by stage and province by province. Each province has to compare with its history performance and should do best in the resent year, which is possible for them achieve with the available technology. In terms of regions, the central and the western can save energy by increasing the share of tertiary, expanding openness and introducing new technology.

In addition, all the provinces should avoid wasting energy, which is a direct and long measure to save energy.

ACKNOWLEDGEMENTS

The author is grateful to the financial support provided by the China Postdoctoral Funding No. 20100471329, Education Ministry Doctor Program No. 20113218120032 and No. 12YJC630004, Jiangsu Postdoctoral Funding (1002044C) and NUAA Research Funding No. NJ2011011 and No. NR2012002.

REFERENCES

[1] Ang, B.W., 2004. “Decomposition analysis for policymaking in energy: which is the preferred method?” *Energy Policy*, 32, pp. 1131-1139.

[2] Ang, B.W., Mu, A.R., Zhou, P., 2010. “Accounting frameworks for tracking energy efficiency trends,” *Energy Economics*, 32(5), pp. 1209-1219.

[3] Murat, K., Kamola, K., 2007. “Energy saving potential in the residential sector of Uzbekistan,” *Energy*, 32, pp. 1319-1325.

[4] Ouyang, Jinlong., Hokao, K., 2009. “Energy-saving potential by improving occupants’ behavior in urban residential sector in Hangzhou City, China,” *Energy and Buildings*, 41(7), pp. 711-720.

[5] Arroyo-Cabañas, F.G., Aguillón-Martínez, J.E., Ambríz-García, J.J., Canizal, G. 2009. “Electric energy saving potential by substitution of domestic refrigerators in Mexico,” *Energy Policy*, 37(11), pp. 4737-4742.

[6] Shi, D., 2006. “Regional differences in China’s energy efficiency and conservation potentials,” *China Industrial Economy*, 10, pp. 49-58.

[7] Wei, Y.M., Liao, H., Fan, Y. 2007. “China' s energy demand and conservation potential forecast during the 11th Five- Year Plan period,” *Bulletin of Chinese Academy of Sciences*, 22(1), pp. 20-25.

[8] Wang Di et al., 2011. “Analysis of regional differences in energy consumption and energy saving potential for Yangtze River Delta,” *Energy Procedia*, 5, pp. 690-694.

[9] Zhou, P., Ang, B.W., Poh, K.L., 2008. “A survey of data envelopment analysis in energy and environmental studies,” *European Journal of Operational Research*, 189, pp. 1-18.

[10] Charnes, A., Cooper, W.W., Rhodes, E., 1978. “Measuring the efficiency of decision making units,” *European Journal of Operational Research*, 2, pp. 429-444.

[11] CNBSa (China’s National Bureau of Statistics), 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010. “*China Statistic Yearbook 1998-2009*,” China Statistical Press, Beijing.

[12] CNBSb (China’s National Bureau of Statistics), 2000, 2003, 2005, 2006, 2007, 2008, 2009. “*China Energy Statistic Yearbook 1997-1999, 2000-2002, 2004, 2005, 2006, 2007, 2008*,” China Statistical Press, Beijing.

[13] Goldsmith, R., 1951. “A perpetual inventory of national wealth,” *NBER studies in income and wealth*, 14, pp. 1143.

[14] Shai, H.J., 2008. “Reestimating the Capital Stock of China: 1952-2006,” *The Journal of Quantitative & Technical Economics* 10, pp. 17-31.