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Research of Regional Energy Efficiency Based on Undesirable Outputs and Its Influential Factors: A Case of Western China

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Abstract

Under the frame of Total-Factor Energy Efficiency, considering desirable outputs and undesirable outputs taking by energy and related factors, this paper uses super efficiency DEA method to measure energy efficiency of 11 provinces (autonomous regions, municipalities) in western China from 1989 to 2009, and utilizes fixed effect model of variable intercept to analysis factors of influencing energy efficiency of provinces (autonomous regions, municipalities) in western China. The analysis shows that: (1) Under the situation of overall low energy efficiency in western China, in region, energy efficiency level presents the slow rise tendency from the year of 2005 after maintaining certain time interval slow drop. In the region the difference is small. (2) Factors of technical progress, industrial structure, government influence, opening degree, system variable as well as structure of energy consumption have different effects on energy efficiency, and these factors to action mechanism of energy efficiency exist difference.

Keywords: Energy efficiency; Undesirable output; Super efficiency DEA; Influential factors; 11 provinces (autonomous regions, municipalities) in western China

1. Introduction

Energy is an important material basis of survival and development of human society, and play an important role in China's economic and social development process of sustained, rapid and healthy. The

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western region with vast territory and rich resources, primary energy resources such as coal, oil, natural gas, hydroenergy have significant advantages compared with the central and eastern regions, and this directly related to national energy production security and sustained and stable growth of national economy. However, its limited resource base is facing enormous pressure, and saving energy as well as improving energy efficiency is imperative.

Energy economic issues have caused many scholars' attention, including energy efficiency which has achieved fruitful research results is one of hot issues. Energy efficiency of traditional single-factor method is very difficult to accurately measure its potential energy efficiency[1].The "Total- Factor Energy Efficiency (TFEE)" method which is proposed by Hu and Wang[2] based on data envelopment analysis (DEA) effectively overcome the defects of traditional single-factor energy efficiency method, which provides a new way of thinking and methods for the study of energy efficiency. In recent years, many scholars have introduced TFEE method into research of China's energy efficiency. However, DEA require the input must reduce as much as possible, the output must increase as much as possible. But in reality, the undesirable output must reduce as much as possible so as to achieve the best economic efficiency, while TFEE index what is constructed by Hu and Wang based on DEA method hypothesis that inputs such as energy, capital and labor only have a single desirable output, such as GDP does not consider undesirable outputs of non-marketing in the process of the production, such as the emissions of CO_2 and SO_2.

This paper will consider the desirable output and undesirable output brought by energy and related elements, use Total-Factor Energy Efficiency indicators based on super efficiency DEA method, assess energy efficiency level of 11 provinces (autonomous regions, municipalities) in western China, and study its influencing factors through establishing econometric model of impacting energy efficiency of the western provinces, so as to provide the scientific basis for establishing strategic objectives of saving energy consumption, and promote the realization of the goal of energy saving and emission reduction.

2. DEA Model Building

Set up a production process includes two types of inputs factors what are energy and non-energy and outputs factors what are desired outputs and undesirable outputs. Suppose there are K decision making units(DMU), among them e_l , x_n , y_m , u_j respectively represent energy inputs, non-energy inputs, desirable outputs and undesirable outputs of each DMU. So production technology with undesired outputs can be described as: $T = \{[x, e, y, u][x, e]$ can produce $[y, u]\}$,and assuming that the production possibility set meet closed bounded conditions. If $[x, e, y, u] \in T$, $[x', e'] \geq [x, e][or y' \leq y]$ then $[x', e', y, u] \in T$ or $[x, e, y', u] \in T$.

As in the input-output activities of economic system, the technology used by decision making units determines the way of volume changes, also determines characteristics of undesirable outputs such as environmental pollutants generated by inputs; moreover, regardless of what technology the decision-making units are taking, undesirable outputs are inevitable, and any desired outputs are produced in certain conditions of environmental carrying capacity. Thus, this article will take undesirable output as input variable to consider, and related research also support this approach[3]. According to Hu and Wang on the idea of TFEE, we consider input oriented DEA model at the conditions of constant returns to scale, as showing in Fig 1. There are three DMU, namely A,B,C, located at the best frontier SS', and C' located outside SS'. Obviously, C' relative to C has excessive investment, that is to say there need more investment in order to achieve the same output. Considering the redundancy problem of energy input, point C can reach point A by further reducing the energy input. Therefore, AA' and A'C is the inputs needed to adjust which point A in order to reach point C, namely it exist radial adjustment quantity and relaxation adjustment quantity. Then this can calculate the ratio of target inputs and actual inputs of energy consumption of each decision making unit.

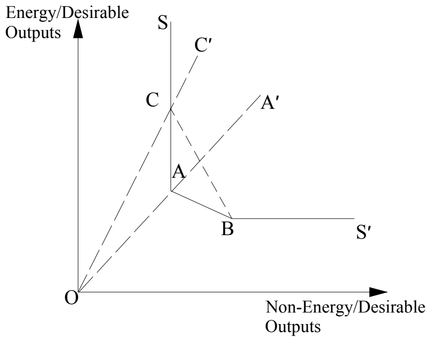


Fig. 1. Input Oriented DEA Model

Using the above ideas to calculate energy efficiency, it can distinguish effective and non- effective DMU, but this is difficult to do further comparison and sorting to effective units, so there we need the help of super-efficiency DEA model. Its basic idea is that they are excluded from the collections of decision making units when we evaluate a decision making unit. As Fig 1, when we calculate the efficiency value of point A, we exclude it from the reference set of decision making units, and the efficient production frontier change from SABS' to SCBS', so the efficiency value of point A becomes OA'/OA>1. The value of no-efficiency C' still remain unchanged. To this end, we can construct the DEA model to calculate it such as Equ 1.

$$\theta^* = \min\left\{\theta - \varepsilon E^T\left[s_n^- + s_i^- + s_m^+ + s_j^-\right]\right\}$$

$$s.t.\begin{cases}\sum_{k=1}^{K}\lambda_k x_{nk} + s_n^- = \theta x_{n0} & n = 1,2,\cdots N\\ \sum_{k=1}^{K}\lambda_k e_{lk} + s_l^- = \theta e_{l0} & l = 1,2,\cdots L\\ \sum_{k=1}^{K}\lambda_k y_{mk} - s_m^+ = y_{m0} & m = 1,2,\cdots M\\ \sum_{k=1}^{K}\lambda_k u_{jk} + s_j^- = \theta u_{j0} & j = 1,2,\cdots J\\ \lambda_k \ge 0, s^- \ge 0, s^+ \ge 0 & \\ and \quad k \ne 0 \quad k = 1,2,\cdots K & \end{cases}$$

By Equ 1 we can calculate θ^*, ① If ≥1 and each s^-、s^+ is equal to 0, then the corresponding DMU are DEA efficient; ② If only θ^*=1, the corresponding DMU are weak DEA efficient; ③ If θ^*<1, the corresponding DMU are non-DEA efficient. The economic implications of DEA efficient are the inputs of effective decision making units can not reduce in the current output level; and non-DEA efficient are that decision making units fail to meet the production frontier surface, and their inputs remain surplus.

For the calculation of the rest of energy input (called energy saving potential) can be calculated by Equ 1, s^-、s^+ are calculated by the formula of $\Delta e_0 = \Sigma\left[\left(1-\theta^*\right)e_{i0} + s_i^-\right]$.

3. Indicator System and Data Sources

Building a reasonable indicator system of input-output is the prerequisite and foundation using DEA method to evaluate Total-factor Energy Efficiency. The choice of indicators must satisfy the request of evaluation, and can objectively reflect the input and output efficiency, also consider the importance and availability of indicators. This paper selects 11 provinces (autonomous regions, municipalities) in western China from 1989 to 2009 for the basic research units (as data collection of indicator is incomplete, Tibet does not include in the scope of analysis), and uses super-efficiency DEA to estimate energy efficiency of 11 provinces (autonomous regions, municipalities) in western China . Input and output variables are defined as follows:

The selection of input variables: (1) Energy variable selection. Using annual energy consumption of the provinces (autonomous regions, municipalities) to represent the invested energy, and data are mainly from the corresponding years of the "China Energy Statistical Yearbook", and the unit is 10 000 tons of SCE. (2) Capital variable selection. This paper uses the perpetual inventory method to estimate the capital stock[4], and concrete steps are: first, according to the formula $K_{1988}^i = I_{1988}^i/(g^i+\delta)$, we can estimate the capital stock of provinces (autonomous regions, municipalities) in 1988, then adopt the formula $K_{1989}^i = K_{1988}^i + I_{1989}^i - \delta K_{1988}^i$ to simulate the capital stock of provinces (autonomous regions, municipalities) in 1989. In the formula, K_{1988}^i and K_{1989}^i are the capital stock of provinces (autonomous regions, municipalities) in 1988 and 1989; I_{1988}^i and I_{1989}^i are investment in fixed assets of provinces (autonomous regions, municipalities) in 1988 and 1989; g^i is the per capital GDP growth rate of provinces (autonomous regions, municipalities) in 1988 and 1989; δ is depreciation rate, and this paper selects the depreciation rate of 6% used by Hall and Jones. Based on this, the capital stock from 1990 to 2009 are calculated, and the unit is 100 million yuan. (3) Labor variable selection. Labor force data which select the average value of employment at the beginning and the end of years of provinces (autonomous regions, municipalities) are from "China Statistical Yearbook", and the unit is million.

The selection of output variables: (1) Desirable output. This paper uses GDP as output indicator. Data are from "China Statistical Yearbook", and the unit is 100 million yuan. (2) Undesirable output. As the emissions of CO_2 account for more than 80% of the greenhouse gas emissions, most scholars take it as undesirable output when they research on environmental efficiency issues, and this paper follows this approach. In practice, we often use energy consumption to estimate emissions of CO_2, and the formula is $CO_2 = \Sigma\alpha_i E_i$. In this formula, E_i represents the i-th energy consumption; α_i is emission factor, and emission factor is from the National Energy Research Institute.

4. Energy Efficiency Measure Results

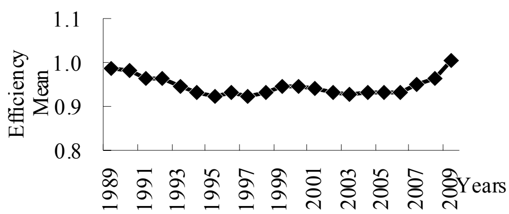
There are five input and output indicators of energy efficiency in this study, which meet the requirement of DEA method to the number of DMU. Table 1 is the results based on the above model and related indicators using MaxDEA-Trial software.

DEA method is based on the concept of the relative efficiency, so when an area is located at the energy production frontier does not mean that efficiency don't have room to improve. It only has advantages relative to the DMU. Most previous studies only evaluate the energy efficiency of the whole country[5], and DMU select the national provinces, so the conclusion is that energy efficiency present a descending order according to "eastern, central and western", and the energy efficiency of western provinces is the lowest. This paper only selects 11 provinces (autonomous regions, municipalities) except Tibet in the western China, and measures and evaluates its energy efficiency from 1989 to 2009.

Table 1. Energy efficiency value of western provinces (autonomous regions, municipalities) from 1989 to 2009

Region	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Gansu	0.85	0.83	0.80	0.80	0.77	0.72	0.71	0.79	0.75	0.80	0.83
Inner Mongolia	1/1.08	1/1.03	0.95	0.95	0.97	0.94	0.94	0.99	0.98	1/1.03	1/1.07
Ningxia	0.97	0.92	0.85	0.85	0.83	0.81	0.82	0.82	0.77	0.75	0.73
Shaanxi	0.94	0.91	0.88	0.88	0.87	0.86	0.86	0.84	0.82	0.82	0.87
Qinghai	0.87	0.91	0.84	0.84	0.83	0.75	0.76	0.76	0.73	0.74	0.73
Xinjiang	1/1.13	1/1.2	1/1.43	1/1.47	1/1.43	1/1.50	1/1.52	1/1.42	1/1.46	1/1.39	1/1.37
Guangxi	1/1.5	1/1.48	1/1.41	1/1.36	1/1.29	1/1.19	1/1.05	1/1.05	1/1.05	1/1.04	1/1.09
Yunnan	0.98	1/1.01	1/1.01	0.98	0.93	0.86	0.82	0.86	0.81	0.82	0.82
Guizhou	0.75	0.69	0.71	0.71	0.76	0.81	0.79	0.80	0.79	0.82	0.87
Sichuan	0.81	0.85	0.84	0.84	0.81	0.84	0.81	0.82	0.82	0.86	0.88
Chongqing	0.98	0.89	0.88	0.88	0.93	0.98	1/1.06	1/1.11	1/1.17	1/1.16	1/1.15
Region	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Area Mean**
Gansu	0.81	0.81	0.79	0.78	0.79	0.85	0.88	0.89	0.89	0.88	0.81
Inner Mongolia	1/1.08	1/1.1	1/1.10	1/1.14	1/1.13	1/1.22	1/1.16	1/1.28	1/1.37	1/1.46	0.99/1.10
Ningxia	0.67	0.67	0.66	0.62	0.61	0.64	0.68	0.74	0.76	0.82	0.76
Shaanxi	0.93	0.91	0.91	0.92	0.96	1.00	1/1.09	1/1.09	1/1.12	1/1.12	0.91
Qinghai	0.72	0.73	0.74	0.73	0.74	0.70	0.71	0.75	0.80	0.82	0.77
Xinjiang	1/1.47	1/1.44	1/1.35	1/1.30	1/1.25	1/1.12	1/1.1	1/1.04	0.99	0.98	1.00/1.31
Guangxi	1/1.05	1/1.02	1/1.07	1/1.07	1/1.16	1/1.13	1/1.14	1/1.17	1/1.12	1/1.10	1.00/ 1.17
Yunnan	0.82	0.83	0.83	0.83	0.84	0.84	0.82	0.81	0.82	0.83	0.86
Guizhou	0.86	0.82	0.76	0.74	0.70	0.77	0.77	0.79	0.84	0.94	0.78
Sichuan	0.88	0.89	0.88	0.89	0.90	0.89	0.89	0.91	0.91	0.91	0.86
Chongqing	1/1.11	1/1.12	1/1.16	1/1.18	1/1.18	1/1.06	1.00	0.99	0.99	0.99	0.98/1.05

(The data after / in the table is calculated by super-efficiency DEA model)



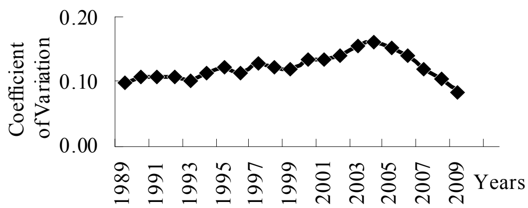


Fig. 2. The average value of energy efficiency of western 11 provinces (autonomous regions, municipalities) from 1989 to 2009

Fig. 3. Coefficient of Variation

As can be seen from Table 1, the average energy efficiency value of all the provinces is 88%, and this indicates that: on the whole, when energy input reduce 12%, outputs can also reach the established level without increasing other inputs. The energy efficiency of Guangxi is the highest, and it locates at relatively efficient frontier from 1989 to 2009; the energy efficiency of Xinjiang, Inner Mongolia, Chongqing and Yunnan exceed 1 in several years; Gansu, Shaanxi and Sichuan reach 80%-90%, and their efficiency level need to improve; the efficiency of Guizhou, Qinghai, and Ningxia are lower than 0.8, what belong to the status of lower level of energy utilization.

Seeing from the evolution trend(Fig 2), energy efficiency level of western provinces present the slow rise tendency from the year of 2005 after maintaining certain time interval slow drop.

Looking from the coefficient of variation, as shown in Fig 3: the energy efficiency of 11 provinces (autonomous regions, municipalities) has a slight divergent trend from 1989 to 2004, and it reaches the maximum 0.16 in 2004, then reduces to 0.08 in 2009. All those indicate that coefficient of variation has a trend of convergence, that is to say, the difference of energy efficiency of western provinces is narrowing, and this, to a certain extent, indicates that energy structure adjustment policy receive some results.

5. Econometric Analysis of Influencing Factors

5.1. Variables and Data Declaration

This paper considers the following influencing factors: technological progress, industrial structure, government's influence, openness, system variables and energy consumption structure. $EE_{i,t}$ represents energy efficiency of region i in t period; technological progress $TP_{i,t}$ can use patent license number of region i in t period to represent; industrial structure $CY_{i,t}$ selects the added value of the tertiary industry in share of GDP to represent; the government's influence $GOV_{i,t}$ can use local financial expenditure in share of GDP to represent; openness $WM_{i,t}$ selects total volume of import and export trade in share of GDP to represent; system variables $ZD_{i,t}$ selects state owned industries output in share of gross industrial output value to represent; energy consumption structure $ES_{i,t}$ uses power consumption (converted into standard coal) accounted for the proportion of total energy consumption to represent. Patent license data of representing technological progress are from State Intellectual Property Office Website, and other data are from "China Statistical Yearbook", "China Industrial Economy Statistical Yearbook", "China Energy Statistical Yearbook" and the provinces yearbook from 2000 to 2010.

5.2. Econometric Model

The estimation methods of panel data include polymerization least squares regression model, fixed effect model and random effect model. For sample data with short period and more cross-sectional units, we can regard the differences of regional energy efficiency as the cross section of the differences between different individuals, and parameters do not change over time or small change, so we first consider the variable intercept model (variable intercept); the fixed effects model and random effects model of variable intercept model correspond to different parameters estimation method. In practice, if researchers only infer with the sample own condition, it is desirable to use fixed effects model; if researchers infer with the sample to overall effect, it is desirable to use the random effects model. From the research purpose of this study, obviously, we choose the fixed effects model, so this paper utilizes fixed effect model of variable intercept.

The basic econometric model is shown in Equ 2. C is for public intercept, C_i is for individual differences of each cross-section. The intercept（$C+C_i$) of each individual member in the model can be used to explain the differences between provincial energy efficiency. As the provinces (autonomous regions, municipalities) do not exist structural change, so coefficient vector β_i is the same, and $\varepsilon_{i,t}$ is for random error term. In order to reduce the effects of heteroscedasticity and serial correlation in the error term, we use feasible generalized least squares (GLS) to estimate parameters.

$$EE_{i,t} = C + C_i + \beta_1 TP_{i,t} + \beta_2 CY_{i,t} + \beta_3 GOV_{i,t} + \beta_4 WM_{i,t} + \beta_5 ZD_{i,t} \beta_6 ES_{i,t} + \varepsilon_{i,t} \quad (2)$$

5.3. Econometric Results

The variable coefficient estimation of 11 provinces (autonomous regions, municipalities) in western China through regression analysis using EVIEWS5.0 shows in Table 2. As can be seen from Table 2:

Table 2 GLS regression results

Explanatory Variable	Variable Meaning	Coefficient	T-Statistic
TP	Regional patent license number	0.037993	4.484239***
CY	the added value of the tertiary industry in share of GDP	-0.169843	-1.331468
GOV	local financial expenditure in share of GDP	-0.448624	-4.076571***
WM	total volume of import and export trade in share of GDP	-0.061867	-3.938379***
ZD	state owned industries output in share of gross industrial output value	0.232967	5.189166***
ES	power consumption accounted for the proportion of total energy consumption	0.045415	0.625214**
Constant		0.626526	6.963015***
Adj.R^2		0.997378	

Note: *** Significant at 1%,** Significant at 5%,* Significant at 10%,the rest did not pass the significance test.

(1)Technological progress, the proportion of state industries and energy consumption structure have significant stimulative effect on energy efficiency. Despite technological progress have a significant enhancement on energy efficiency, but the role of enhance is relatively small, also shows that technological progress in the western region should be further enhanced, so as to promote the improvement of energy efficiency. The proportion of state owned industries have a positive impact on energy efficiency, and the result is not consistent with expected, which probably related with the selected time period. From 1999 to 2009, the western region owned a larger proportion of state industries with "Western Development Project" improve its scientific and technological level of state owned industries, what have a positive impact on enhancing the energy efficiency. The increase of power consumption in energy consumption structure can improve energy efficiency in western China, indicating that the increase of power consumption may improve energy efficiency.

(2) Government influence and openness have a negative impact on the energy efficiency. The growing influence degree of government to the economy can cause partial loss of energy efficiency. The intervene of government to market economy every increase 1%, energy efficiency will be down 0.22%, also shows that the larger impact of government to market mechanisms, the lower of economic efficiency. Openness have a negative impact on energy efficiency, because the reduction of energy efficiency of western China caused by the little degree of absorption and utilization of foreign capital, and the little efficiency brought by absorbing and utilizing the advanced technology, equipment, and management.

(3) While most scholars have demonstrated that the adjustment of industrial structure can improve energy efficiency, however, the regression analysis of western 11 provinces (autonomous regions, municipalities) show that the change of industrial structure to energy efficiency is not significant.

Showing that the western region with a large proportion of resource-intensive industries, and its improvement of energy efficiency caused by the increase of proportion of the third industry is resisted by steadily improvement of energy-intensive industries proportion, so the adjustment of industrial structure do not produce obvious effect on improvement of energy efficiency.

6. Conclusion

The regression analysis results of using fixed effect model of variable intercept help to judge the improvable direction of energy efficiency of western provinces (autonomous regions, municipalities):

(1) Technical progress is one of the main ways of improving energy efficiency, so we should continue to encourage and support technical invention, promote energy technical innovation, as well as research and innovate renewable energy technology along with clean energy technology.

(2) Simple to improve the added value of the tertiary industry in share of GDP cannot fundamentally improve energy efficiency of western region, so we should adjust industry structure from two aspects: one is to vigorously develop the tertiary industry; two is to curb the excessive growth of gas-guzzling industry in order to reduce the proportion of secondary industry.

(3) The government's influence has a negative effect on energy efficiency, stating that there still exist price control and the social regulation in energy fields, and this hinder the operation of market mechanism, also reduce the energy efficiency; government should reduce the intervention of energy marketization based on deepening market reform in energy prices and strengthening the social regulation.

(4) The impact of opening degree show that: on the one hand, it can improve the region's energy efficiency through introducing the advanced technology, equipment and management expertise, on the other hand, foreign direct investment increase the difference of technical level in various regions, therefore reducing the relatively frontier average level of the entire region.

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