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ScienceDirect

Energy Procedia 61 (2014) 2518 – 2523

Energy Procedia

The 6th International Conference on Applied Energy – ICAE2014

Inefficiency and Congestion Assessment of Mix Energy Consumption in 16 APEC Countries by using DEA Window Analysis

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Abstract

This paper proposes a two stage Range-Adjusted model to assess the inefficiency and congestion of mix energy consumption. In order to investigate the case over time, DEA window analysis is combined with our model. The proposed two-stage DEA approach has been applied to examine the inefficiency and congestion in 16 APEC countries considering the energy mix effects from 1996 to 2011. Our results of empirical study show that the energy congestion in 16 APEC countries is still mainly comes from the fossil energy, however, we also should take some useful measures to control the congestion comes from non fossil energy according to its rising trend in recent years.

Keywords: Energy efficiency; Energy congestion effect; Energy consumption structure; DEA window analysis; APEC

1. Introduction

Concerning climate change and energy security, energy efficiency policy has become an important part of the energy strategy in a lot of nations to attain a sustainable society. Former studies, e.g. Hu & Wang(2006), Zhou et al.(2008), and Yeh et al.(2010), started a lot of discussion on energy efficiency issues. Along with the development of different energy form, energy input structure is becoming one of the important factors that impact energy efficiency. Recently, some studies e.g. Jafar et al.(2008), Zhou & Ang(2008) and Guo et al.(2011) further extended the issues considering the mix energy effect.

Based on the previous studies, this paper proposes a two stage Range-Adjusted model combined with DEA window analysis to analyze the inefficiency and congestion of mix energy consumption. The model concerns both desirable and undesirable outputs. We shall first utilize the proposed method to measure the unified efficiency of 16 APEC nations. Then the degree of inefficiency on energy consumption will be

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Peer-review under responsibility of the Organizing Committee of ICAE2014
doi:10.1016/j.egypro.2014.12.036

examined as well. Moreover, we also assess the congestion for five categories of energy including oil, natural gas, coal, hydroelectricity and nuclear energy &renewable in different APEC countries.

2. Methodology

2.1. Stage 1-Inefficiency and Unified efficiency

Considering a production activity in which desirable and undesirable outputs are jointly produced. Assume that there are n DMUs. The j-th DMU uses non-energy inputs vector X_j and energy inputs vector E_j to produce desirable outputs vector G_j along with undesirable outputs vector B_j, where $X_j=(x_{1j},x_{2j},\ldots,x_{mj})^T$, $E_j=(e_{1j},e_{2j},\ldots,e_{lj})^T$, $G_j=(g_{1j},g_{2j},\ldots,g_{sj})^T$, $B_j=(b_{1j},b_{2j},\ldots,b_{hj})^T$. A DMU wants to utilize the given inputs to maximize the desirable outputs meanwhile minimize the undesirable outputs. To measure the unified efficiency that considering operation and environment jointly, a number of DEA models are proposed, such as Sueyoshi & Goto(2012), Zhou et al. (2008), Meng et al.(2013), Wang et al.(2013) and so on. While measuring the unified efficiency, in order to obtain the slacks of energy inputs for examining the inefficiency of mix energy consumption, we adopt the followed radial DEA model which is similar to Sueyoshi & Goto(2012):

$$
\begin{aligned}
Max\quad & \xi+\varepsilon\left(\sum\nolimits_{i=1}^{m}R_i^x d_i^x+\sum\nolimits_{k=1}^{l}R_k^e d_k^e+\sum\nolimits_{r=1}^{s}R_r^g d_r^g+\sum\nolimits_{f=1}^{h}R_f^b d_f^b\right)\\
s.t.\quad & \sum\nolimits_{j=1}^{n}x_{ij}\lambda_j+d_i^x=x_{i0}\quad (i=1,2,\ldots,m),\\
& \sum\nolimits_{j=1}^{n}e_{kj}\lambda_j+d_k^e=e_{k0}\quad (k=1,2,\ldots,l),\\
& \sum\nolimits_{j=1}^{n}g_{rj}\lambda_j-d_r^g-\xi g_{r0}=g_{r0}\quad (i=1,2,\ldots,s),\\
& \sum\nolimits_{j=1}^{n}b_{fj}\lambda_j+d_f^b+\xi b_{f0}=b_{f0}\quad (i=1,2,\ldots,h),\\
& \sum\nolimits_{j=1}^{n}\lambda_j=1,\lambda_j\ge 0\quad (j=1,2,\ldots,n),\\
& \xi: Unrestricted, d_i^x\ge 0, d_k^e\ge 0, d_r^g\ge 0, d_f^b\ge 0.
\end{aligned}
\tag{1}
$$

In Eq.(1), d_i^x, d_k^e, d_r^g and d_f^b are all slack variables related to non-energy inputs, energy inputs, desirable outputs and undesirable outputs respectively. A scalar value ε is a small number be set as 0.0001 in this study. The ranges for non-energy inputs, energy inputs, desirable outputs and undesirable outputs are specified respectively by

$$
\begin{aligned}
& R_i^x=1/[(m+l+s+h)(\max_j\{x_{ij}\}-\min_j\{x_{ij}\})], R_k^e=1/[(m+l+s+h)(\max_j\{e_{kj}\}-\min_j\{e_{kj}\})],\\
& R_r^g=1/[(m+l+s+h)(\max_j\{g_{rj}\}-\min_j\{g_{rj}\})], R_f^b=1/[(m+l+s+h)(\max_j\{b_{fj}\}-\min_j\{b_{fj}\})].
\end{aligned}
\tag{2}
$$

After obtaining the optimal solution of Eq.(1), the unified efficiency and inefficiency of mix energy consumption can be defined as:

$$
\text{Unified Efficiency}(\theta^*)=1-[\xi^*+\varepsilon(\sum\nolimits_{i=1}^{m}R_i^x d_i^{x*}+\sum\nolimits_{k=1}^{l}R_k^e d_k^{e*}+\sum\nolimits_{r=1}^{s}R_r^g d_r^{g*}+\sum\nolimits_{f=1}^{h}R_f^b d_f^{b*})] \tag{3}
$$

$$
\text{Inefficiency of mix energy consumption}(INE)=\sum\nolimits_{k=1}^{l}d_k^{e*} \tag{4}
$$

Here we use * to designate an optimum. If and only if a DMU satisfies the following two conditions, we say that it is fully efficient: (i) $\theta^*=1$; (ii) the optimal slack values are all zero. In fact, there exists some DMUs with unified efficiency equal to 1, but the values of optimal slacks are not all zero. This brings us to the topic of congestion.

2.2. Stage 2-Congestion

According to Brockett et al.(1998), congestion is defined as follows: "*Evidence of congestion is present when reductions in one or more inputs can be associated with increases in one or more outputs--or, proceeding in reverse, when increases in one or more inputs can be associated with decreases in one or more outputs—without worsening any other input or output.*" To examine the amounts of congestion for mix energy consumption, we develop the following model:

$$\begin{aligned}
&Max \quad \sum\nolimits_{k=1}^{l}\eta_k\\
&s.t. \quad \sum\nolimits_{j=1}^{n} x_{ij}\lambda_j = x_{i0} - d_i^{x*} \quad (i = 1,2,\ldots,m),\\
&\qquad \sum\nolimits_{j=1}^{n} e_{kj}\lambda_j - \eta_k = e_{k0} - d_k^{e*} \quad (k = 1,2,\ldots,l),\\
&\qquad \sum\nolimits_{j=1}^{n} g_{rj}\lambda_j = (1+\xi^*)g_{r0} + d_r^{g*} \quad (i = 1,2,\ldots,s),\\
&\qquad \sum\nolimits_{j=1}^{n} b_{fj}\lambda_j = (1-\xi^*)b_{f0} - d_f^{b*} \quad (i = 1,2,\ldots,h),\\
&\qquad \sum\nolimits_{j=1}^{n} \lambda_j = 1, \lambda_j \ge 0 \quad (j = 1,2,\ldots,n),\\
&\qquad \eta_k \le d_k^{e*}, \quad \xi : Unrestricted,\\
&\qquad d_i^{x} \ge 0, d_k^{e} \ge 0, d_r^{g} \ge 0, d_f^{b} \ge 0.
\end{aligned} \tag{5}$$

Finally, the congestion for mix energy consumption under the highest unified efficiency can be defined as:

$$Mix\ energy\ congestion\ (MEC) = d_k^{e*} - \eta_k^{\ *} \tag{6}$$

By using Eq.(6), we can get the amounts of congestion for each kind of energy. It allows us to analysis the input structure inefficiency of mix energy consumption, and improve the allocation efficiency of different categories of energy.

2.3. DEA window analysis

DEA window analysis is introduced by Charnes and Cooper (1985). DEA window analysis establishes efficiency measures by treating each DMU in different periods as a separate unit. This treatment enables increasing the number of data points and is useful when handling the small sample (Zhang et al, 2011). In our study, there are 16 APEC nations and a time period of 16 years (from 1996 to 2011), so n=16 and T=16. Besides, we choose 3 as the window width.

3. Empirical study

3.1. Unified efficiency and Inefficiency analysis considering energy mix effects

Due to the data availability, we choose 16 APEC countries for which all data can be obtained. We use annual consumption data on the following five categories of energy as the energy input variables, i.e. oil, natural gas, coal, hydroelectric and nuclear & others. While non-energy input variables include labor force and capital stock. In regard to the output variables, we adopt gross domestic product (GDP) as the desirable output, and CO_2 emissions related to energy consumption as the undesirable output. We first apply model (3)-(4) to calculate the unified efficiency and inefficiency of mix energy consumption in 16 APEC nations. DEA window analysis is used in this case focusing our interest on changes in efficiency over time.

Given space limitations, table 1 shows the values of unified efficiency in 16 APEC countries from 2000 to 2011. From table 1 we can find that the unified efficiency for four nations, namely Japan, Malaysia, Preu and US are always lying on the frontier from 2005 to 2011. According to the average values of different countries, it is found that Preu, Malaysia and Philippines are the top three performers. They consume the least fossil energy among the 16 APEC countries. However, Russia, Indonesia and China are the bottom three performers accounting to the high level of fossil energy consumption in these nations except Indonesia.

Table 1. Unified efficiency values in 16 APEC countries from 2000 to 2011 (The values are all between 0 to 1)

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Average*
AUS	1.000	0.827	0.654	0.495	0.693	0.846	1.000	1.000	1.000	1.000	1.000	0.970	0.904
CDA	1.000	0.803	0.610	1.000	0.617	0.816	1.000	0.991	0.991	0.997	0.999	1.000	0.921
CHL	1.000	0.857	0.734	0.889	0.722	0.870	1.000	1.000	1.000	0.978	1.000	1.000	0.941
PRC	1.000	0.675	0.350	0.009	0.348	0.674	1.000	1.000	1.000	1.000	0.961	0.785	0.792
INA	0.802	0.567	0.413	0.295	0.430	0.658	0.969	0.959	0.979	0.991	0.986	0.979	0.782
JPN	1.000	0.990	0.979	0.816	0.996	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.986
ROK	0.996	1.000	0.922	0.488	0.756	1.000	1.000	1.000	1.000	1.000	1.000	0.975	0.944
MAS	1.000	1.000	1.000	1.000	0.962	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.998
MEX	1.000	0.703	0.407	0.140	0.403	0.697	1.000	1.000	1.000	1.000	1.000	0.988	0.833
NZ	1.000	1.000	1.000	0.918	1.000	1.000	0.997	1.000	1.000	1.000	1.000	1.000	0.995
PE	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
RP	1.000	1.000	1.000	1.000	0.959	1.000	1.000	1.000	1.000	0.982	1.000	0.995	0.996
RUS	0.693	0.512	0.282	0.017	0.329	0.657	0.998	1.000	0.985	0.876	0.889	0.841	0.613
THA	0.970	0.855	0.679	0.560	0.724	0.873	0.872	0.820	0.947	0.911	1.000	0.883	0.864
US	1.000	1.000	0.991	0.004	0.996	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.935
VN	1.000	1.000	1.000	1.000	0.873	1.000	0.978	0.931	0.889	0.833	0.878	1.000	0.961

* The average values are calculated from 1996 to 2011.

Shifting our interest to the inefficiency for different categories of energy, the amount of inefficiency computed according to Eq.(4) by using DEA window analysis are shown in Fig. 1. Firstly, we focus on the trend of inefficiency values. From 1996 to 2000, the trend of inefficiency in 16 APEC countries is relatively stable. While from 2000 to 2003, a sharp rise occurs and the inefficiency value increases to the maximum in 2003. After 2003, there is a decreasing period for four years until 2006. That is because of the growth rate of fossil energy is large in the 6 yeas. From 2006 to present, the inefficiency values show a rising trend according to the figure. We think the financial crisis in 2008 may have some positive effects on the energy consumption because that the countries all take measures such as encouraging firms to yield more products in order to develop the national economy and then respond to the financial crisis. Secondly, we explore the degree of inefficiency for different categories of energy. Before 2000, the inefficiency mainly occurs on the consumption of natural gas. Different from that, from 2001 to 2006, the inefficiency comes from oil consumption takes the first place. However, in recent years, coal consumption presents the most inefficiency level among the five categories of energy.

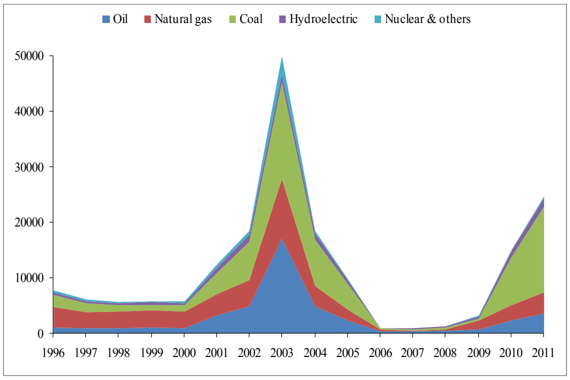

Fig. 1. Amount of inefficiency for different categories of energy from 1996 to 2011 (Mtoe)

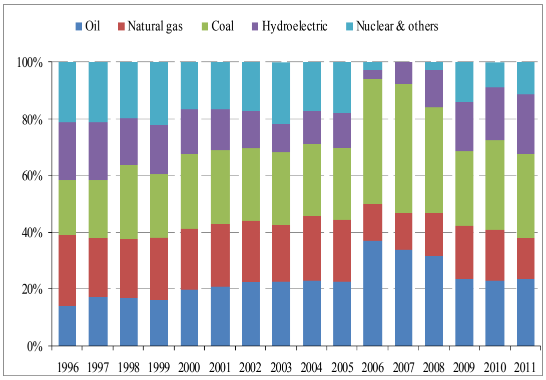

Fig. 2. The share of different categories of energy in the total energy congestion, 1996-2011

3.2. Congestion analysis considering energy mix effects

Table 2 provides the total energy congestion values in different APEC countries from 2000 to 2011. The information in Table 4 reveals that there is no congestion in Preu's energy inputs due to its low energy consumption level. Besides, Malaysia, New Zealand and Philippines also perform well with their MEC values are all less than 1%. On the contrary, Russia performs worst considering the energy mix effects because the MEC value is equal to 61.96%. Indonesia and China also gain the high MEC values of 25.24% and 21.47% respectively. The three nations mentioned above all consume fossil energy too much.

Table 2. Total energy congestion values (MEC) in 16 APEC countries from 2000 to 2011(%)

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Average*
AUS	0.00	15.45	32.28	55.55	38.56	20.46	0.00	0.00	0.00	0.00	1.26	3.91	10.96
CDA	0.00	22.22	41.80	0.00	40.87	20.60	0.00	3.19	8.21	4.35	2.00	0.00	10.77
CHL	0.00	11.45	20.84	15.76	17.05	8.74	0.00	0.00	0.00	4.33	0.00	0.00	4.89
PRC	0.00	29.34	58.51	94.17	59.31	29.80	0.00	0.00	0.00	0.00	24.89	41.25	21.47
INA	22.95	33.88	41.52	53.33	40.40	33.11	21.60	22.95	20.64	14.35	30.11	19.20	25.24
JPN	0.00	28.23	31.39	66.28	1.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.02
ROK	0.82	0.00	5.87	35.95	17.94	0.00	0.00	0.00	0.00	0.00	1.36	3.77	4.52
MAS	0.00	0.00	0.00	0.00	3.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22
MEX	0.00	26.59	52.10	69.97	52.31	27.85	0.00	0.00	0.00	0.00	0.00	1.58	14.57
NZ	0.00	0.00	0.00	12.85	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.83
PE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RP	0.00	0.00	0.00	0.00	4.85	0.00	0.00	0.00	0.00	3.56	1.49	4.81	0.92
RUS	84.74	89.10	92.59	96.29	67.22	37.13	5.63	0.00	4.05	37.81	59.69	81.68	61.96
THA	4.01	10.61	19.38	27.03	16.55	11.06	6.34	8.45	7.33	5.78	4.29	9.45	8.85
US	0.00	0.00	1.31	98.47	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.85
VN	0.00	0.00	0.00	0.00	8.69	0.00	8.37	14.71	14.97	22.46	14.80	0.00	5.25

* The average values are calculated from 1996 to 2011.

Fig. 2 shows the share of different categories of energy in the total energy congestion. Before 2000, the five categories of energy are all the main cause of energy congestion. While after 2005, the degree of congestion in hydroelectric is reducing. Moreover, from 2006 to 2011, the energy congestion is mainly due to the congestion of coal and oil. But the percentages of them were decreasing. In contrast, the proportion of non fossil energy (including hydroelectric and nuclear & others in our study) in terms of congestion shows an increasing tendency. In general, the energy congestion in 16 APEC countries is still comes from the fossil energy, however, we also should take some useful measures to control the congestion comes from non fossil energy according to its rising trend in recent years.

4. Conclusion

In this study, we assess inefficiency and congestion in 16 APEC countries considering the energy mix effects from 1996 to 2011. We apply a two-stage DEA model combined with window analysis in order to investigate the case over time. Firstly, we measure the unified efficiency using a radial DEA model of the first stage. Secondly, the amounts of inefficiency under the optimal unified efficiency considering the energy mix effects are calculated also by applying the DEA model mentioned above. Thirdly, to explore the scale efficiency of energy input and find that which kind of energy is the main drive force, we finally examine the congestion for five categories of energy by using a RAM model of the second stage. According to our empirical study, the following conclusions can be obtained: (1) Among the 16 APEC countries Preu, Malaysia and Philippines are the top three performers in unified efficiency. However, Russia, Indonesia and China are the bottom three performers. (2) The inefficiency of energy consumption is mainly due to fossil energy and shows a periodic fluctuation from 1996 to 2011. (3) In terms of energy congestion, Preu, Malaysia, New Zealand and Philippines perform well while Russia, Indonesia and

China perform worse. (4) In general, the energy congestion in 16 APEC countries is mainly comes from the fossil energy, however, we also should take some useful measures to control the congestion comes from non fossil energy according to its rising trend in recent years.

Acknowledgements

The authors are grateful for the financial support provided by the National Natural Science Foundation of China (nos. 71273005 & 71203151), NUAA Research Funding (no. NE2013104), the Ph.D. Programs Foundation of Ministry of Education of China (No. 20123218110028) and the Funding of Jiangsu Innovation Program for Graduate Education (no. CXZZ13_0182).

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