E3S Web of Conferences **122**, 03004 (2019) https://doi.org/10.1051/e3sconf/201912203004
REEE 2019

Power energy system sustainability performance evaluation and improving path of two regional economic circle in China

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Abstract. The power energy system is the foundation of the sustainable development of the human society and has an important impact on the economic, environmental and security of human society development. This paper first establishes the input and output evaluation index system of sustainable development capability of power energy system from the economic, social, environmental and security dimensions, and then uses the CCR-DEA model considering the undesired output and Malmquist index to dynamically measure the sustainable development efficiency of the power system in the Beijing-Tianjin-Hebei and Yangtze River Delta from 2005 to 2016 and decompose the corresponding items. The future development situation was analyzed through scenario analysis. The results show that: (1) Beijing and Shanghai is better than that in other provinces and cities in the same region, showing an upward trend; (2) The changes in the efficiency of sustainable development of power energy systems in Beijing, Shanghai, Zhejiang and Anhui provinces are mainly caused by technical efficiency changes. That in Tianjin, Hebei and Jiangsu are from two aspects: technical efficiency and scale efficiency; (3) The sustainable development capacity of the power system in the Beijing-Tianjin-Hebei economic circle is higher than that of the Yangtze river delta power system, and this gap has the tendency of further widening according to the strategic development plan of the two regional power energy systems; (4) In the future, China's regional electric energy system development plans should draw on the energy development strategic plan of the Beijing-Tianjin-Hebei region, especially the Xiong'an National New District, so as to achieve coordinated and sustainable development of power energy systems in various regions.

1 Introduction

With the deepening of urbanization and industrialization, there is an ever-growing demand for energy in human society. As the world's fastest growing economies, China has become the world's largest energy consumer now. The total energy consumption amount of China has reach 4.486 billion tons standard coal in 2017, about one third of total global energy consumption. Among them, China's urban energy consumption presents obvious agglomeration characteristics in spatial distribution. Energy consumption is concentrated in developed areas along the east coast and several regional central provinces and cities. Especially in Yangtze River delta, the Pearl River delta and the Beijing-Tianjin-Hebei regions, large urban agglomerations are highly concentrated in energy consumption. In 2017, the three regions' energy consumption accounted for about 15%, 20% and 10% of China's total energy consumption respectively. However, due to the differences in power supply structure, resource endowment and management level in different regions, there are gaps in the aspects of economy, safety and environmental protection in the power system, that is, the sustainable development ability of the power energy system in different regions varies. This paper takes the Beijing-Tianjin-Hebei region and the Yangtze River delta region as the research objects to carry out relevant research on the assessment of the sustainable development ability of electric power and the improvement path.

Data Envelopment Analysis (DEA) can decompose the total production productivity with consideration of the multi-input and output indexes, which is an excellent method to calculate directional distance function. Among current study of total factor productivity model based on DEA method, a large number of literature have combined Total Factor Index (TFP) and Malmquist function[1] to measure the spatial difference and spatial aggregation effect of total factor productivity in different regions of China under the constraint of environmental resources, and used panel model to decompose the influencing factors of TFP[2-5]. Among the existing studies, there are few studies using total factor production efficiency to evaluate and compare the energy sustainable development ability of urban agglomerations.

In this paper, the energy sustainable development capacity of major cities in the Yangtze River delta (Shanghai, Jiangsu, Zhejiang and Anhui) and the Beijing-Tianjin-Hebei urban agglomeration is compared

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under the framework of DEA full-efficiency energy efficiency model. This paper is structured as follows: the second part constructs the DEA full efficiency model to measure the energy consumption efficiency of the Yangtze River delta region and the Beijing-Tianjin-Hebei region. The third part analyzes and compares the energy sustainable performance of the two major urban agglomerations by the TFP index of energy consumption and its decomposition results.

2 Sustainable development evaluation model of power energy system

The use of energy produces both desirable and undesirable outputs. Here, every city of the Yangtze River delta region and the Beijing-Tianjin-Hebei region is a DMU (Decision-making unit).

Data envelopment analysis (DEA) uses mathematical programming and statistical data to identify the relatively efficient production frontier. The decision-making unit is projected onto the production frontier and then their relative validity is evaluated by comparing the extent to which decision-making units deviate from the production frontier. The DEA method has its unique advantages. It is suitable for evaluating the validity of multiple-input and multiple-output. Besides, there is no need for non-dimensional data processing when applying this method. It also eliminates many subjective factors without any weight assumption. Because the output indexes include desirable and undesirable, here use the Unified efficiency DEA model to evaluate the sustainable development ability of power energy system. The formulas of the unified efficiency DEA model are as follows:

Fare [6] proposed the following directional distance function:

$$Max\left\{\theta \mid \left(G+\beta\zeta_g, B-\beta\zeta_b\right)\in P(X)\right\} \quad (1)$$

Here, P(X) = {(G, B): X can produce (G, B)}. The P(X) indicates a production possibility set, which has a column vector of inputs(X) that can produce not only a column vector of desirable outputs (G) but also a column vector of undesirable outputs (B). $\zeta=\left(\zeta_g,-\zeta_b\right)$ is suggested as $(1, 1, \ldots.1, -1, -1, \ldots, -1)^T$ which contains $s+h$ components.

Mandal and Madheswaran [7] assumed that if the firm's objective is to simultaneously expand the desirable output and reduce the undesirable one by same proportion without increasing the inputs, the directional technology distance function becomes:

$$\vec{D}_T\left(x,y,b;0,y,-b\right)=\sup\left[\beta:\left[\left(1+\beta\right)y,\left(1-\beta\right)b\right]\in P(x)\right] \quad (2)$$

The value β represents technical inefficiency. The direction vector $g=\left(g_x,g_y,-g_b\right)=\left(0,y,-b\right)$ determines the direction in which efficiency is measured. Given the technology and direction vector, the directional distance function measures the maximum feasible expansion of desirable output and directional distance function β is zero. The directional distance function β is obtained by solving the maximization problem in model (3).

$$\begin{aligned} & Max\beta \\ s.t. \quad & \sum_{j=1}^{n} x_{ij}\lambda_j \le x_{ik} \qquad (i=1,\ldots. \\ & \sum_{j=1}^{n} g_{rj}\lambda_j \ge grk+\beta g_{rk} \qquad (r=1,\ldots. \\ & \sum_{j=1}^{n} b_{fj}\lambda_j \le b_{fk}-\beta b_{fk} \qquad (f=1,\ldots. \\ & \sum_{j=1}^{n} \lambda_j = 1 \\ & \beta\ge 0, \lambda_j \ge 0 \qquad (j=1,\ldots. \end{aligned} \quad (3)$$

Here, the outputs in the *jth* DMU are separated into desirable outputs (g_{rk}) and undesirable outputs (b_{fk}). This model measures the efficiency by $\theta=1-\beta$, where β is obtained from optimality of the Model (3).

In addition to Model (3), Zhou and Ang [8] proposed the following model to measure the unified efficiency of the energy firms:

$$\begin{aligned} & Min\theta \\ s.t. \quad & \sum_{j=1}^{n} x_{ij}\lambda_j \le x_{ik} \qquad (i=1,\ldots. \\ & \sum_{j=1}^{n} e_{qj}\lambda_j \le \theta e_{qk} \qquad (q=1,\ldots. \\ & \sum_{j=1}^{n} g_{rj}\lambda_j \ge g_{rk} \qquad (r=1,\ldots. \\ & \sum_{j=1}^{n} b_{fj}\lambda_j = b_{fk} \qquad (f=1,\ldots. \\ & \theta\ge 0 and \lambda_j \ge 0 \qquad (j=1,\ldots. \end{aligned} \quad (4)$$

Here, the *jth* DMU input is divided into non-energy (x_{ij}:i=1) and energy-related input (e_{ij}: q=1,…). Model (4) can be considered as an extension of CCR (Charnes-Cooper-Rhods) and the production possibility set of Model (4) is shaped by constant RTS (returns to scale).

Then Malmquist index is used to decompose the sustainability performance of power energy system. Besides, the Malmquist productivity index (TFPCH) can be decomposed into the technical efficiency change index (EFFCH) and the technical change index (TECHCH). The transformation of the Malmquist index is as follows:

$$\begin{aligned} & M(x^{t+1},y^{t+1},x^t,y^t) \\ & =\frac{D^{t+1}(x^{t+1},y^{t+1})}{D^t(x^t,y^t)}\times\left[\frac{D^t(x^{t+1},y^{t+1})}{D^{t+1}(x^{t+1},y^{t+1})}\times\frac{D^t(x^t,y^t)}{D^{t+1}(x^t,y^t)}\right] \\ & =\text{EFFCH}\times\text{TECHCH} \end{aligned} \quad (5)$$

When the revenue scale changes, the EFFCH can be further decomposed into pure technical efficiency change (PECH) and scale efficiency change (SECH).

$$\begin{aligned} \frac{D^{t+1}(x^{t+1},y^{t+1})}{D^t(x^t,y^t)} &= \frac{D^{t+1}(x^{t+1},y^{t+1}/V)}{D^t(x^t,y^t/V)}\times\frac{S^{t+1}(x^{t+1},y^{t+1})}{S^t(x^t,y^t)} \\ &= \text{PECH}\times\text{SECH} \end{aligned} \quad (6)$$

The final transformation of the Malmquist index is as follows:

$$M(x^{t+1},y^{t+1},x^t,y^t)=\text{EFFCH}\times\text{TECHCH}$$

$$=\text{PECH}\times\text{SECH}\times\text{TECHCH} \quad (7)$$

$M(x^{t+1}, y^{t+1}, x^t, y^t)$ represents the variation of the TFP level. If EFFCH>1, it indicates that the relative technical efficiency of *t* and *t*+1 period is increased, whereas, in the contrary, it is the reverse. If TECHCH> 1, it indicates that *t*+1 period has technological progress compared to *t* period, whereas, in the contrary, it is the reverse. PECH indicates whether the technology is fully utilized. If it is larger than 1, it shows that the resource allocation is reasonable, whereas, in the contrary, it is the reverse. SECH expresses the index of the change of scale efficiency in two periods. If SECH is larger than 1, it means that the scale efficiency is optimized, whereas, in the contrary, it is the reverse.

3 Power energy system sustainability performance evaluation of urban agglomeration in Yangtze river delta region and the Beijing-Tianjin-Hebei region

Energy intensity means energy consumed per unit of GDP output, which is a common indicator to measure the energy efficiency of different economies, but it cannot fully reflect the input of labor, capital or other resources. Energy sustainable development performance is an ideal indicator to measure regional energy utilization efficiency and evaluate energy sustainability on the basis of resource input and energy cost in the Yangtze River delta region and the Beijing-Tianjin-Hebei region. The comprehensive consideration of multi-factor inputs by Total Factor Productivity is effective to judge the sustainability of regional energy sustainable development and can provide a scientific reference for the government's energy utilization policies.

3.1 Data processing

The evaluation index of the sustainable development capability of power energy system includes input and output. Input indexes represent the input factors of the labor force in the energy industry with the employment population of power, steam, hot water production and employment in supply industry respectively. Investment in the production and supply of electricity, steam and hot water represents delegate the financial input. The installed scale and transmission line length represent material input. In terms of output indicators, GDP represents the output of the power and energy system supporting economic development. Carbon dioxide emissions from power systems represent undesired outputs from an environmental perspective. The average outage time represents the undesired output from the safety perspective. The power supply population represents output in social services.

The study is based on the relevant data of the Yangtze River delta region (Shanghai, Jiangsu, Zhejiang and Anhui) and the Beijing-Tianjin-Hebei region (Beijing, Tianjin and Hebei) from 2005 to 2016. Data are from China statistical yearbook (2005-2016) and electric power statistical yearbook.In order to eliminate the influence of price level, the urban economic output value was processed based on 2005.

3.2 Measurement and comparison of sustainability performance of electric power system

The total factor energy consumption efficiency of model (5) is used to measure the energy sustainable performance of each provinces and cities in these two regions. The results of the energy sustainable development performance of seven provinces and cities in the two delta regions are shown in table 1 and figure 1.

Table 1. Beijing-Tianjin-Hebei and Yangtze River delta regions total factor energy consumption efficiency

Region	Provinces and Cities	Energy consumption TFP rate of change												Average value
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	
Beijing-Tianjin-Hebei	Beijing	0.985	0.956	0.972	1.005	0.967	1.185	1.129	1.015	1.242	1.044	2.692	1.063	1.188
	Tianjin	1.159	0.998	1.003	0.913	0.953	1.023	0.961	0.983	1.061	1.018	0.936	0.974	0.999
	Hebei	1.057	1.031	1.028	0.999	1.015	1.203	0.961	0.896	0.942	0.848	0.765	0.702	0.954
	Average	1.067	0.995	1.001	0.972	0.978	1.137	1.017	0.965	1.082	0.970	1.464	0.913	1.047
Yangtze River delta	Shanghai	0.998	0.987	0.992	0.976	0.975	1.097	1.132	0.999	1.062	1.244	2.119	1.074	1.138
	Jiangsu	0.941	0.988	1.015	1.019	1.006	1.467	1.268	1.030	0.936	1.204	1.079	1.174	1.094
	Zhejiang	0.708	0.722	0.721	0.627	0.653	0.686	0.721	0.726	0.679	0.678	0.720	0.668	0.692
	Anhui	1.126	1.052	0.990	1.077	1.161	1.173	1.041	1.203	0.863	0.807	0.703	0.647	0.987
	Average	0.943	0.937	0.930	0.925	0.949	1.106	1.041	0.990	0.885	0.983	1.155	0.891	0.978

As can be seen from table 1:

(1) Overall, the performance of energy sustainable development in the Beijing-Tianjin-Hebei region from 2005 to 2016 was higher than that in the Yangtze River delta region, and the energy efficiency index remained above 0.9. The performance of Zhejiang province in the Yangtze River delta region is the lowest, between 0.6 and 0.8.

(2) The change rate of energy consumption in most provinces grew fastest from 2008 to 2010, and the index growth rate of Beijing and Shanghai reached a new peak in 2015.

(3) As to the change trend, the energy consumption efficiency of most provinces remains at the original level and fluctuates to some extent. The change rate of TFP of energy consumption in the capital Beijing has been greater than 1 since 2010, indicating that the energy performance keeps increasing. However, the total factor energy efficiency value of Anhui province gradually showed a downward trend from 2012, while that of Hebei province showed a downward trend from 2013. The poor performance of energy sustainability is worth our vigilance.

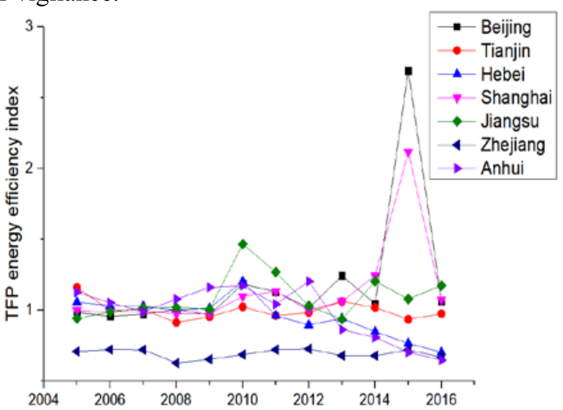

Fig. 1. Comparison of energy sustainable development performance among Yangtze River delta and Beijing-Tianjin-Hebei regions

3.3 Comparison of TFP index among provinces and cities with similar economy scale

Considering the different levels of economic development, it is more reasonable to compare the energy sustainability of provinces with similar economy scales. Therefore, this paper divides the Beijing-Tianjin-Hebei region and the Yangtze River delta into four groups according to the urban economic output value: Very high, high, medium and low. Then the cumulative TFP index is analyzed under upper four groups. The lower group include Tianjin and Anhui. The middle group includes Shanghai and Beijing. The high group include Hebei and Zhejiang. Because the economic output value of Jiangsu province is much higher than that of the other six provinces and cities, so Jiangsu province belongs to the very high group. Figure 2 shows the dynamic change trend of the cumulative TFP index of the four groups. The change rate of TFP index of energy consumption in the lower group fluctuated around 1 from 2005 to 2016. Due to its economic and political core position, the middle group is the focus of national energy consumption efficiency improvement. In recent years, energy consumption efficiency in Beijing and Shanghai has been on the rise. The energy sustainable performance of the higher group was lower and showed a downward trend. The sustainable energy performance of Jiangsu province, which has the highest economic output value, is also high and has an overall trend of growth.

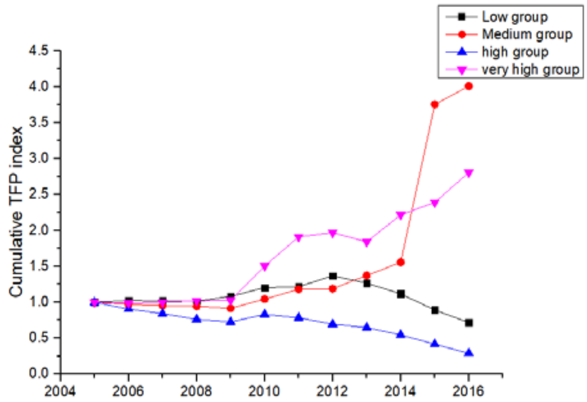

Fig. 2. The dynamic trend of the cumulative TFP index of the two urban agglomerations grouped by economic aggregate

3.4 Comparison and decomposition of urban agglomerations average annual energy consumption efficiency

From 2005 to 2016, the average annual total factor productivity of power energy sustainable performance of the four major provinces and provinces in the Yangtze River delta and the Beijing-Tianjin-Hebei region showed an upward trend. The decomposition results are showed in Figure 3 and Table 2.

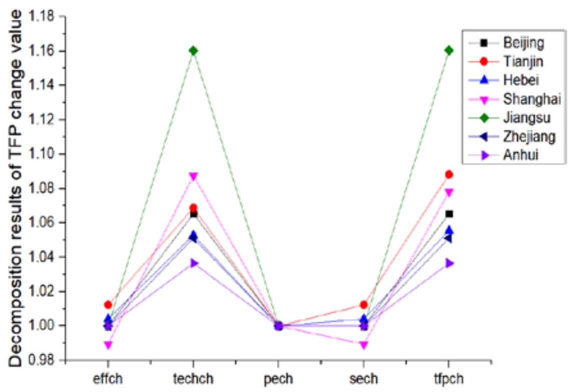

Fig. 3. Decomposition of urban agglomerations average annual TFP change value

Table 2. Average annual TFP change and decomposition of power energy system in the Yangtze River delta and Beijing-Tianjin-Hebei region

District	Effch	Techch	Pech	Sech	Tfpch
Beijing	1.00000	1.06527	1.00000	1.00000	1.06527
Tianjin	1.01236	1.06873	1.00000	1.01236	1.08818
Hebei	1.00418	1.05291	1.00000	1.00418	1.05555
Shanghai	0.98945	1.08755	1.00000	0.98945	1.07827
Jiangsu	1.00000	1.16036	1.00000	1.00000	1.16045
Zhejiang	1.00000	1.05118	1.00000	1.00000	1.05118
Anhui	1.00000	1.03655	1.00000	1.00000	1.03655

3.4.1 Yangtze River region

The improvement of urban energy sustainable development performance in the Yangtze River delta region in the past decade comes from technological progress. From 2006 to 2016, the average annual growth rate of technological progress in the Yangtze River delta region was 8.39%, while the technical efficiency decreased by 0.3%. Lower technical efficiency of which comes from the low scale efficiency, annual scale efficiency by 0.03%. It means the improvement of urban energy sustainable development performance in Yangtze River region depended on advanced technology and technical innovation in past ten years, but as a result of ignoring the improvement of the technical efficiency, the actual development model still needs to be improved, the performance growth comes from economies scale are becoming weakened gradually.

3.4.2 Beijing-Tianjin-Hebei region

The improvement of technical progress and technical efficiency in the Beijing-Tianjin-Hebei region jointly drives the improvement of total factor production efficiency, and the contribution of technical progress is far greater than that of technical efficiency, with the growth rate being 0.55% and 6.23% respectively. Among the increase of technical efficiency, the pure technical efficiency contributed 0%, and the annual increase of scale efficiency was 0.55%, indicating that the improvement of technical efficiency in the region comes from scale effect. The results show that the introduction of advanced technology has achieved certain effects in reducing energy consumption and improving the sustainability of energy use in the Beijing-Tianjin-Hebei region.

4 Conclusion

Based on the super-efficiency data envelopment analysis model and Malmquist index, the sustainable performance of power energy system in the Yangtze River delta, Beijing-Tianjin-Hebei regions were analyzed, calculated and decomposed the performance, and analyzed the main reasons and trends of performance changes. The specific conclusions are as follows:
(1) Beijing and Shanghai is better than that in other provinces and cities in the same region, showing an upward trend; (2) The changes in the efficiency of sustainable development of power energy systems in Beijing, Shanghai, Zhejiang and Anhui provinces are mainly caused by technical efficiency changes. That in Tianjin, Hebei and Jiangsu are from two aspects: technical efficiency and scale efficiency; (3) The sustainable development capacity of the power system in the Beijing-Tianjin-Hebei economic circle is higher than that of the Yangtze river delta power system, and this gap has the tendency of further widening according to the strategic development plan of the two regional power energy systems; (4) In the future, China's regional electric power system development plans should draw on the energy development strategic plan of the Beijing-Tianjin-Hebei region, especially the Xiong'an National New District, so as to achieve coordinated and sustainable development of power energy systems in various regions.

Acknowledgments

This work has been supported by the Fundamental Research Funds for the Central Universities (no. 2018ZD14) and the Science and Technology Project of SGCC ”Research on lean investment optimization method based on benefit analysis of the whole process of power grid”.

References

1. S. Honma, J.L. Hu, Energy Policy, **36**: 821-823 (2008)
2. G. Hao, Y. XU, X. ZHANG, et al., Chin. Pop. Res. Environ.，**28**: 75-83 (2018)
3. J.C. Li , D.X. Niu , J.Y. Li , J.X. Qi , Power Dem. Side Manage., **11**: 11-15 (2009)
4. Q.W. Wang, D.Q. Zhou , L.T. Zhang, Ind. Technol. Econ., **27**: 53-55 (2008)
5. Q.L. TAN, H. SUN, X.P. ZHANG, PROC. CHIN. SOC. ELECTRICAL ENG., **32**: 105-111 (2012)
6. R. Färe, S. Grosskopf, D.W. Noh, et al., J. ECONOMETRICS, **126**:469-492 (2005)
7. S.K. Mandal, S. Madheswaran, Energy Policy, **38**:1108-1118 (2010)
8. P. Zhou, B.W. Ang, Energy Policy, **36**:2911-2916 (2008)