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Energy Efficiency Evaluation of Power Equipment Based on DEA

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Abstract
As the current situation of imperfect model algorithm of electrical equipment for energy efficiency evaluation, we set up energy efficiency DEA model. In the model, we got average load rate, average power factor and tri-phase unbalance factor as inputs indexes. And we got economic output of per unit of power consumption and energy pollution as outputs indexes. Then we transformed multiple pollutants into a pollutant index through principal component analysis. And we got it as the desired output. The result of 12 industrial enterprises in the energy efficiency of electrical equipment shows that the evaluation model is suitable for energy efficiency evaluation and system analysis. The DEA model is useful to further improvement in the energy efficiency of equipment.

Key words: Electrical equipment; Energy efficiency; DEA; Evaluation unit

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INTRODUCTION

In recent years, the world economic trends and energy development pattern are undergoing profound change, energy saving and environmental protection, clean energy, low-carbon economy and sustainable development having become focus of common concern, advocating the intelligent electricity being a consensus. Under the double pressure of the energy shortage and environmental pollution, the Chinese government has carried out a series of energy saving measures in administrative region and corporate level, and the energy reduction targets is made clear in" the twelfth five-year guideline", namely the energy consumption of unit GDP should reduce by 16% during the period. In addition, the combination of mandatory and voluntary become consensus of promotion model for environmental pollution liability insurance in the following five years.

Currently, energy efficiency research has been focused on two aspects: First, the macro analysis of the energy efficiency of the whole society; second, the microscopic analysis of energy efficiency of some specific electrical equipment. Wu et al. (2009) established evaluation model of energy efficiency is based on data envelopment analysis under the framework of total factor energy efficiency. Yang et al. (2012) proposed optimization strategies and models of energy efficiency of electricity from the perspective of load management. Yan (2008) has put forward the identification of energy efficiency of major electrical equipment from the viewpoint of the greenfield projects and expansion projects. Zhang et al. (2012) has reviewed evaluation characteristics of energy efficiency of boilers, elevators and other equipments. Shi et al. (2009) and he (2002) have summarized the measurement of energy efficiency targets of home air conditioning, the limits of energy efficiency and the development of energy conservation technology. Lu (2012) and ji (2012) have made qualitative analysis on the efficiency of the motor, proposing energy-saving technologies and measures of motor. Zhou (2013) analyzed energy-saving technologies of three phase asynchronous motors from the aspects of the hardware systems and software design. Thus, the quantitative

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research for broader sense of the analysis of the energy efficiency of electrical equipment is still a lack.

Additionally, Liu et al. (2012) have analyzed the theoretical limit of energy efficiency, and compared various energy efficiency index for the factor that they vary in index symbol of current air-conditioning system. Based on DEA method, Wei et al. (2007) has constructed an index that reflects the inherent efficiency of the energy efficiency index, followed by the estimation of decade panel data of provinces. Wu et al. (2010) have classified into three layers by evaluation index system of energy efficiency, and established evaluation model of energy efficiency by the principle of fuzzy comprehensive evaluation. By combining the fuzzy mathematics and expert acknowledge, Zhang et al. (2004) have proposed a new algorism for evaluating health condition of transformation equipment with the preventative test results, which can organize preventative test dates effectively. However, the latter two model algorithms are heavily influenced by uncertainty and subjective factors.

In the light of imperfect model algorithm of electrical equipment for energy efficiency evaluation, this paper aims to establish a more comprehensive evaluation model of energy efficiency. Firstly, the reasonable evaluation of energy efficiency should be selected, and the appropriate DEA model be established. Then supplemented by empirical, numerical examples will show that the applicability of proposed algorithm, which can be widely used.

2. MODEL

2.1 Establishment of the input indexes

It is found that the average load rate, average power factor and tri-phase unbalance factor met and directly affect the vast majority of the energy efficiency of electrical equipment by analyzing the commonality factor of electrical equipment. The average load factor refers to the ratio of actual power and rated power from an average sense during a period of time, which is calculated as:

$l = \frac{p_a}{p_r} \times 100\%$, where p_a is actual power, while p_r acts as rated power.

Since the existence of no-load loss, equipment should not run in too low load rate. The higher the load is on the motor, for instance, the higher the efficiency it owns, and the motor efficiency can reach a peak when the load rate approximate to 70%, which is called active economic load rate. In the dc circuit, the voltage multiplied by current is active power, but it severs as apparent power in the ac circuit, as the active power which acts will be less than apparent power. The ratio of active power and apparent power from an average sense during a period of time is called average power factor, which is expressed by $\cos\phi$.

$\cos\phi = \frac{P}{S} \times 100\%$, $\cos\phi = \frac{P}{S} \times 100\%$, where P is active power, and Q is reactive power. S works as apparent power, meaning the voltage multiplied by the current in the current with resistance and reactance, which is formulated as $S^2=P^2+Q^2$.

Furthermore, the electrical equipment, especially single-phase power equipment is widely used, resulting in tri-phase current asymmetry, that is the relation with large load is low, and vice versa. This phenomenon will cause reverse rotation of the magnetic field affecting the output power of electrical equipment. The greater the degree of unbalance, the more serious line loss is. By definition, tri-phase cur-rent imbalance equal to the difference of max-imum and minimum phase current divided by the maximum phase current, namely, $\tau_i = \frac{|I_i^{\max} - I_i^{\min}|}{I_i^{\max}}$, where $I_i^{\max}$ is maximum phase current, and $I_i^{\min}$ is minimum phase current.. The standard of tri-phase unbalance of electrical distribution is that eligibility can be determined if it is not more than 15%, according to state regulations.

2.2 Establishment of the Output Indexes

Patterson (1996) noted that the energy efficiency itself is a generic term, which can be measured by a variety of quantitative indicators. Energy efficiency is, generally, to obtain the same number of service or use output with less energy consumption. Wei et al. (2007) pointed out in the text that the current guidelines for energy efficiency measurement can be divided into four categories: First, the thermodynamic index, which is completely dependent on heat measurement of input and output. Second, the physical - heat index, in which energy input is counted by heat units, and the output is measured in physical units generated in the production of services, such as the weight or transport mileage of product. Third, the economy - heat index, which is a mixture of indexes, including the production of services in accordance with market prices and energy inputs calculated according to the traditional thermal units. The fourth is purely economic index, which is measured based on the market value of the energy inputs and outputs. In this paper, the fourth is selected as expected output index, which means economic output of per unit power consumption.

Besides, some undesired output will be produced during the operation of the electrical equipment, such as harmonics, power loss, electromagnetic pollution. Therefore, the three sub-indexes are converted into electricity pollution index using principal component analysis. Wu (2009) pointed out that non-homogeneous input resources can be summed and the efficiency of evaluation unit relative to the surface of the production frontier can be studied with the use of conventional DEA model. But the output index is generally expected output, like value index, so is not applicable for pollutants and other undesired output. Fare et al. (2004) found that the undesired output and the desired output have two relationships: (a) null-joint. With $P(x)$ meaning output set, including the set of all outputs the input can be output, and (x,y,u) meaning the observed value of an evaluation unit, this nature can be described as: If (y,u) belongs to $P(x)$ and u=0, then y=0. in order not to export any undesirable output, the only way is not to produce. (b) weak-disposability. When we built model DEA, assuming that the input variables are strongly disposable, while desirable and undesirable outputs are jointly weakly disposable, this nature can be described as: If $(y,u)\in P(x)$,as to $\forall\theta$, $(\theta y,\theta u)\in P(x)$ can be founded. This shows that the desired output and the undesired output can increase or decrease in the same proportion. Ford, et al. (2002) has proposed a linear data transformation method, which is effective in maintaining the convexity and linear relationship of DEA model and ensuring the invariance of classification, being widely used in treatment of pollutants. Here is applied to make the smaller the better undesired outputs convert into the bigger the better the expected output. In the fist, data conversion function like $y_2'{}_j$= $-y_{2j}+\delta>0,(j=1,2,\cdots n)$is used for transformation of pollutants and δ is vector large enough, then $y_2'{}_j$ can be added to conventional DEA model as the desired output.

Make ε a non-archime DEA infinitesimal, a number greater than zero and less than the number of arbitrary positive number. Through the establishment of above input and output indexes, the dual model of bcc input model with a non-archime DEA infinitesimal can be set up:

$$\min\{\theta-\varepsilon[\hat{e}^T s^- + e^T(s_1^+ + s_2^+)]\}$$

$$s.t.\quad \sum_{j=1}^{n} x_{ij}\lambda_j + s^- = \theta_o x_{io} \quad ,i=1,2,3$$

$$\sum_{j=1}^{n} y_{1j}\lambda_j - s_1^+ = y_{1o}$$

$$\sum_{j=1}^{n} y_{2j}\lambda_j - s_2^+ = y_{2o}'$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j, s^-, s_1^+, s_2^+ \geq 0$$

where $\hat{e}^T=(1,1,\cdots 1)\in E_{m,}$ $e=(1,1,\cdots 1)\in E_s$. θ_o is valid values for the evaluation unit DMU_{jo}, and λ_j act as combined ratio of the "j" assessment unit from reconstructed valid combination DMU with respect to DMU_j. While s^-, s^+_1, s^+_2, serves as slack variables.

2.3 Determine Efficiency

Evaluation unit is DEA efficient when it is of preferred optimal—the input is minimum and the output is maximum in terms of the production possibility set. For the above model, evaluation unit can be determined the DEA efficient or not according to the following rules:

If θ <1, then DMU_{Jo} is DEA-inefficient; if θ = 1, and $\hat{e}^T s^- + e^T(s^+_1+s^+_2)>0$, then DMU_{Jo} is only weakly active for the DEA, meaning that in a system composed of n evaluation units, the input x can be reduced to maintain the original output y it which is technologically effective ,but not effective in scale, as far the theory of production is concerned; if θ = 1, and $\hat{e}^T s^- + e^T(s^+_1+s^+_2)=0$, then DMU_{Jo} is DEA-efficient.

In view of the superior characteristics of DEA in relative efficiency of evaluations, we can not only analyze whether an evaluation unit is DEA-efficient, but can analyze the redundancy of input indexes or deficiency of output indexes in a specific evaluation unit. This is conducive to propose targeted solutions.

3. EXAMPLE

This study focuses on the issue of equipment with low efficiency and high power consumption, in order to identify the electrical equipment which is low energy efficient. Fujian province has long been committed to reducing consumption and raising efficiency, implementing energy efficiency loans to help enterprises improve equipment efficiency. Wherein, Fuzhou city vigorously rectify energy equipment market, urging enterprises' equipment with high consumption and inefficiency to exit. And Xiamen city focusses on promoting energy conservation, strictly enforcing energy efficiency assessment. Taking into account the integrity and availability of data, from statistics of Fujian province equipment management association, this study selected technical data of energy efficiency of 12 three-phase asynchronous motors as evaluation sample from Fuzhou, Xiamen cities typical enterprises.

Since the magnitude gap of input and output indexes, to facilitate to solve the model, the data were normalized. Standardized methods used are:

Standardized data β_{ij}=Raw data α_{ij}/Standardized deviation of the index σ_{ij}. The standardization processing of data, not only makes the volatility of index data reduction, computing process simplified, but does not affect the selection of evaluations and results of evaluation models. The non-dimensional data standardized is shown in Table 1.

Table 1
Raw Data After Preferment

No.	Input indexes			Output indexes	
	X1	X2	X3	Y1	Y2
Dmu1	20	21.58	5.39	6.87	6.29
Dmu2	15.29	21.58	4.81	7.54	8.94
Dmu3	13	20.11	6.88	5.63	9.83
Dmu4	15.02	20.35	9.01	7.32	8.11
Dmu5	13.61	19.13	7.93	4.69	11.4
Dmu6	13.79	19.62	6.06	6.12	9.73
Dmu7	15.81	22.07	4.57	8.45	9.11
Dmu8	15.81	22.32	6.06	7.8	10.52
Dmu9	12.99	21.58	5.53	6.1	8.18
Dmu10	14.76	21.58	5.77	6.77	5.49
Dmu11	14.13	20.6	6.29	5.46	8.84
Dmu12	14.13	20.84	4.33	6.54	7.72

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Adopting DEAp2.1 software to calculate the energy efficiency of the evaluation unit, the total number of input and output indexes of energy efficiency in this study is 5, in line with the requirement that number of evaluation units should be at least twice the number of input and output indexes for DEA method.

Energy efficiency of 12 evaluation units are evaluated in table 2, and the following conclusions can be founded according to the above criteria:

For DMU_j, j = 1, 2, 6, 9, 10, 11, 12, θ <1, then the DMU_j is DEA-inefficient; for $DMU_{j,}$ j=4, θ=1, and $\hat{e}^T s^-$ $+e^T(s^+_1+s^+_2)$>0, then DMUJ is only weakly DEA -efficient; for DMU_j, j = 3, 5, 7, 8, θ = 1, and $\hat{e}^T s^- + e^T(s^+_1+s^+_2)$=0, then DMU_j is DEA-efficient.

Specifically, the analysis from table 2 also shows that, with respect to the system of every evaluation unit, the following corollary can make sense: the average load rate and tri-phase unbalance factor of dmu1 go slightly high; the average power factor of dmu2, dmu6, dmu11 and dmu12 is relatively low, and economic output of per unit power consumption still enjoy the room for improvement; the input of dmu4 is redundant but the output is saturated, so it is technologically effective but not effective in scale; the average power factor and tri-phase unbalance factor of dmu9 is a bit high; the average power factor and tri-phase unbalance

Factor of dmu10 is high and economic output of per unit power consumption still owns per unit power consumption still owns the room for improvement.

Table 2
results

No.	Dmu1	Dmu2	Dmu3	Dmu4	Dmu5	Dmu6	Dmu7	Dmu8	Dmu9	Dmu10	Dmu11	Dmu12
Λ1	0	0	0	0	0	0	0	0	0	0	0	0
Λ2	0	0	0	0	0	0	0	0	0	0	0	0
Λ3	0	0	1	0	0	0	0	0	0	0	0	0
Λ4	0	0	0	0	0	0	0	0	0	0	0	0
Λ5	0	0	6.99×10^{-15}	0	1	0.28	0	0	0	0	0	0
Λ6	0	0	0	0	0	0	0	0	0	0	0	0
Λ7	0.81	0.69	0	0.77	0	0	1	0	0.02	0.8	0.08	0.67
Λ8	0	0.25	6.44×10^{-15}	0.1	4.44×10^{-16}	0.62	0	1	0.76	0	0.77	0.15
Λ9	0	0	0	0	0	0	0	0	0	0	0	0
Λ10	0	0	0	0	0	0	0	0	0	0	0	0
Λ11	0	0	0	0	0	0	0	0	0	0	0	0
Λ12	0	0	0	0	0	0	0	0	0	0	0	0
S1-	3.78	0	0	0.44	0	0	0	0	0	0	0	0
S2-	0	0.16	0	0	0	0.18	0	0	3.09	0.84	0.63	0.99
S3-	0.76	0	0	4.41	0	0	0	0	0.56	1.29	0	0
S1+	0	0.25	0	0	0	0.03	0	0	0	0	0.23	0.32
S2+	1.12	0	0	0	0	0	0	0	0	1.81	0	0
Θ	0.83	0.97	1	1	1	0.99	1	1	0.95	0.86	0.95	0.92

Through the determination of planning variables and the analysis of the input and output indexes of evaluation units, the relative energy efficiency among sample devices can be easily got, and more targeted and more specific suggestions can be gave for improvement.

CONCLUSION

Given the current situation of imperfect model algorithm of electrical equipment for energy efficiency evaluation, energy efficiency DEA model is set up, including average load rate, average power factor and tri-phase unbalance factor as inputs indexes and economic output of per unit of power consumption and energy pollution as outputs indexes. Multiple pollutants are converted to a pollutant index through principal component analysis, which is then converted to desired output using data envelopment analysis. The result of 12 industrial enterprises in the energy efficiency of electrical equipment shows that the evaluation model

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is suitable for energy efficiency evaluation and better meets the requirements of system analysis. Redundancy of input and deficiency of output identify the specific direction needed to improve, providing decision support to further improvement for the energy efficiency of equipment.

REFERENCES

Fare, R., Grosskopf, S., & Hemandez-Sancho. (2004). Environmental performance: an index number approach. *Resource and Energy Economics,* (26), 343-352.

Fare, R., Grosskopf, S., & Pasurka, Jr. C. (2007). Environmental production function and environmental directional distance function. *Energy, 32*(7), 1055-1066.

He, S. (2002). Review of energy efficiency standards of household air conditioners and energy-saving technology development. *Standard,* 62-63.

Ji, Y. (2012). Research on voltage and energy technology of tri-phase asynchronous motor. *Science and Technology Innovation Herald,* (5), 1-3.

Liu, H. C., Hu, P. F., Wu, T. H., & Zhu, N. (2012). Investigation on energy efficiency indexes for air-conditioning system. *Refrigeration and Air-Conditioning, 12*(6), 5-8.

Lu, J. B. (2012). Motor energy-related issue. *Hunan Agricultural Machinery, 39*(3), 115-116.

Patterson, M. G. (1996). What is energy efficiency? Conception, indicators and methodological issures. *Energy Policy, 24*(5), 377-390.

Seiford, M., & Zhu, J (2002). modeling undesirable factors in efficiency evaluation. *European Journal of Operational Research, 142*(1), 16-20.

Shi, M., Jia, L., Zhang, X. P., Zhong, Y., & Zhang, M. S. (2009). Energy efficiency and evaluation method development of refrigeration and air-conditioning equipments. *Refrigeration and Air-Conditioning, 9*(1), 15-19.

Wei, C., & Shen, M. H. (2007). Energy efficiency and energy productivity: A comparison based on the panel data by province. *Quantitative & Technical Economics Research,* (9), 110-121.

Wu, J. F., Yao, J. G., Chen, H. L., Gong, C. X., & Li, Y. (2010). Fuzzy comprehensive evaluation of power customer energy efficiency assessment. *Power System Protection and Control, 38*(3), 95-98.

Wu, Q., & Qu, C. Y. (2009). Research on evaluation model of energy efficiency based on DEA. *Management Science, 22*(1), 103-112.

Yan, F. (2008). Energy efficiency identification of major energy-using equipment of new and expansion projects. *Energy Conservation*, (1), 14-15.

Yang, Y., Zhang, L. Z., & Wang, S. Z. (2012). Optimization strategy and model of load control considering power consumption efficiency. *Automation of Electronic Systems, 36*(8), 103-108.

Zhang, J. P., Liu, G. X., Yuan, Q., Yang, X. C., & Zheng, M. T. (2004). Design and realization of evaluation of health condition system for transformation equipment. *Modern Electric Power, 21*(4), 45-49.

Zhang, J., Xia, S., & Chen, Y. R. (2012). Problems and process in energy efficiency evaluation of Special equipments. *Development and Innovation of Machinery and Electrical Products, 25*(5), 32-34

Zhou, Z. K., & Zhang, Q. G. (2013). Analysis on energy-saving technology of tri-phase asynchronous motor. *Science and Technology Forum, 96*.

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