Energy 38 (2012) 96–103

Contents lists available at SciVerse ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Operational and non-operational performance evaluation of thermal power plants in Iran: A game theory approach

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ARTICLE INFO

Article history:
Received 6 April 2011
Received in revised form
18 December 2011
Accepted 22 December 2011
Available online 21 January 2012

Keywords:
Data envelopment analysis
Nash bargaining game
Unified efficiency
Operational and non-operational measures
Thermal power plants

ABSTRACT

This research introduces a new approach to evaluate thermal power plants. In this study, we define two categories of inputs (operational and non-operational) to measure performance of power plants. In a real case study, it is necessary to explore how to combine two separated efficiency measures in a unified structure. The conventional data envelopment analysis (DEA) may fail to discriminate among decision making units (DMUs) and the resulting efficiency scores may not be meaningful, especially when the number of DMUs is insufficient. In this paper, a new approach is presented based on DEA and game theory to evaluate DMUs by a large scale of measures. For this purpose, bargaining game as a cooperative game model and the conventional DEA models are combined. The proposed approach regardless of the number of DMUs does discriminate among the DMUs more effectively. Moreover, DMUs do be compared by different categories of measures in the competitive environment. Furthermore, the case study of thermal power plants in Iran is presented to show the abilities of the proposed approach. Power plants usually have the governmental structure in Iran. Finally, we answer the question of "why the power plants should move towards becoming private in Iran?".

1. Introduction

Data envelopment analysis (DEA) is a methodology for measuring the relative efficiency of DMUs. DEA was proposed by Charnes et al. [1] and extended by Banker et al. [2]. DEA models scores for efficient DMUs are equal to one and less than one to inefficient DMUs. With using DEA, the relative efficiency of DMUs that produce multiple outputs by using multiple inputs, is calculated. If the relative efficiency of a set of DMUs with same production function is being evaluated to have the same types of outputs, the same types of input should be used.

Suppose we have n DMUs, where each DMU_j ($j = 1,\ldots,n$) produces s outputs y_{rj} ($r = 1,\ldots,s$) by utilizing m inputs x_{ij} ($i = 1,\ldots,m$). DEA uses the following measure for evaluation of DMU_o's performance:

$$\begin{aligned} &\max \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}} \\ &\text{s.t.} \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1, \quad j = 1,\ldots,n \\ &u_r, v_i > 0, \quad i = 1,\ldots,m,\ r = 1,\ldots,s \end{aligned} \tag{1}$$

Note that the relation between the number of DMUs and the number of inputs and outputs is commonly defined as $3(m+s) < n$ [3]. Further discussion about this problem can be found in [4–6]. This paper is aimed to overcome the mentioned limitation and to discriminate among DMUs. In addition, DMUs do be compared by two different categories of measures in the competitive environment.

The paper is organized as follows: Section 2 provides a review on power plants performance and the related articles. The suggested approach based on DEA and bargaining game model is given in Section 3. Section 4 presents the case study of power plants to show the abilities of the proposed approach. The results and analyses of case study are provided in Section 5. Finally, the summary and conclusion are given in Section 6.

2. Literature review

Since DEA was proposed by Charnes et al. [1], it has been widely used to various applications such as industries, banks, healthcares and etc. But in this paper, the usage of DEA is considered for measuring performance of thermal power plants. In the following, some main researches in this field are briefly reviewed.

Chitkara [7] used DEA as a non-parametric approach to evaluate the operational efficiency of generating units. For this purpose, the author used time series to identify which units need renovation

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doi:10.1016/j.energy.2011.12.030

and repowering and which units' performance could be improved by extensive training of operating personnel. The data sets belonged to National Thermal Power Corporation of India over the period 1991 to 1995. Park and Lesourd [8] used DEA and stochastic frontier method for determining the efficiencies of 64 conventional fuel power plants operating in South Korea. They used a statistical analysis for comparing the results of two different methods.

Pombo and Taborda [9] assessed the evolution in performance of Colombia's power distribution utilities before and after the 1994 regulatory reform. In their work, Malmquist productivity index and its evolution in time was calculated. Based on the econometric results on DEA efficiency scores, they showed a positive effect of policy reform.

Sarica and Or [10] used DEA to analyze and compare the performance of electricity in Turkey. They considered 65 thermal, hydro and wind power plants from private and public sectors. The results have been included public versus private sector plants, and natural gas versus coal versus oil fired plants. Also, some trends are identified and relationships between efficiency scores and evaluations measures are discussed. Cook and Zhu [11] considered a state in which DMUs could be put into groups. DMUs must be evaluated in each groups under own assumptions. The authors used DEA and goal programming for obtaining common-multiplier set. For this purpose, they minimized the maximum discrepancy among within-group scores from their ideal levels. They applied this approach for evaluation a set of power plants, where each power plant contains a set of power units under a common plant management. Martínez [12] proposed a theoretical framework based on DEA to measure energy efficiencies of non-energy-intensive sectors (NEISs) in Germany and Colombia. The author compares energy efficiency performances at two levels of aggregation and then applies several alternative models. The results of their proposed approach show considerable variation in energy efficiency performance in the NEISs of both countries.

Sözen et al. [13] applied DEA for measuring the efficiency of power plants in Turkey. They considered three types of power plants to evaluate. The authors used the CCR and BCC models to compare and analyze the results for offering the suggestions to reveal the redundancies in the input variables and for reduction of environmental effects. Also, Sueyoshi and Goto [14], for evaluating and comparing the power plants, used range-adjusted measure (RAM) as an original non-radial DEA model. They evaluated the power plants under two variable alternatives (with and without CO_2 emission control). Then, they examined the influence of US Clean Air Act (CAA) on acid rain causing gases (NO_x and SO_2) and its extension to CO_2 regulation. A methodology for comparison between operational and environmental efficiency measurements has been proposed by Sueyoshi and Goto [15]. They considered the operational, environmental and both-unified efficiency measures of US coal-fired power plants. The power plants as a result of their plants operations, not only produce desirable outputs but also undesirable outputs (e.g., CO_2 and NO_x). Also, Sueyoshi and Goto [16] compared the new type of unified measures. They divided the inputs classification into energy and non-energy inputs in environmental studies. It is important for managers to incorporate two separations (desirable and undesirable) outputs as well as energy and non-energy inputs. In their research, both inputs and outputs classification have been divided into two categories which can be used for more realistic evaluation of power plants. Sueyoshi and Goto [15] proposed an approach based on non-radial DEA for evaluation of power plants with consideration to unified efficiency measurements. They separated the outputs into desirable and undesirable outputs, and then they applied DEA to measure the operational efficiency on desirable outputs and environmental efficiency on undesirable outputs. Other researches in this field can be found in [17–19].

3. Proposed approach

As it was mentioned, to evaluate unified performance, DEA and Nash bargaining game are combined. Friedman and Sinuany-Stern [3] have suggested a guideline for DEA when the number of DMUs is greater than triple times of the sum of input and output numbers ($3(m + s) < n$).

This rule has been accepted by many researches and has been considered in many papers and textbooks. It can be found whatever the ratio of the number of DMUs to the number of inputs/outputs is greater, DEA models is more robust and reliable. The greater the number of input and output variables in DEA leads to higher dimensionality of the solution space, and gives less discriminating of the results. If the number of inputs and outputs increases, the DMUs in the data set are projected in an increasing number of orthogonal directions and the Euclidean distance among DMUs increases. It results in many DMUs lying on the efficiency frontier; thus DEA may sometimes fail to discriminate among DMUs [20–22]. Hence, most of DMUs may be efficiently rated. In other words, the resulting efficiency scores may not be meaningful when the number of DMUs is insufficient. Therefore, the standard DEA models may be failed when the equation is not satisfied. The researchers have been interested in using tools of multivariate statistics to identify which variables can be omitted with least loss of information. There are various statistical methods to indicate a number of variables that are correlated, and which ones can be eliminated with least loss of information. But the standard DEA models are sensitive to inputs/outputs set changes. Dyson et al. [20] discussed on "pitfalls and protocols in DEA". One of their discussions is about input/output set selection. Subsets of the inputs or outputs are often correlated, and it is tempting to omit such correlated variables in order to increase discrimination. It was shown that even removal of a highly correlated output (or input) can greatly change the evaluation results [20]. Furthermore, Removal of highly correlated data may not be rational in the evaluations, where it is well accepted that DMUs may have many inputs/outputs which are complementary but often highly correlated. Often the decision makers wish to include many such correlated measures in order to present a relatively comprehensive evaluation.

Because of limitation of DEA methodology as mentioned above, we divide inputs into two categories: operational and non-operational. Suppose n DMUs and each DMU_j ($j = 1,\ldots,n$) has m_1 inputs to the category 1 (operational) denoted by x_{ij}^1 ($i = 1,\ldots,m_1$), m_2 inputs for the category 2 (non-operational) denoted by x_{ij}^2 ($i = 1,\ldots,m_2$), and s outputs denoted by y_{rj} ($r = 1,\ldots,s$). These s outputs are common measures for two categories of inputs. In the first stage, we apply standard DEA to evaluate DMUs by each category of measures. In the second stage, by using bargaining game model, the performance of DMUs by two categories of inputs and outputs is measured simultaneously.

3.1. Bargaining game

The goal of Nash bargaining game as a cooperative game is dividing of benefits between two players based on their competition. Nash model [23] requires that the feasible set to be compact, convex and contains some payoff vectors, so that each individual payoff is greater than the individual breakdown payoff. Breakdown payoffs are the starting point for bargaining which represent the possible payoff pairs obtained if one player decides not to bargain with the other player. If u is the utility function for the player 1 and v is the utility function for the player 2, they will maximize $|u(x) - u(d)|\ |v(y) - v(d)|$, where $u(d)$ and $v(d)$, are the utilities obtained if one decides not to bargain with the other player.