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AN EFFICIENCY ANALYSIS OF COMBINED CYCLE POWER PLANTS USING DEA MODELS: A CASE STUDY IN BANGLADESH

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ABSTRACT

The purpose of this research was to analyse the operation efficiency of existing combined cycle power plants in Bangladesh and identify potential areas for efficiency improvement. This study proposed the application of data envelopment analysis (DEA). A non-parametric linear programming method to efficiency measurement. Based on the empirical results, efficient and inefficient power plants were determined and ranked by using three variants of DEA models which are CCR, BCC and Super-efficiency. It was also revealed that there existed considerable waste in the production process of power plant and the main source of inefficiency was attributed to the inadequate operating scale. According to the results the suggestions for improving efficiency were provided in the study. The insights gained from the study will contribute to the planning of energy efficiency policies required for electric power plants.

KEYWORDS: Technical Efficiency, Data Envelopment Analysis, Combined Cycle Power Plants & Sustainable Energy

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Original Article

INTRODUCTION

Bangladesh is a developing country with a population of over 160 million, which marked it as one of the densely populated country in the world, where the demand of electricity energy remained high since its liberation and still the requirement continues to be increasing every year. An important catalyst of this increasing demand has been identified as the recent years' sustained growth of gross domestic product (Islam & Khan, 2017). Numerous projects have been undertaken by the government in order to meet these increasing needs along with drafting of new policies as well. The government has established Sustainable and Renewable Energy Development Authority (SREDA) as a dedicated national nodal authority to promote, facilitate and propagate a sustainable energy agenda for energy efficiency, energy conservation and renewable energy in the country (Hossain,2018).

It is noted that the electric power consumption per capita was reported at 310kWhin 2014 (IEA, 2018)which was one of the lowest in the world. Presently around half of the population got access to consume electricity, properly due to inadequate and unreliable supply. Some steps the government currently taking include managing supply-side resources such as power plants and demand-side resources such as energy efficiency programs. In this context, it is a practical and important research issue to study how to improve the operational performance or resource utilization efficiency of existing power plants.

For this purpose, the current study applies Data Envelopment Analysis (DEA) models to measure and evaluate the operational efficiency of electric power plants.DEA is a non-parametric and deterministic methodology that uses linear programming techniques for determining the relative efficiencies of a set of decision making units (DMUs)with multiple inputs and multiple outputs(So et al., 2007).In this study, two basic DEA models, namely the CCR model which assumes Constant Returns to Scale (CRS) and the BCC model which assumes Variable Returns to Scale (VRS) are used to evaluate technical, pure technical and scale efficiencies of power plants. In addition, the super-efficiency model is used for ranking the relative performance of power plants.

The rest of this paper is structured as follows. Firstly, DEA models including CCR, BCC and super-efficiency models are briefly described. Subsequently, the data used in the study are presented and the results obtained are discussed, and finally the conclusions and future research directions are given.

RESEARCH METHODOLOGY AND STUDY DESIGN

Data Envelopment Analysis

In this study, the input-oriented CCR and BCC models from the DEA methodology are used to analyse how to improve efficiency by minimizing the inputs required to produce the desired level of output. A brief explanation of the CCR Model (Charnes et al., 1978) is as follows.

Assume that there are n DMUs, where each DMU produces s outputs by utilizing $m$inputs. For the i^{th} DMU these are represented by the column vectors x_i and y_i respectively. The $m \times n$ input matrix, X, and the $s \times n$ output matrix, Y, represent the data for all n DMUs. Then, the relative efficiency of the i^{th} DMU can be found by solving the following fractional programming problem:

$$max_{u,v} \ (u'y_i/v'x_i), \quad s.t. \ u'y_j/v'x_j \leq 1, \quad j = 1,2,\cdots,n, \quad u,v \geq 0 \tag{1}$$

where u is a $s \times 1$ vector of output weights and v is a $m \times 1$ vector of input weights (the prime denotes a transposedvector). This fractional programming problem can be easily transformed into the following equivalent linear programming problem:

$$\max_{u,v} \ (u'y_i) \quad s.t. \ v'x_i = 1, \quad u'y_j - v'x_j \leq 0, \quad j = 1,2,\cdots,n, \quad u,v \geq 0 \tag{2}$$

Alternatively, the same solution can be obtained by solving the dual problem of the formula (2). The dual to the above multiplier form is the envelopment form, which is shown below:

$$min \ _{\theta,\lambda} \ \theta, \quad s.t. \ -y_i + Y\lambda \geq 0, \quad \theta x_i - X\lambda \geq 0, \quad \lambda \geq 0 \tag{3}$$

where θ is a scalar representing the efficiency score for the i^{th} DMU and λ is a $n \times 1$ vector of constants.The efficiency scores range between 0 and 1, with 1 being fully efficient.

The BCC model (Banker et al., 1984) is formulated by adding a convexity constraint$e'\lambda = 1$ to the equation (3). It is expressed as follows:

$$min \ _{\theta,\lambda} \ \theta, \quad s.t. \ -y_i + Y\lambda \geq 0, \quad \theta x_i - X\lambda \geq 0, \quad e'\lambda = 1, \quad \lambda \geq 0 \tag{4}$$

where e is the $n \times 1$ unit vector. The efficiency calculated from the BCC model is pure technical efficiency, whereas the one from the CCR model is the aggregate measure of technical and scale efficiency. Therefore, scale efficiency can be defined as the ratio of CCR efficiency over BCC efficiency ($SE_i = \theta_i^{CCR}/\theta_i^{BCC}$). $SE = 1$ indicates scale efficiency and $SE < 1$indicates scale inefficiency.

According to the efficiency scores obtained from the CCR and BCC models, DMUs can be classified into two categories namely efficient and inefficient DMUs. However, the above DEA models cannot distinguish differences between efficient DMUs because all efficient DMUs have equal scores of 1. To overcome this limitation, Anderson and Peterson(1993) proposed a super-efficiency model for ranking among efficient units. Figure 1 provides an input-oriented illustration of the super-efficiency model. The efficient frontier consists of the line segments connecting DMUs A, B and C. If DMU B is excluded from the reference set, the effect is to construct a new frontier consisting of the broken line segments connecting DMU A and C. The super-efficiency of DMU B becomes OB*/OB > 100%. This implies that DMU B could increase both inputs and still remain efficient. Through this method, we could get the value of super-efficiency for A and B, and the higher the value, the higher the rank. On the while, in the case of inefficient DMUs, the value of efficiency does not change in the calculation of super-efficiency.

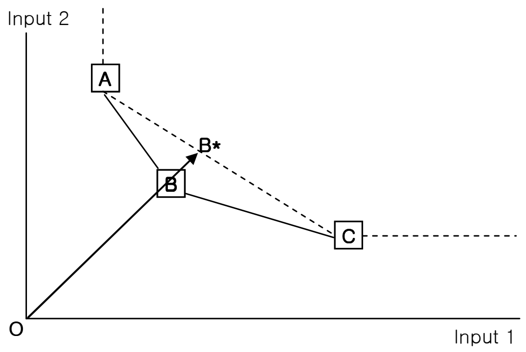

Figure 1: Super-Efficiency Evaluation of DMU B

Sample and Variables

For the case study, power plants that are operated by Ashuganj Power Station Company Limited (APSCL), a wholly government-owned enterprise in Bangladesh, was taken as the sample for analysis. Electricity generated by APSCL is supplied to the national grid and distributed to the consumers throughout the whole country. APSCL plays an important role in the national economic development by generating about 11% of the country's total electricity production. There are different types of power plants in APSCL such as thermal power plant, gas turbine power plant and combined cycle power plant. Considering the data availability, this study focuses on Combined Cycle Power Plants (CCPL) which is known to be more efficient and cost-effective than other power plants. APSCL has three CCPL currently up and running, namely Ashuganj CCPP North, Ashuganj CCPP South, Ashuganj CCPP 225MW.

The selection of the input and output variables for this study has been determined based on the data available for analysing the efficiency with DEA models, where the input variables include total manpower, cost of fuel, effective operating hours (EOH) and available capacity and the output variable includes net generation of each power plant over the latest financial year period. Details of the input and output variables have been adopted from the data provided in the annual report 2016-2017 of the company (APSCL, 2017). The data obtained were analysed using the Max DEA Pro 6 software for calculating the various forms of efficiency.

EMPIRICAL RESULTS

The results obtained by CCR, BCC and Super-efficiency models are presented in Table 1.As shown, CCPP North is technically an inefficient power plant with the score of 0.652in the CCR model, while the other power plants are efficient with perfect score of 1. This implies that a technically inefficient power plant over-uses all the inputs by 14.8 % compared to the efficient power plants. On the other hand, in the case of the BCC model, all the power plants, including CCPP North show the pure technical efficiency score of 1.

From the results above it is concluded that the power plant of Ashuganj CCPP North which is inefficient in the CCR model, but efficient in the BCC model has been operating efficiently but less efficient production scale. This indicates that the cause of the overall inefficiency is mainly due to the scale inefficiency rather than the pure technical inefficiency. Moreover, Ashuganj CCPP North exhibits Increasing Returns to Scale (IRS) indicating that increasing its operational scale would lead to greater efficiency improvements. Meanwhile, Ashuganj CCPP South and CCPP 225MW are identified fully efficient in both the CCR and BCC models. Hence, these two power plants are operating at the Most Productive Scale Size (MPSS) which corresponds to Constant Returns to Scale (CRS).

The ranking results generated by the super - efficient model are also provided in Table 1. The super-efficiency allows the ranking of efficient power plants and the determination of the best performing power plant. As indicated in the table, Ashuganj CCPP 225MWis ranked as the leading power plant, as it has the highest super-efficiency score with 2.105 followed in accordance of their ranking by CCPP South and CCPP North.

The potential improvements listed in Table 1 indicate by how much and in what areas an inefficient power plant needs to reduce its inputs in order to become efficient. For Ashuganj CCPP North the table shows it is needed to decrease its current number of manpower by 81.6%, fuel cost by 34.8%, EOH by 62.8% and capacity by 84.2%while maintaining the same level of outputs.

Table 1: Efficiency Scores and Potential Improvements for Power Plants

DMU	TE	PTE	SE	RTS	Super Efficiency	Potential Improvements in Input Variables (%)			
						Man Power	Fuel Cost	EOH	Capacity
CCPP North	0.652	1	0.652	IRS	0.652	-81.6%	-34.8	-62.8	-84.2
CCPP South	1	1	1	CRS	1.409	0	0	0	0
CCPP 225MW	1	1	1	CRS	2.105	0	0	0	0

Note: TE = Technical Efficiency, PTE = Pure Technical Efficiency, SE = Scale Efficiency, RTS = Returns to Scale, IRS = Increasing Returns to Scale, CRS = Constant Returns to Scale

CONCLUSIONS

The recent rapid economic growth of Bangladesh has been driving the increasing demand for energy. With the growing imbalance between electricity demand and supply in the country, many new power plant development projects are being planned or constructed. However, from the recent perspective of energy policy in general, it is more economically and environmentally beneficial to reduce or manage electricity demand through efficiency efforts, rather than simply increasing supply through more power plants (Riedel, 2010).

In this perspective the present study has analysed the operational efficiency of existing combined cycle power plants in Bangladesh and identified potential areas for overall efficiency improvement. Through the empirical research, efficient and inefficient power plants were determined and ranked based on three variants of DEA models which are CCR, BCC and Super-efficiency. It was also revealed that there existed considerable waste in the production process of power plant and the main source of inefficiency was attributed to the inadequate operating scale. According to the results the suggestions for improving efficiency were provided in the study. The insights gained from the study will contribute to the planning of energy efficiency policies required for power plants. This study, however, has a limitation of data availability. Hence, further study involving big data and time series models is required in detail.

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