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Evaluation of thermal power plant operational performance in Taiwan by data envelopment analysis

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ABSTRACT

Electricity is essential in the economic development of a nation. Due to the rapid growth of economy and industrial development in Taiwan, the demand for use of electricity has increased rapidly. This study evaluates the power-generation efficiency of major thermal power plants in Taiwan during 2004–2006 using the data envelopment analysis (DEA) approach. A stability test was conducted to verify the stability of the DEA model. According to the results, all power plants studied achieved acceptable overall operational efficiencies during 2004–2006, and the combined cycle power plants were the most efficient among all plants. The most important variable in this DEA model is the "heating value of total fuels". Findings from this study can be beneficial in improving some of the existing power plants and for more efficient operational strategies and related policy-making for future power plants in Taiwan.

1. Introduction

Electricity plays a crucial role in modern society and is the lifeline of a country. Its abundant supply and continuous quality enhancement are the foundations of national economic development. In 2008, the soaring energy price caused worldwide concern and enormous pressure in management of power generation, especially for thermal power plants. The greatest difficulty faced by thermal power plants is the issue of fuel source. Taiwan is one of the countries with limited self-producing energy resources and depends nearly 99% on imported foreign fossil fuels. According to the report of The energy supply and demand situation of Taiwan (2008), Taiwan's dependence on imported energy was 99.32% in 2007, with an increase of 5.58% compared to that of 2006. As energy sources have continually decreased and become more and more precious, and as international energy prices have increased, the challenges confronted by thermal power plants are definitely much more severe as compared to those of other enterprises. In this regard, it is essential for Taiwan to improve the operational performance of thermal power plants and analyze the critical variables of the existing utilities in order to maintain its domestic demand and economic growth. An important issue is how to provide sufficient electricity with less fuel and to improve the efficiency of a power plant's operation.

However, modes of power plant efficiency evaluation in Taiwan are lacking and relatively less comprehensive. The efficiency of a power plant is generally defined as the electricity produced per energy input. This ratio takes only the heating value of fuels into account, while neglecting other variables such as installed capacity and electricity used. Golany (1994) suggested an alternative method to measure the efficiency of a power plant using data envelopment analysis (DEA), a technique originally proposed by Charnes (1978) for evaluating the relative efficiency of decision making units (DMUs). The purpose of this study is not only to use the DEA to evaluate the operational efficiency of thermal power plants but also to identify ways to decrease the energy consumption of some inefficient plants in Taiwan. In order to verify the stability of our DEA model and the importance of each input variable, a stability test is also conducted. The innovative content of the paper is to apply DEA to Taiwan's thermal power plants and pay attention to the variance of variables. Finally, we hope that the results can be regarded as one of the foundations of making policy suggestion and management strategy for Taiwan electricity sector.

2. Power generation in Taiwan

According to energy statistical annual reports from the Bureau of Energy (2008), the gross power generation in Taiwan grew from 150,486 GWh in 1997 to 243,120 GWh in 2007, an average annual increase of 4.91%. Of the power generation in 2007, 161,157 GWh

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was produced by the state-run utility Taiwan Power Company (Taipower), accounting for 66.29% of total output, followed by 44,308 GWh from cogeneration (18.22%) and 37,656 GWh (15.49%) from independent power producers (IPPs). Thermal power comprised 193,785 GWh, accounting for 79.71% of the total electricity generation, nuclear power comprised 40,539 GWh (16.67%), hydro power comprised 8350 GWh (3.43%), and wind power and other energy sources comprised 446 GWh (0.18%). It shows that thermal and nuclear powers are currently the most dominant sources of electricity supply in Taiwan. The generation of renewable energy such as wind power, solar power, etc. are restricted by the technology and cost. In recent years, the long-range administrative goal of a "nuclear-free homeland" policy has become a consensus in Taiwan. Under the framework of this consensus, the government has completed an expansive policy analysis and proposed a policy means by which to extend the lifespan of nuclear power plants and gradually phase out most plants to march towards a "nuclear-free homeland." Completion of the Fourth Nuclear Power Plant project has been delayed for 10 years; therefore, the percentage of nuclear power generation overall has decreased from 24.10% in 1997 to 16.67% in 2007. On the contrary, the overall percentage share of thermal power generation increased from 69.54% in 1997 to 79.71% in 2007 (Energy statistical annual reports, 2008). In order to support the continuous growth of Taiwan's economy, an increase in the proportion of thermal power generation is inevitable.

3. Literature review

Recent studies using DEA models to analyze the efficiency of electricity generations include that of Park and Lesourd (2000), who determined the efficiencies of 64 conventional fuel power plants operating in South Korea. Their results showed that the null hypothesis of equality of means between all fuel types could be accepted. In addition, they found that the efficiency for the oldest plants is significantly smaller than the newer ones. A comparison of the plants' efficiencies by geographical area revealed no significant difference. Lam and Shiu (2001) measured the technical efficiency of China's thermal power generation based on the cross-sectional data for 1995 and 1996. According to their results, municipalities and provinces along the eastern coast of China and those with rich supplies of coal achieved the highest levels of technical efficiency. They also found that fuel efficiency and the capacity factor significantly affect the technical efficiency. Nemoto and Goto (2003) evaluated productive efficiencies of Japanese electric utilities over 1981–1995. Results indicated that utilities are efficient in their use of variable inputs, and that the inefficiency is attributable to a failure in adjusting quasi-fixed inputs to their optimal levels. Thakur (2006) assessed comparative efficiencies of Indian state owned electric utilities (SOEUS), and the impact of scale on the efficiency scores was also evaluated. Their results indicated that the performance of several SOEUS is sub-optimal, suggesting the potential for significant cost reduction. It was also found that bigger utilities display greater inefficiencies and have distinct scale inefficiencies. Vaninsky (2006) estimated the efficiency of electric power generation in the United States for the period of 1991 through 2004 using DEA. His results point to a relative stability in efficiency from 1994 through 2000 at levels of 99–100% with a sharp decline to 94–95% levels in the years following. Barros and Peypoch (2007) analyzed the technical efficiency of hydroelectric generating plants in Portugal between 1994 and 2004. They concluded that the hydroelectric generating plants are very distinct and therefore any energy policy should take into account this heterogeneity. It is also concluded that competition, rather than regulation, plays the key role in increasing hydroelectric plant efficiency. Sarica and Or (2007) analyzed and compared the performance of electricity generation plants in Turkey, and they showed that coal-fired plants have lower efficiency values than natural gas-fired ones. Operational performance efficiency of the public thermal plants was significantly lower than their private counterparts. Wang (2007) analyzed the efficiency of Hong Kong's electricity supply industry and its effects on prices under the price-cap performance-based regulation (PBR) model. A DEA method was employed to compute the total factor productivity with the Malmquist productivity index. Results support the use of the approach to account for the relation of the X-factor and the PBR model. Barros and Peypoch (2008) analyzed the technical efficiency of Portuguese thermoelectric power generating plants with a two-stage procedure. In the first stage, the plants' relative technical efficiency was estimated with DEA. In a second stage, the efficiency drivers were estimated by regression analysis. Their results show that the majority of the thermoelectric energy plants were not operating within the efficient frontier. Barros (2008) studied the efficiency of hydroelectric generating plants with a two-step procedure. In the first step, a Malmquist DEA model is used to identify the efficient scores of each unit. In the second stage, the efficient scores are regressed in contextual variables to identify the drivers of efficiency. His results showed that the hydroelectric plants exhibit on average improvements in technical efficiency as well as technological change. The increase in technological change was higher than the increase in technical efficiency. Nakano and Managi (2008) measured productivity in Japan's steam power-generation sector and examined the effect of reforms on the productivity of this industry over the period 1978–2003. Results showed that the regulatory reforms have contributed to the productivity growth in the steam power-generation sector in Japan. The methods and inputs and outputs from the references mentioned above are presented in Table 1.

4. Methodology and data acquisition

4.1. Methodology

The DEA is a mathematical programming method for assessing the comparative efficiencies of DMUs. This methodology is a non-parametric approach determining a linear efficiency frontier along the most efficient utilities to derive relative efficiency measures of all other utilities. It produces detailed information on the efficiency of each unit, not only relative to the efficiency frontier but also to specific efficient units that can be identified as role models or comparators (Hawdon, 2003). DEA allows for efficient measurement of multiple outputs and inputs without pre-assigned weights and specifying any functional form on the relationships between variables (Thakur (2006)). Therefore, it is not only a non-parametric approach but also a data-driven frontier analysis technique that floats a linear surface to rest on empirical observations (Cooper, 2006).

In the literature, two DEA models are commonly used. The first model was suggested by Charnes (1978), and hence is named the *CCR* model. The second model, named the *BCC* model, was developed by Banker (1984). The CCR model is built on the assumption of constant returns to the scale (CRS) of activities, but the BCC model is built on the assumption of variable returns to the scale (VRS) of activities. It means that if variables (x, y) are feasible, then for every positive scalar k, the variables (kx, ky) are also feasible. On the other hand, the BCC model has its production frontiers spanned by the convex hull of the existing DMUs. The frontiers have piecewise linear and concave characteristics, which lead to variable returns to scale characteristics (Önüt and Soner,