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Assessment of operational and environmental performance of the thermal power plants in Turkey by using data envelopment analysis

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ABSTRACT

In this study, efficiency analyses of the eleven lignite-fired, one hard coal-fired and three natural gas-fired state-owned thermal power plants used for electricity generation were conducted through data envelopment analysis (DEA). Two efficiency indexes, operational and environmental performance, were defined and pursued. In the calculation of the operational performance, main production indicators were used as input, and fuel cost per actual production (Y) was used as output (Model 1). On the other hand, in the calculation of the environmental performance, gases emitted to the environment were used as output (Model 2). Data envelopment analysis (DEA) is the main instrument for the measurement of relative performances of the decision making units with multiple inputs and outputs. Constant returns to scale (CRS or CCR) and variable returns to scale (VRS or BCC) type DEA models were used in the analyses. The relationship between efficiency scores and input/output factors was investigated. Employing the obtained results, the power plants were evaluated with respect to both the cost of electricity generation and the environmental effects.

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1. Introduction

In the recent years, accompanied by the economic growth, energy demand has been increasing at a higher rate as compared to the past (Balat, 2008; Tunç et al., 2006; Fang et al., 2009). Turkey's energy demand has risen rapidly as a result of social and economic development (Bilen et al., 2008; Balat, 2008). The strategic importance of energy resources to be used in the power plants particularly in developing countries like Turkey is extremely high, which are dependent on foreign energy. Besides, the environmental effects of power plants are unignorably important to meet the requirements not only of the Kyoto Protocol by also of the environmental policies of the European Union as a strong candidate for membership (Erdoğdu, 2010).

According to the 2009 Report of the International Energy Agency, the distribution of world electricity generation in terms of resources is as follows: petroleum 5.6%, gas 20.9%, coal 41.5%, nuclear 13.8%, hydraulic 15.6%, new and renewable and others 2.6%. Fossil fuels will maintain their importance in satisfying the world energy demand in the future (Key World Energy Statistic, 2009). Most power plants in Turkey use two main fuels. The first one is the low-quality lignite (this is the primarily used fuel and has the heating value of 90%) (Fig. 1), which is less than 3000 kcal/kg (12,556.5 kJ/kg), and the second is natural gas (a very large amount is imported (97%)) (Electricity Generation Company, 2008; Bilen et al., 2008). The fluctuations in oil prices, the limited life span and the negative environmental effects of fossil fuels push the developing industries to search alternative resources for electricity generation and to use their resources efficiently. Efficiency measurements of power plants are dependent on their main performance characteristics.

Turkey has poor conventional energy resources such as oil and natural gas, and she is dependent on foreign countries for the provision of these resources. The main energy resources she has are the low-quality lignite and hydroelectric resources (29.08% of the total production was generated from hydraulic sources in 2008). Turkey's energy generation share among OECD countries was 1.79% in 2007 (Key World Energy Statistic, 2007). In order to increase this share, it is necessary to develop and implement right energy policies (such as diversifying energy sources, ensuring energy supply and security, encouraging new burning technologies) that are fitting to the country's energy perspective. Therefore, she has to efficiently convert her lignite resources into electrical energy. In this context, performances of lignite-based power plants have to be determined in relation to both operational cost and environmental effects.

In this study, an efficiency analysis was conducted to determine the operational (Model 1) and environmental (Model 2) performances of the electricity generating lignite-fired

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(11 plants), hard coal-fired (1 plant) and natural gas-fired (3 plants) power plants whose data to be analyzed was full accessible. There exist two fuel-oil, 13 coal and 4 natural-gas power plants operated by Electricity Generation Cooperation Company (EÜAŞ), the state's electricity generation company. 57.34% (23.977 MW) of the total installed power of Turkey, and 49.25% (97.717 GWh) of the total production in Turkey are operated by EÜAŞ. The distribution of the production of EÜAŞ by sources in 2008 is as follows: 38.11% lignite, 29.08% hydraulic, 27.44% natural-gas, 1.93% coal and 3.44% liquid fuels. The power plants chosen for analysis had 34.71% share in the total amount of electricity generated in Turkey (34.71% of the 49.25% generated by EÜAŞ was considered in the analysis; in other words, those power plants having a share of 70.47% in the total production of EÜAŞ were considered). The contribution rates of the power plants are given in Fig. 2 (Electricity Generation Company, 2008).

In this study, both the operational and the environmental performances of the power plants were investigated. In Model 1, main production indicators were taken as inputs, fuel cost per actual production was taken as output and then efficiency analysis was conducted. In Model 2, environmental wastes of the power plants (CO_2, SO_2, N_2O and others) were taken as outputs. Efficient plants were determined and inefficient plants' deficiencies in output and redundancies in inputs (wasted inputs) were pointed as compared to efficient plants.

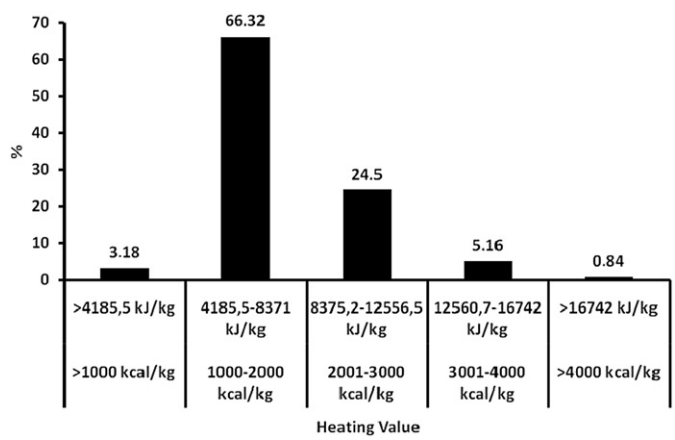

Fig. 1. Heating value of Turkey's lignite.

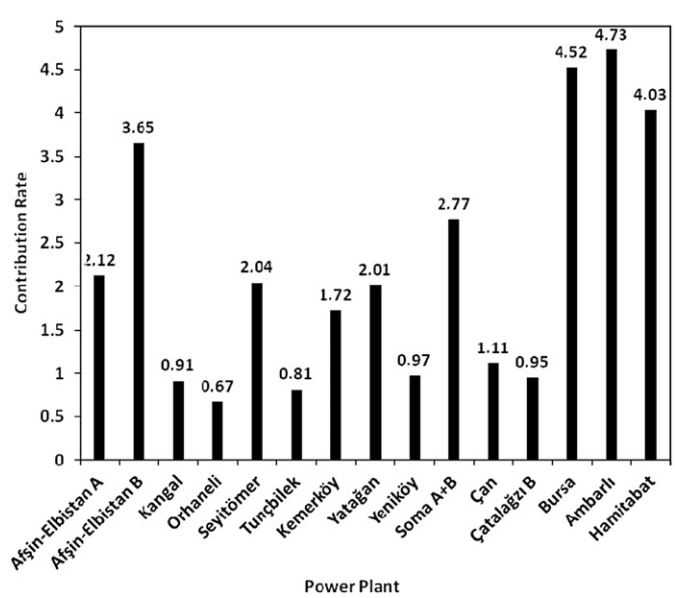

Fig. 2. Individual shares of power plants in Turkey's total production.

Tangible and quantitative findings of this study will contribute to Turkey, a country with limited energy resources, in her efforts to enhance the existent power plants, so that they can efficiently convert the resources into energy. Finally, we hope that the results of this study are regarded as one of the resources for making policy suggestions and establishing management strategies for Turkey.

2. Literature survey

DEA approach has gained great popularity in energy and emissions modeling and measuring efficiencies of thermal power plants during the past decade. Zhou et al. (2008) have summarized around 100 studies conducted on the use of DEA in works on energy and environment with an invited paper. In this paper, a summary of the literature on the use of DEA in the determination of the efficiency of thermal power plants will be presented.

Färe et al. (1990) used the Malmquist index to study the productivity growth of 19 coal-fired power plants between 1975 and 1981. They found that the average rates of productivity growth were relatively stable, except during a productivity slowdown from 1976 to 1977.

Coelli (1997) applied the DEA approach to measure the total factor productivity changes of 13 base-load, coal-fired plants in Australia from 1981–1982 to 1990–1991. The empirical results suggested a total factor productivity growth over the period of 10 years up to 16%.

Olatubi and Dismukes (2000) used the DEA approach to measure cost efficiency opportunities for coal-fired generation facilities in the US and found that allocative inefficiency was the most important source of inefficiency in 1996.

Lam and Shiu (2001) applied the DEA approach to measure the technical efficiency of China's thermal power generation based on cross-sectional data for 1995 and 1996. Their results demonstrate that municipalities and provinces along the eastern coast of China and those with rich coal supplies achieved the highest levels of technical efficiency.

Abbott (2006) used the DEA approach to measure productivity and efficiency of Australia's electricity supply industry. The purpose in that paper was to analyze the changes that had occurred in the Australian electricity supply industry over the past 30 years.

Thakur et al. (2006) used the DEA to compare the efficiencies of the state owned electricity utilities in India. Their results show that the bigger utilities display greater inefficiencies.

Liu et al. (2010) used the DEA approach to evaluate operational performance of Taiwan's major thermal power plants during 2004–2006. According to the findings of this study, all of the examined power plants achieved acceptable overall operational efficiencies during 2004–2006.

Sueyoshi et al. (2010) used the DEA to analyze the performance of US coal-fired power plants. Their results suggest that plant managers need to balance between their environmental performance and operational efficiency.

3. Turkish thermal power plants

As of 2008, the total installed power of Turkey was 41.813 MW, and the total production was 198.418 GWh (Electricity Generation Company, 2008). Thermal power plants constitute 66%, hydroelectric power plants constitute 33.06% and

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