EFFICIENCY ASSESSMENT OF ELECTRICAL ENERGY GENERATION PLANTS USING DATA ENVELOPMENT ANALYSIS

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Abstract: Performance of electricity generation plants in Turkey are analyzed and compared. The data set contains inputs from 65 thermal, hydro and wind power plants, owned by the private and public sectors. Data Envelopment Analysis (DEA) is used as the primary mathematical tool. Two efficiency indexes, reflecting operational and investment performance, are defined and pursued. Constant returns to scale, variable returns to scale and assurance region type DEA models are used in the analysis. Scale efficiency is also considered. Performance comparisons include public versus private sector plants, natural gas versus coal versus oil fired plants. Also, relationships between efficiency scores and various input / output factors are investigated and some interesting trends are identified.

Keywords: *Energy, Data Envelopment Analysis, Efficiency Analysis, Multi Input-Output Models, Power Plants*

1. Introduction

This study involves a multi input-multi output performance evaluation and comparison of a large set of power plants in Turkey based on real data. A key issue in any such multi factor study is the determination of an objective and realistic set of weights on the inputs and outputs. This difficulty is handled within the framework of Data Envelopment Analysis (DEA).

Accordingly, two DEA models (one focusing on operational performance efficiency and the other on long term investment performance) are defined for the power plants investigated. Evaluations and comparisons within the framework of these models give consideration to various cost, resource availability, production and environmental factors. The quantification (and monetarization) of environmental effects are done based on a study supported by the European Commission, named ExternE Project. The results of the study not only provide a general efficiency ranking and evaluation of the investigated power plants, but also facilitate various interesting efficiency comparisons such as public versus private sector plants, coal versus natural gas plants, renewable versus thermal plants. Furthermore, relationships between efficiency scores and various input / output factors are investigated and some interesting trends are identified.

2. Model Description

As indicated, the aim is to develop mathematical models and approaches which will facilitate efficiency/effectiveness comparisons of electric energy generation facilities. For this purpose, two models are formed. One is related to operational performance of the targeted facilities and other is related to their long term investment performance.

2.1. Models to Evaluate Operational Efficiency of Power Plants

In this context, two Operational Efficiency Models have been developed: one for thermal power plants, the other for renewable source power plants.

The basic DEA model for the operational performance of thermal power plants consists of 6 parameters. These are: fuel cost, production, availability (utilization), thermal efficiency, environmental cost, and CO. First three parameters are chosen in order to give due consideration to the primary missions of a power plant (which is reliable generation of electric energy at an acceptable cost). The last three parameters are chosen to reflect the key societal condition imposed on power plants (which are related to its effects on the local and global environment).

Fuel cost is the total cost of the fuel used in the plant for a one year period. It is chosen to be an input since it is one of the main resources used for production, and its inclusion basically eliminates the necessity to consider other monetary factors in the model at the operational level. Production reflects the electricity produced by the power plant over one year period. It is chosen as a factor since it provides a good quantitative measure of the primary output of a power plant. Utilization is the annual percentage of time a power plant is actually producing power. Here the expectation is to characterize the plant availability for electricity production in one year. It is taken to be as an output since an increase in utilization is a positive sign. Thermal efficiency is the average efficiency over one year period that relates how much of the heat dissipated is converted into electric energy. It has important environmental and economic implications such that maximization of efficiency minimizes emissions and fuel consumption simultaneously. No unit is given since it is a ratio. Environmental cost has been included in order to take into account the negative environmental effects of power plants. It is derived from the SO2, NOx and particules emission data (in tones per year) of each plant. The negative effects are then converted to monetary units using the $ per tone conversion value obtained from ExternE Project, Finland results. CO is selected since its emissions have serious environmental and health effects, while it is not covered by the ExternE project. It is also a measure of burning quality of plants. Like emissions, it is measured in tones per year (but it is not monetarized).

The DEA model developed for the operational performance of renewable power plants has one input factor (operating cost) and two output factors (production and utilization). These three parameters are chosen in order to give due consideration to the primary missions of a power plant (which is reliable generation of electric energy at an acceptable cost). In this case, environmental effects of renewable power plants are not considered. A new factor included in the renewable power plant operational performance model is operating cost, which is used in place of fuel cost for thermal power plants (since there is no direct "fuel cost" in this case). It includes annual maintenance and operational costs.

2.2. Models to Evaluate the Long Term Investment Performance

The DEA model developed for the evaluation of long term investment performance of power plants has 4 parameters. These are investment cost, installed power capacity, construction time (duration), and average utilization percentage. These parameters are chosen to reflect the overall effectiveness of a electricity generating facility project, during its full economic life. As such their values should be representative of the full economic life of the facility.

Investment cost is the total funds used for the construction of the power plant including its electromechanical components. It is treated as an input since a decrease in investment amount (while keeping other factors unchanged) is a positive sign. Construction time is the time between start up of construction and initiation of electricity production. It is treated as an input since a decrease in construction time (while keeping other factors unchanged) is a positive sign. Power is an important design parameter reflecting the potential amount electricity that can be produced in a unit of time (units deployed are MW). It is treated as an output since an increase in power (while keeping other factors unchanged) is a positive sign. Utilization percentage is the average utilization period of a plant over 8 years (eight year period is considered because of the limited data available). It is expected to characterize the long term availability of the plant. It is treated as an output since an increase in utilization (while keeping other factors unchanged) is a positive sign.

Throughout this study the DEA software package developed by Saitech Inc. is used for the DEA calculations (primarily the imbedded L.P. optimization procedures). All input data is prepared on Excel worksheets and also outputs are compiled in Excel environment.

3. Analysis and Conclusions

After the formulation of the models, data collection and compilation is done. From the public sector, data regarding the operational and/or investment performance of 18 thermal power plants and 32 hydro power plants have been compiled through MENR (Ministry of Energy and Natural Resources), EÜAŞ and DSİ. The data obtained from the private sector covers eleven thermal plants, two hydro plants and two wind power plants. Throughout data compilation environmental factors are unified under a general environmental cost concept defined based on the ExternE project. Then related data is normalized for ease of manageability.

Performance evaluation of considered power plants is done through the DEA models developed. The CCR, the BCC, the AR-I-C, the AR-I-V efficiency scores of all plants are determined. Then Scale efficiencies are calculated based on these scores. Finally, relationships between plant efficiencies and key input / output factors are investigated and some interesting trends are observed.

Conclusions to be drawn from this study can be summarized as follows:

- Regarding thermal power plants' investment performance efficiency, the private sector plants perform significantly better than the public sector plants.
- One main cause of investment performance inefficiency of the public sector is because of the poor performance of its coal fired plants.
- Natural gas fired power plants have significantly higher investment performance efficiency score than coal fired power plants.
- Publicly owned natural gas power plants have slightly higher investment efficiency scores than privately owned natural gas power plants.

- Operational performance of the publicly owned thermal power plants is significantly lower than the privately owned thermal power plants.
- Operational performance of coal and liquid fuel fired power plants are considerably lower than that of the natural gas fired power plants.
- Lower operational efficiency of public sector is the reflection of coal and liquid fuel fired plants in its' portfolio.
- Operational performance efficiency of publicly owned natural gas fired power plants is slightly lower than that of the privately owned power plants.
- Renewable power plants are very sensitive to natural factors (like wind, amount of rain fall) thus relationships found are small and insignificant.
- There can not be made any distinction between public and private sectors' efficiencies based on data at hand for renewable power plants' investment performance.
- Wind power plants has the highest efficiency values at operational and investment performance models, which shows their high future potential for Turkey.
- In renewable power plants, excluding very small size plants, scale efficiency shows an exponential decreasing trend with respect to plant size.
- Thermal power plant scale size has negative effect on scale efficiencies of plants.
- Without reducing environmental cost (negative effects) of thermal power plants, it is not possible to reach higher efficiency scores.
- Another importance of this study is its being the first such study in Turkey assessing the power plants performance through a multi input / output analysis based on real data.

References

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