Scenario analysis and rankings of Iran power plants using mathematical models of DEA with the factor of the type of chemical consumption fuel

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Abstract: In this article, considering the importance of the optimum utilization of feasibilities for gaining more efficiency, first, Iran power plants status is surveyed. Then the methodology of data envelopment analysis, taken as the suitable scientific and non-parametrical method of the performance assessment and determination of DMU (Decision Making Units) efficiency has been introduced for the performance improvising and rankings of electricity production; moreover, by using the improvised model the scenario analysis of the data envelopment for gaining the concerned targets will be assessed. Then the various kinds of the consumptive fuels undergo discussion.
[Hadi Mohammadi Zarandini, Mohammad Reza Sheikhnabi. **Scenario analysis and rankings of Iran power plants using mathematical models of DEA with the factor of the type of chemical consumption fuel.** *Life Sci J* 2012;9(4):2035-2040] (ISSN:1097-8135). http://www.lifesciencesite.com. 304

Key words: data envelopment analysis (DEA), efficiency, chemical consumption fuel, power plants, rankings models, scenario analysis

Introduction

The basic efficiency management of any organization is to benefit wisely from the existent feasibilities in which the access to this goal requires overall thinking and scientific resolution. Considering the power industry being an expensive and important one and without suitable investment in developing this industry one cannot reach the economical development, so one of the related discussions is the assessment of the performance and measuring the efficiency of its units and the pursuant consequences and devices that affect on the operation of the electricity generating power plants.

The surveyed power plants in this article can be grouped in two main categories:

- Steam power plants
- Gas synthetic-cyclic power plants

All the steam power plants surveyed in this article ranging from the dominant gas consumption along with Mazut (black oil) fuel as the second one have used. The gas fuel in the warmer seasons and Mazut is mostly used in cold days of the year. Overall, the average efficiency of gas power plants is lower than the steam power plants. However, synthetic- cyclic power plants cause the increment of the efficiency median of these power plants. One of the points that can be effective in increasing the efficiency of the synthetic cyclic power plants is to re-heat through the duct burner in the retrieving boiler. This efficiency increment may be observed in Kerman and Neka synthetic-cyclic power plants. By using duct burner, the rate of gas consumption in torches is much lower in relation to the gas flow but its effect in efficiency increment is very considerable. Of the points both in the gas, unit's and steam units' efficiency is efficient percentage composition of the gas constituents, this matter can be seen in the synthetic- cyclic power plant of Khayam and Ramin power plants. In Khayam power plant in spite of the fuel heating value, the efficiency increment is reduced compared to other power plants.

In this article, first, a general consideration concerning the country power plants including the steam, gas and synthetic-cyclic power plants will be presented ; and concerning the chemical fuel consumption and its heating value is discussed and then the mathematical models used in the article including CCR model, ranking model and the scenario envelopment analysis model will be reconsidered. Afterwards, the evaluation indexes of the power plants will be presented and finally the evaluation consequences using GAMS software will be discussed and conclusions will be drawn.

Types of Power Plants

In generation of electricity the mechanical energy will transfer to electrical energy, in this field our country uses four types of steam, gas, diesel, and water power plants. Moreover, the synthetic- cyclic power plants are a combination of gas and steam power plants; and a nuke power plant has been considered in recent years too.

Steam power plant

In this type, power plant for converting water to steam uses high pressure and heating so that the steam in passing through turbine can make circular mechanical energy and at the end the circular mechanical energy will change to electrical energy in the generator. The smallest unit of steam power plant is Tarasht power plant with production capacity of 12.5 Mega watts installed in 1338 and the biggest one is Neka power plant with the production capacity of 440 Mega watts installed in the year of 1358.

Gas Power plant

In this type, the gasses produced from gasoil or natural gas under high pressure and temperature is coming out from the input route of the compartment in which the turbine is on the way and causes the turbine to rotate and in the consequence causes electrical energy in generator that its axis is connected to the turbine shaft. Due to the lower efficiency of these power plants, they are put in the electricity cycle net during the hours of high daily consumption.

Synthetic-cyclic configuration Power plant

These types of power plants are combination of gas and steam units that are for efficiency increment, the total gas taken from the gas turbine enters an area of boiler steamed unit and of its heating energy is used for steam.

Assessment of mathematical Models

Data envelopment analysis is a mathematical programmed method, which without the requirement of knowing the production function by using a border of non-parametric production can assess the efficiency in the relative form. This method was introduced called CCR Model through an article by Charnez and Roods (1987) [4]. In pursuant, Banker, Charnez and Copper (1984) [3] took the conception of return to scale in this method (BCC Model). And such the basis of a totality of the performance assessment methods took root which are disposed at the services of managers the suitable and efficient instruments for the assessment of industrial, cultural, economical and … called in the literature of data envelopment analysis the decision taking units(DMU) .

Ranking Model

Ranking of the decision taking units and determination of any units based on their activities in the direction of goals and taken policies, the result and objective of ranking incurring motives and sound competition in the decision making units in order to increase their efficiency for short and long terms objectives. The retrieval models to the decision-taking units allow that to compensate for their shortages or weakness of their inputs with the help of other inputs and or the extra consumption in some of their outputs is compensated with other inputs. In the retrieval models, which was presented, by Anderson and Peterson[2] the intervention of the unit under the survey was omitted in the assessment so that in this form in nature of input (output) the smaller (greater) grades or equitant one for the efficient units and the greater grades (smaller) than one for the inefficient units be obtained. In this respect the complete ranking model is:

$$\begin{aligned} Max \quad & \theta \\ s.t. \quad & \sum_{\substack{j=1 \\ j \neq p}}^{n} \lambda_j y_{rj} \geq \theta\, y_{r\theta} \qquad r = 1,\ldots,s \\ & \sum_{\substack{j=1 \\ j \neq p}}^{n} \lambda_j = 1 \\ & \lambda_j \geq 0 \qquad j = 1,\ldots,n \end{aligned}$$

In the above model, giving weight or relative value to the recipients for determination of score to the units is not required. In consideration to this fact that the recipients of a unit is usually from the quality viewpoint may be of such difference which regarding any relative value would be illogical for them. In addition, due to the individual interest in relative giving value may intervene therefore this matter is open to discussion and cannot be optimum value giving.

The retrieval specification of this model to the decision-taking units makes it feasible to compensate the shortages. This specialty in many systems gives this possibility to the units to expand its abilities in special branches. In this article, this model has carried out for Iran power plants generation and so we analyze the resulted outputs.

Data Envelopment Scenario Analysis

There are scenarios for objective determination, which enable the decision takers for utilization of the new policies in relation to the future performance of the organization. The design of these scenarios for determination of objects results in formulation of a data envelopment model.

- **The first scenario**

The inefficient decision-taking units should assume to obtain sub-optimal results with the performance improving methods. Finding the sub-optimal units should also be in accordance with the general strategy of the organization that that organization considers reaching the goal.

- **The second scenario**

The inefficient decision-taking units by simultaneous improvement of inputs/outputs can consider parts of the efficiency border by which create the increment of lower expenditures inputs and or reduction of lower value inputs to be in the privilege of the organization. In this respect, it can be said that the decision –taking units may reach greater input results to consume greater levels of inputs and or the decision-taking units can by choosing tactical decisions to contract inputs and output of a selected operational units.

I have presented a model, which is the improvised model of DESA[1] in which at onset we consider a set of n units of decision-taking units that any unit consume the input quantities of $x \in R^m$ for generation of output quantities of $y \in R^n$ .We represent the output indices set by $I = 1,2,\cdots,m$ and the set of input indices by $O = 1,2,\cdots,s$.

$$\gamma = Max \quad \sum_{r\in O} z_r - \sum_{i\in I} w_i$$

$$s.t \qquad \sum_{j=1}^{n} \lambda_j x_{ij} = w_i x_{ij_0} \qquad i \in I$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} = z_r y_{rj_0} \qquad r \in O$$

$$w_i \le 1$$

$$z_r \ge 1$$

$$\lambda_j \ge 0 \qquad j = 1,\cdots,n$$

The duality between inputs and outputs in DESA will reduce considerably. In fact, it can be said that DESA considers the centers activities by pursuing a practical process obtained from input and output which some of them are for minimizing and some for maximizing. For example it can be said in the index of generating power pollution is an input, which should be minimized while the staff salary is an output that is better to be maximized. Therefore, in the DESA model, pollution is considered as output index and staff salary is an input index. The DESA model considers the decision takers actively in the process of object determination because the object determination is not irrelevant with the organization strategy and managers should be considered too for reaching the determined goals.

Power Plants performance assessment indexes

- **Inputs**

1. Production conditions

Production condition as first input equals to the reverse multiplication output of the numbers of emergency stops. The performance factor or the factor of depreciation (AS), the factor type of the consumptive fuel (FF) , and the factor of work difficulty(Hardness) (HF) that these factors will be calculated and put for power plants by weight combination of practical power of their units.

$$PRD = 1/NFF \times FF \times HF \times (AS - 0.05)$$

This factor for the power, which has no emergency stops, the years of its performance more than 30 years all its units use Mazut and only has steam unit will be the number of 1 which represents the least input employed by this power plant. Moreover, if any one of these parameters change these numerical factor will be greater than one that is the representative of greater input consumption.

- **The factor of the emergency numbers of stops**

First, the emergency stops have bad effects on the main unit equipments. Namely by each stoppage the heating shocks will be imposed on the unit various points which in turn will decrease the life longevity of the unit. Second, any units by each emergency stoppage will cause disturbance in the network status and the control center should enterprise any readiness for this stopped compensations and return the network to a primary stable status. Therefore, it is logical to consider the numbers the stops in relation to performance time. This index depends on the factors such as the emergency stop time and the program stoppage time and the performance duration of the unit.

- **Performance efficiency or depreciation factor**

By the increase of a unit performance, the various systems will gradually depreciate and the probability of failures and unit stoppage will increase. On the other hand, through the passing of time the more advanced systems in various fields will be invented and are put at the disposal of this industry, which is more efficient, compared the old models. Therefore, one can discriminate from two dimensions viewpoints the old depreciated equipments and the accelerating progress in equipments. For this reason, by using the existing experiences depending on the unit age the efficiency factor of the years will be defined so that there would a balance between the old and new units.

Therefore, the following table in this respect is suggested:

Performance age(year)	More than 30	25-30	20-25	15-20	10-15	Less than10
Gas and Steam units	1.05	1.04	1.03	1.02	1.01	1
Water Units	1.025	1.02	1.015	1.01	1.005	1

Factor of the type of fuel consumption

All the steam power plants surveyed in this article have used ranging from the dominant gas consumption along with Mazut (black oil) fuel as the second one. The gas fuel in the warmer seasons and Mazut is mostly used in cold days of the year. Since gas fuel has generally more heating value compared to Mazut; therefore, the usage is more often causes the efficient performance of the units of these power plants. However, in some cases in some power plants the use of Mazut despite the lower heating value not only caused not the reduction of the performance compared to the times that gas has been used but also the efficiency has been similar to the units that had used gas and in some plants the efficiency has been even more. The chemical type of the consumption fuel of the heating units regarding to the existing impurities in these fuels is of importance. The steam units can simultaneously use Mazut or natural gas and or both. Regarding various fuels are used in a power plant all can be measured equally by a common scale. Therefore, a factor can be considered for the user unit of different fuels. These factors can be considered in accordance with the following table so that by using the necessary scale factor among the power plants is balanced. For the units that use two types of fuels the above factor will be assessed by calculating the average related weight considering the used fuels during the course of assessment.

Consumption fuel type	Mazut	gasoil	gas	water
Consumption fuel factor	1	0.98	0.95	0.9

- **Work hardness factor**

Regarding the type of the employed equipments and operation complexity or simplicity, for water and gas units the number 0.8 and for the steam units, the number 1 are considered as the factors of work hardness.

2. Personnel

The number of the affiliated equipments to the power plants types are different compared to each other; and consequently, the required personnel number with the regard to production process are different. So that the steam power plants with consideration of the equipment number and different sections require more personnel for production and units maintenance and gas and water power plants with respect to the limitations in equipment number and the executive sections have less personnel relatively. Therefore regarding the country different power plants circumstances, a factor in conformity with the production capacity in any productive unit can be defined so that it would be possible to determine the same index as the personnel number factor while installing a new unit or removing the old units. Therefore, for steam units regarding the more required personnel the factor of 0.5 individual for each production capacity Mega watt and in gas and water units the factors of 0.3 and 0.25 can be taken respectively.

- **Outputs**

1. Unit performance factor (UPF)

In order to assess the power plants performance it is better to investigate the different power plants units one by one and to define the effective factors in their performance separately and at the end to intervene the factors that are related totally to the power plant. The unit performance factor involving the main performance factors are such as energy generation, energy power and production continuity in the peak time hours.

2. Production Coefficient (CAB)

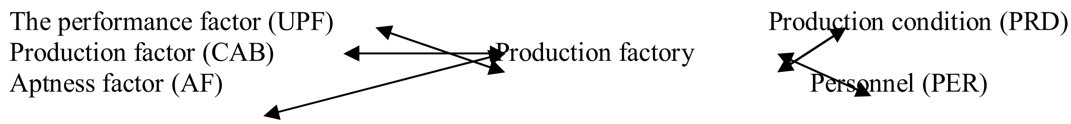
Daily load consumption fluctuations cause any type of the power plants to follow a special pattern in the production times. The low load consumption hour during the day and night reaches to the half of the maximum load of consumption and this causes that some units to reduce their load and some to get totally out of the circuit. Therefore, the volume of the production total activities in any power plants should be defined during the assessment course as a production factor index. Since the produced energy volume in appropriation of useful performance time duration, considering the amount of produced energy during the course will be a correct criterion of the total produced activities volume, which in this relation the factor index is defined as follow:

$$\text{Production factor} = \frac{\text{the produced gross energy during the evaluation}}{\text{Practical power performance hours during the evaluation}}$$

3. Aptness Factor (AF)

Aptness of the units from the viewpoint of control center for keeping the network stable status through coordination of the produced amount of consumption is of great importance. Actually, we can say the aptness of a unit is the actual percent of being apt to work. One aptness under one hundred percent shows that there is a default in getting target compliance. On the other hand one aptness above one hundred percent for maximizing the benefit is not a bad index and this phenomenon occurs when between budget and real force demand there is a disfigure. Therefore, a lower expenditure factory can be put in the network for production and this is out of the devices that have been considered for them. Therefore, a factor can e considered as an index for aptness.

Considering the above-mentioned matters, the factors are defined for the evaluation of the power plants performance as follows:



Models executions, results and their analysis

Ranking Model execution

By using this model, the power plants according to the defined indexes for the recipient units are ranking and the only used input in the ranking model equals to one. In the table number 3, the power plants are listed as the in the first column. In the second column, the ranks related to every power plant, in the third col. The index (reference) power plants for ranking have been listed respectively. Regarding the obtained results, one can see that the power plant number 23 with the score of 1.44752 has an excellent grade and the power plant number 39 with the score of 0.92862 has the lowest grade. In addition, in the table 5 the power plants with greater score or equal one in one group and the power plants with the score less than one are classified which attribute the concept of first grade to the first group power plants and the second grade to the second group power plants . It can be observed that such power plants as the power plant number 23 which are excellent grade is relatively inefficient because this production unit has an upper expenditure that obviously can be seen from the table 1 quantities and explains clearly that this power plant has a big volume but cannot have maximum production from its existing resources. This analysis is of great importance for management points of view.

The execution of DESA Model

Scenario analysis of data envelopment aforesaid on the country power plants with two input indexes and three recipient indexes at first executed for the group one power plants and then for the group second power plants. In execution of model, we consider a state with equal priority to the all inputs and recipients. Out of this model analysis with regard to the obtained results one can suggest the recipients' increment and reduction of inputs regarding the w_i and z_i quantities which can deliver the rate of recipient expansion and input contraction. For the interpretation of the results obtained in the tables 5 and 6 for example the power plant number 16 with the reduction of the second its input that is the personnel factor can increase its first and third recipients to the rate of 1.25 and 1.13 respectively. We observe that the units number 1 and 7 as the index (reference) units have acted as for the unit 16 and a weighted combination of units 1 and 7 with defined weights are introduced which both equals to 0.564, one figurative unit presents as the pattern are for performance improvement. In addition the z_1, z_2, z_3 , w_1 , w_1 coefficients have presented the improvement rate on the unit 16 recipient and input vector. The interpretation of these coefficients is that if unit 16 reduces its second input up to 0.61 against previous input amount in the figurative level obtained from the linear combination will act as two efficient units 1 and 7. In other words with the change mentioned in the second input of unit 16, its recipient will equal to 1.25,1 and 1.13 respectively. Therefore, we have the amounts of $w_1 = 1$ and $w_2 = 0.61$ for the unit 16 input:

$$\begin{pmatrix} x_1' \\ x_2' \end{pmatrix} = \begin{pmatrix} 1.19 \\ 0.16 \times 0.995 \end{pmatrix} = \begin{pmatrix} 1.19 \\ 0.60695 \end{pmatrix}$$

In addition, we have for its recipient vector:

$$\begin{pmatrix} y_1' \\ y_2' \\ y_3' \end{pmatrix} = \begin{pmatrix} 1.25 \times 80.4 \\ 1 \times 81.21 \\ 1.13 \times 87.87 \end{pmatrix} = \begin{pmatrix} 100.5 \\ 81.21 \\ 99.2931 \end{pmatrix}$$

On the other hand, by calculating the amounts of the figurative unit input and recipient we have:

$$\begin{pmatrix} x_1'' \\ x_2'' \end{pmatrix} = 0.564 \begin{pmatrix} 1.06 \\ 0.333 \end{pmatrix} + 0.564 \begin{pmatrix} 1.05 \\ 0.75 \end{pmatrix} = \begin{pmatrix} 1.19004 \\ 0.610812 \end{pmatrix}$$

$$\begin{pmatrix} y_1'' \\ y_2'' \\ y_3'' \end{pmatrix} = 0.564 \begin{pmatrix} 88.4 \\ 64.35 \\ 86.27 \end{pmatrix} + 0.564 \begin{pmatrix} 90.22 \\ 79.65 \\ 89.97 \end{pmatrix} = \begin{pmatrix} 100.82 \\ 81.216 \\ 9.2931 \end{pmatrix}$$

We observe that the obtained quantities through the improvement of input-recipient and the figurative unit are approximately equal. Therefore, by changing the priorities on the input and recipient quantities, quantities that are more specific can be obtained for the improvement rate in order to be useful for managers' taking decisions. The results obtained in the tables 5 and 6 can generalize for all the power plants.

Conclusion

What presented is the application of data envelopment analysis in the evaluation of Iran electricity generation power plants, the results obtained from this assessment through considering the scenarios that are dependent on objectives. It gives the feasibility to power plant management in order to take the different priorities to assess the performance improvement. The information obtained from the execution of the DEA models, first gives management a relatively specific recognition of system in order to control the parts under its surveillance with a specific and scientific conception. Secondarily, we can recognize the power plants performance improvement ways, finding out capabilities and or barriers on the way of power plants development, presenting scientific pattern for control centers decision takers, dedication of resources to the power plants etc.

Data and Resources

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10/5/2012