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Estimating Efficiency of Thermal and Hydroelectric Power Plants in Iranian Provinces

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Abstract

This paper aims at estimating the efficiency of hydroelectric power plants (renewable energy resources) and thermal power plant (non-renewable energy resources) in Iranian provinces. Data Envelopment Analysis (DEA) approaches is applied to estimate the efficiency. The network is modeled as a linear system with multiple inputs and one output. Fuel cost, labor force, operation cost are used as inputs. Electrical energy delivered per year is used in the model as output. The study offers some detailed policies to improve the efficiency of the plants. Mean technical efficiency of hydroelectric power plant in 2011 and 2010 are 62% and 53%, respectively. Mean technical efficiency of thermal power plant in 2011 and 2010 is 82% and 77%, respectively. The results of the study indicate that mean technical efficiency of thermal power plant in 2010 and 2011 is higher than efficiency of hydroelectric power plants.

Keywords: Efficiency, Data Envelopment Analysis (DEA), Hydroelectric Power Plants, Thermal Power Plants, Iran.
JEL Classifications: C14; O44; Q20.

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1. Introduction

Generation in each country needs providing generation infrastructures. Generation increase requires creating input factors and also optimizing them. One optimization method is combining generation factors, using efficiency and productivity concepts. The first step in the process of efficiency and productivity improvement is measurement. Measuring efficiency and productivity creates the information for decision-makers about present conditions to plan future.

Increasing efficiency and productivity in all industries is a confident way to reach higher economic growth with the same resources. Electricity industry plays important role in this regard along with other economic factors. Thus, efficiency and productivity increase in this industry has great eminence. Electricity industry can be divided into 3 groups of generation, transfer, and distribution. Accordingly, the power generation sector (power plants) is capital intensive, so electricity plants are significant sections. They are divided into water, renewable, thermal, and nuclear types. Common power plants are water and thermal types. Iran has the advantage of using these plants because of its rich resources of fossil fuels (main fuel of steam, gas, and combined cycle power plants) (Heydari, 2000).

In this article, first, a comparative study of efficiency for hydroelectric (renewable fuels) and thermal (fossil fuels) power plants in Iran's economy in panel form (province data and time series from 2010-2011) is conducted. Using data cover analysis, efficiency of electricity power plants in different provinces is assessed. Then, optimum input combination regarding a definite output for each power plant is suggested. Also, according to calculations, the best power plant for each province is suggested (hydroelectric or thermal?).

Second, we are discussed the concept of efficiency, its types, evaluation methods, and experimental works. In third part, theoretical basis of used methods for data envelopment analysis was examined. In fourth section, a review of different power plants in different provinces is offered. Then, the results supposing fixed and variable return to scale are offered, yielding the rank of each power plant in each province. Last section deals with conclusion.

2. Literature Review

Parametric frontier models and non-parametric methods have almost used in recent literature on efficiency measurement, especially for the electricity supply sector. Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) are the best methods to use for determining the efficiency and relative performance of the firms.

Coelli (1995), Pitt and Lee (1981) and Pollitt (1995) have developed consideration of efficiency in the economic literature. There has been a several and varied ranging of papers and articles on the measurement of productivity and efficiency. There has always been a close link between the measurement of efficiency and use of frontier functions. Different techniques and variables have been used to estimate the frontier generation or cost function. In this study, we go through the use of non-parametric approaches as well as their application to the electricity generation sector of Iran.

Olatfubi and Dismukes (2000) attempts to measure cost efficiency opportunities for coal-fired electric generation facilities. Their results show considerable opportunities for cost reduction in the industry that could result in price reduction to electricity consumers.

Park and Lesourd (2000) determine the efficiencies of the 64 conventional fuel power plants operating in South Korea by DEA approach and stochastic-frontier method.

Lam and Shiu (2001) apply DEA approach to measure the productivity performance of China's stated-owned power sector, based on panel data (1996 and 1999) and time-series data (1952 and 1999). Greater levels of competition in electric power markets offer the promise of increased efficiency, with lower costs to consumers. Yet, despite these perceived benefits, little empirical work has been conducted to quantify existing power plant performance characteristics. In the past, empirical work has focused on average determination of cost performance, and their associated scale implications, and not on measure of best practice (Olatfubi et al., 2000).

Jukka et al. (2008) examined the benchmarking results of electricity distribution companies in Finland. They used a DEA approach to measure the efficiency of 95 companies and also completed sensitivity analysis for the period of 1999-2000. The effects of the changes in operational costs are different for efficient and inefficient companies. For efficient companies, the changes affect slowly or they do not affect at all. For inefficient companies, the effects of changes in operational costs are logical because they behave according to DEA approach.

Vaninsky (2006) used DEA method, supposing variable returns to scale (input-orientation) and examined efficiency of electric industry in USA. According to the results of 1991-1994, efficiency reduced to 98.6%; but, from 1994-2000, efficiency remained constant at the highest level. But, it reduced to 94.6% in 2004.

Abbot (2006) used the index of Malmquist, an output of electricity delivery, and 4 inputs of capital inventory, labor force, fuel, and other services regarding input-orientation, evaluating total factor productivity of generation factors in electronic industry of Australia from 1969-1999. Results show positive growth of technologic changes with the mean annual growth rate of 1.8% in all states. Efficiency of scale in all states remained constant. Thus, 2.5% growth of total factor productivity resulted from technologic advances.

Fabrizio et al. (2007) studied the impact of electricity restructuring on generation efficiency in the United States, using a difference-in-difference approach to measure efficient input use. Using a plant-level panel (1981–1999) of gas- and-coal-fired thermal power plants, the authors estimate cost-minimizing input demands as a function of plant characteristics while controlling for the regulatory regime. They show that privately owned utilities in restructuring states experienced greater gains in efficiency of nonfuel input use compared to similar utilities in non-restructuring states and cooperatively or publicly owned generators that were insulated from the reforms. Because of the nature of the restructuring process in the United States, their restructuring measure combines the effect of unbundling of generation from transmission and distribution with opening the generation sector to retail competition. The authors, however, attribute most of their impact to the unbundling of generation, as retail competition was limited to only seven states during the period of analysis.

Behera et al. (2010) efforts to estimate the relative performance of the coal-fired power-generating plants in India, exploring the key determinants of the inefficient units.

Also Behera et al. (2010) study non- parametric Data Envelopment Analysis (DEA) to estimate relative technical efficiency and scale efficiencies of coal-based power plants in India. Distribution of less efficient plants in different sectors, regions, their peer groups and the return to scale properties are analyzed.

Liu et al. (2010)'s results for China showed that the most important variable in DEA model is the “heating value of total fuels” (Liu et al. 2010 page 1054). Finding from this study can be beneficial in improving some of the exiting power plants and for more efficient operational strategies and related policymaking for future power plants.

There are some studies on efficiency of different sections in electricity industry in Iran some of which are as follows:

Emami Meibodi (1997) used DEA method and index of Malmquist, regarding input-orientation view, technical efficiency and total factor productivity of electricity generation in thermal power plants of 26 developing countries. Based on the results, on average, developing countries have 23% inefficiency. Thailand is the most efficient and Salvador is the most inefficient country in this study. Iran’s power plants had average efficiency of 60.3% and ranking of 24 among 26 countries.

Fallahi and Ahmadi (2005) used DEA approach, technical efficiency (in total and theoretical forms), scale efficiency, total efficiency of generation factors, and technological revolutions of 42 companies of electricity distribution from 1995-2002. Based on the results, scale inefficiency is the most important factor of inefficiency in Electricity Distribution Company of Iran. Factor productivity growth of the companies in the study period is negative. The main reason for that result can be using overused and old equipment in distribution companies.

Sadeghi Shahedani and tavakkolnia (2011) examined the effect of structural corrections on productivity of electricity industry based on DEA method and Malmquist index. Based on the results, in correction period, productivity of electricity industry has improved in which technical efficiency changes have more significant role than technologic changes.

Regarding previous literature, there is no study on comparing efficiency of hydroelectric power plants (with renewable energy) and thermal power plants (with fossil fuels) for Iranian economy in panel form (province data and time series from 2010-2011). Also, this study offers suggestions for each power plant. These suggestions can be tools for policy-makers to optimize investments on electronic power plants in each province.

3. DEA and Structure of Models

Despite limitations like the lack of measuring absolute efficiency, changes in efficiency values, variation in efficiency values, adding new corporations, and the lack of conducting statistical tests for non-parametric nature of it, DEA is gaining growing popularity for the following capabilities.

DEA is a method for measuring the performance efficiency of decision units, characterized by multiple input and output variables (Donthu and Yoo, 1998). DEA technique uses linear programming to estimate the maximum potential efficiency for various levels of inputs based on each firm's actual inputs and output. DEA includes two major models, the CCR model, and the BCC model. Charnes et al. (1978) proposed a model under the assumption of constant return to scale (CRS), called the CCR model. This model is only appropriate when all DMUs are operating at an optimal scale. Banker et al. (1984) extended the CCR model to include the variable returns to scale, named the BCC model, which can further decompose the TE into two components: pure technical efficiency (PTE) and scale efficiency (SE).

3.1 CCR Model

CCR Model is the first model of DEA, consisting of an acronym of its innovators (i.e. Charns, Cooper, Roodes). In this model, to determine the highest efficiency ratio and involvement of inputs and outputs of other decision-making units in identifying optimum weights for under-study units, Model 1 is suggested.

$$
\begin{aligned}
& Max \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}} \\
& s.t. \\
& \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1,\ j = 1, 2, \ldots, n \\
& u_r \geq 0, v_i \geq 0
\end{aligned}
\qquad \textbf{(Model 1)}
$$

Where,

u_r : r *th* input weight

v_i : i th output weight

o : Subscript of decision-maker unit ($o \in \{1, 2, ..., n\}$)

y_{ro} and x_{io} : values of r th output and i th input for o unit

y_{rj} and x_{ij} : values of r th output and i th input for j th unit

s: number of outputs
m: number of inputs
n: number of units

It is worth mentioning that definition of efficiency in CCR model is the result of dividing output weight combination into input weight combination (Charnes et al. 1978).

3.2 Input and Output Orientation in CCR Model

In DEA model, a way of improving inefficient units is reaching efficient frontier. Efficient frontier consists of units with efficiency size of 1. Generally, there are 2 strategies for improving inefficient units and bringing them to efficient frontier (Charnes and Cooper, 1985).

1. Decreasing inputs without reducing outputs till reaching a unit on efficient frontier (named input nature of performance improvement or measuring efficiency with input orientation)

2. Increasing outputs till reaching a unit on efficient frontier without absorbing more inputs (named output nature of performance improvement or measuring efficiency with output-orientation)

Two above-mentioned efficiency improvement patterns are shown in Fig 1. Regard to this figure unit A is inefficient. In this figure, A1 is improved version with input-orientation and A2 is improved version with output-orientation.

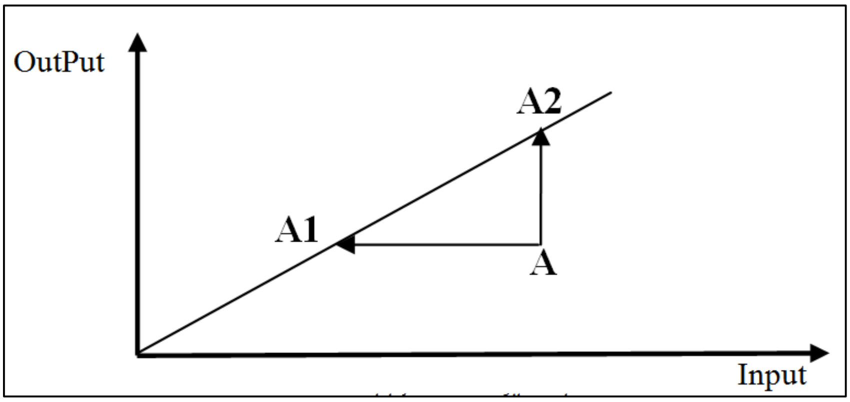

Figure 1: Efficiency improvement model

In DEA models with input-orientation, one looks for reaching the ratio of technical inefficiency. This must be resulted by reducing inputs to be placed on efficient frontier without changes in outputs. But, in output-orientation, one searches for a ratio by which outputs need an increase to reach efficient frontier without any changes in inputs. Exercising restriction of $\sum_{i=1}^{m} V_i x_{io} = 1$ in planning model of CCR, suggested by Charnes et al. (1978), this model has changed into linear planning Model 2.

$$Max \sum_{r=1}^{s} u_r y_{r\circ}$$

$$s.t.:$$

$$\sum_{i=1}^{m} V_i x_{i\circ} = 1 \qquad \textbf{(Model 2)}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0 \qquad j = 1, \ldots, n$$

$$u_r \geq 0 \qquad v_i \geq 0$$

Efficiency determination model is famous as CCR.I. But, for turning CCR model into a linear planning model, another method can be used.

Exercising restriction of $\sum_{r=1}^{s} u_r y_{ro} = 1$, CCR model changes into Model 3 which identifies CCR.O model. If the constraint of $\sum_{r=1}^{s} u_r y_{ro} = 1$ is applied to the model 2, we get the following modified model.

$$Min \sum_{i=1}^{m} V_i x_{io}$$

$$s.t. \sum_{r=1}^{s} u_r y_{ro} = 1$$

(Model 3)

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0 \quad j = 1, \ldots, n$$

$$u_r \geq 0 \quad v_i \geq 0$$

3.3 Envelopment Input Orientation in CCR Model

The curve of equal generation and non-parametric frontier generation function which results in the form of broken line for efficient corporations may create problems in measuring efficiency in the form of input slack or output slack.

In DEA, this problem is solved using two-stage model of CCR. Model 4 and Model 5 show optimization in first and second stages of this method.

$$Min \quad \theta$$

$$s.t. \quad \sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta x_{io} \quad , \; i = 1, 2, \ldots, m$$

(Model 4)

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{ro} \quad , \qquad r = 1, 2, \ldots, s$$

$$\lambda_j \geq 0, \qquad j = 1, 2, \ldots, n$$

Then,

$$Max \quad w = \sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+$$

$$s.t. \quad \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta^* x_{io} \quad , \quad i = 1,2,...,m$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{ro} \quad , \qquad r = 1,2,...,s \qquad \textbf{(Model 5)}$$

$$\lambda_j \geq 0, \qquad j = 1,2,...,n$$

$$s_i^- \geq 0, \qquad i = 1,2,...,m$$

$$s_r^+ \geq 0, \qquad r = 1,2,...,s$$

Where, in Model 5, θ^* is optimum value result from the model 4. s_r^- And s_r^+ show input slack or output slack. A corporation is efficient if and only if $\theta^* = 1$, and for some *i*'s and *j*'s we had $s_r^{-*} = 0$ and $s_r^{-*} = 0$. If for one corporation, $\theta^* = 1$ and for some *i's* $s_r^{-*} \neq 0$, corporation will be weak efficient (for more about DEA models you can see Mehrgan,2004).

This study uses CCR Envelopment method. After solving the pattern, first, power plants of each province have been introduced in the order of efficiency; then, input slack in inefficient were identified in power plants.

4. Application for Iranian power generation

In this study, in all 17 provinces of Iran, power plants have been divided into 2 types:

1. Hydroelectric power plants (examples of power plants with renewable energies and zero fuel cost)
2. Thermal power plants (collection of steam, gas, diesel, and combined cycle power plants)

For each power plant in 2010 and 2011, technical efficiency was calculated. Hydroelectric power plants in Azerbaijan, Esfahan, Bakhtar, Tehran, Khorasan, Khuzestan, Zanjan, Semnan, Sistanand Baluchistan, Gharbi, Fars, Kerman, Gillan, Mazandaran, Hormozgan,Yazd, Kish provinces for two years (2010 and 2011) were considered as decision-making units (DMU).

Names of these decision-making units are shown in Table.1 (e.g.

regarding this table, hydroelectric power plant in Fars province in 2011 is called DMU45). In aggregate, there are 52 decision-making units. They use 4 inputs of fuel, labor force, repair cost, and maintenance for electricity generation. In Table 2, input and output variables and studies concerning them have been shown.

Thus, input and output variables in this study include the following cases:

1. Fuel: the DMU's used fuel in hydroelectric power plant equals zero. But fuel of thermal power plant can be gasoline, oil, and natural gas. In different reports, these 3 fuel types have different units. To assimilate units in this study, units of 3 fuel types have turned into BTU[1] (*British thermal unit*).
2. Labor force: The staff employed in different power plants of each province based on person unit.
3. Installation, repair, and maintenance costs: The costs considered for repair and protection of utilities depend on installed capacity of each power plant. Repair and maintenance cost of each power plant is presented in Table 3.
4. Startup Cost: Cost of establishing each power plant

Table 1. Number of Decision Making Unit for Power Plants in Various Provinces in 2010 and 2011

Order	Year	Provinces		DMU No.		DMU No.
1	2010	Azerbaijan	Thermal Power Plant	DMU02	Hydroelectric Power Plant	DMU36
2		Esfahan		DMU04		DMU38
3		Bakhtar		DMU06		DMU40
4		Tehran		DMU08		DMU42
5		Khorasan		DMU10		-
6		Khuzestan		DMU12		DMU44
7		Zanjan		DMU14		-
8		Semnan		DMU16		-
9		Sistan and Baluchistan		DMU18		-
10		Gharbi		DMU20		-
11		Fars		DMU22		DMU46
12		Kerman		DMU24		DMU48
13		Gillan		DMU26		DMU50
14		Mazandaran		DMU28		DMU52
15		Hormozgan		DMU30		-
16		Yazd		DMU32		-
17		Kish		DMU34		-
18	2011	Azerbaijan		DMU01		DMU35
19		Esfahan		DMU03		DMU37
20		Bakhtar		DMU05		DMU39
21		Tehran		DMU07		DMU41
22		Khorasan		DMU09		-
23		Khuzestan		DMU11		DMU43
24		Zanjan		DMU13		-
25		Semnan		DMU15		-
26		Sistan and Baluchistan		DMU17		-
27		Gharbi		DMU19		-
28		Fars		DMU21		DMU45
29		Kerman		DMU23		DMU47
30		Gillan		DMU25		DMU49
31		Mazandaran		DMU27		DMU51
32		Hormozgan		DMU29		-
33		Yazd		DMU31		-
34		Kish		DMU33		-

Source: The research findings

Table 2. Input and Output Variables

Input Variables	
Name	**source**
Fuel Cost	IEA; Glaser, 1977; Thorpe, 1999; Schneider and McCarl, 2003;Owen, 2004; Bedard et al., 2005; Previsic et al., 2005; Dowaki and Mori, 2005
Labor force	Buonafina, 1992; Adjaye, 2000; Morey, 2001;Ghosh, 2002; Dugan and Autor, 2002
Startup Cost	Dorian, 1998; Morey, 2001; Dugan and Autor, 2002
Maintenance Expenses	Kannan and Pillai, 2000; Herman, 2002; AMEC, 2004
Output Variables	
Electricity generation	

Source: The research findings

Table 3. Maintenances Cost According to Installation Capacity

Power plant	**Cost ($\frac{\$}{kw-yr}$)**
team	0.1015
Gaseous	0.0978
Combined cycle	0.0796
Hydro	0.108
Nuclear and renewable	0.16
Diesel	0.078

Source: The research findings

Statistics of each variable regarding library method in time series of 2010 and 2011 have been gathered from Journal of Electricity Industry Statistics during different years. Gathering necessary information and calculations for earning inputs and outputs of power plants in each province, technical efficiency of thermal and hydroelectric power plants for 2010 and 2011 was estimated using a two-step method of DMU52 (Model 4 and 5). Next, efficiency of each power plant in different provinces was calculated.

This study is input-oriented; because, it seems that in power plants which are in charge of producing a definite amount of electricity, such generation using minimum input in framework of input-orientation can cover the goals of this study. To measure technical efficiency, was used programming in GAMS software. Outputs of this software are shown in Appendix 1 and Appendix 2.

If the efficiency is equal to 1 in any DEA model, but the sum of slacks is not equal to 0 in the corresponding second-stage optimization, the unit can be considered to exhibit mix inefficiency. Above statements are also valid for the CRS technology. According to result of calculation we have not mix inefficiency for DMU's with efficiency of 1.

According to the results, the following information was achieved:

- Mean technical efficiency of hydroelectric power plants in 2010 and 2011 is 62% and 53%, respectively. Efficiency increase in 2011 can be for rainfall increase which leads to enhancement of generation capability in hydroelectric power plants.
- Technical efficiency of thermal power plants in 2010 and 2011 is 77% and 82%, respectively. Thus, efficiency in 2011 has increased.
- Mean technical efficiency of thermal power plants in 2010 and 2011 is higher than hydroelectric power plants which can be for low rainfall and the lack of working with maximum capacity of hydroelectric power plants.

Also we used the result (App. 1) and plotting the figure 2 and table 4. Based on Fig.2 and Table 4, the following results were achieved:

- Thermal power plants of Kerman and Kish (DMU23, DMU24, DMU33, and DMU34) had efficiency of 1.
- Hydroelectric power plants of Gilan and Azerbaijan (DMU35, DMU36, DMU49, and DMU50) in 2010 and 2011 had efficiency of 1. Since; they work with their maximum generation capacity.
- Technical efficiency of hydroelectric power plants of Bakhtar (DMU39, DMU40) in 2010 and 2011 and Fars and Kerman (DMU46, DMU48) in 2010 had efficiency of below 15%. This can be for low rainfall in 2010.

Based on results 1 and 2, thermal power plants in hot areas have high technical efficiency while hydroelectric power plants have maximum efficiency in areas with high rainfall; since, they can work with their maximum capacity.

According to Fig. 3 and 5, the highest technical efficiency of hydroelectric power plants in 2011 belongs to Gilan and Azerbaijan with efficiency of 1 and the lowest efficiency of 31% and 10% belongs to Bakhtar and Kerman.

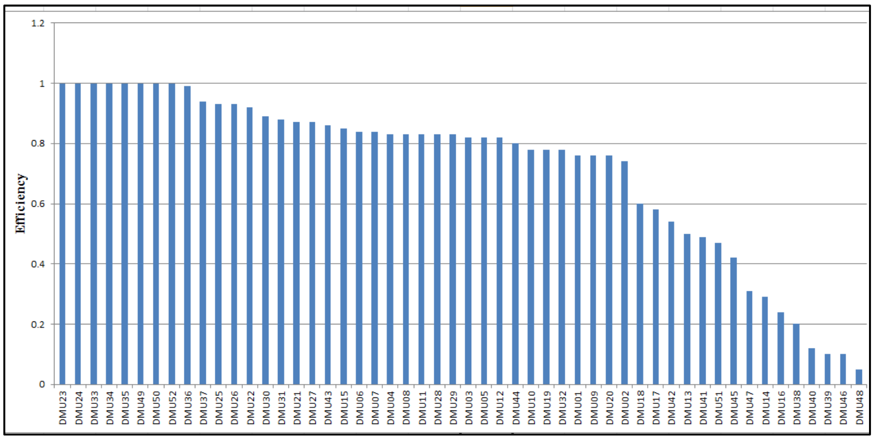

Figure 2: Efficiency of all Decision Making Unit

Source: The research findings

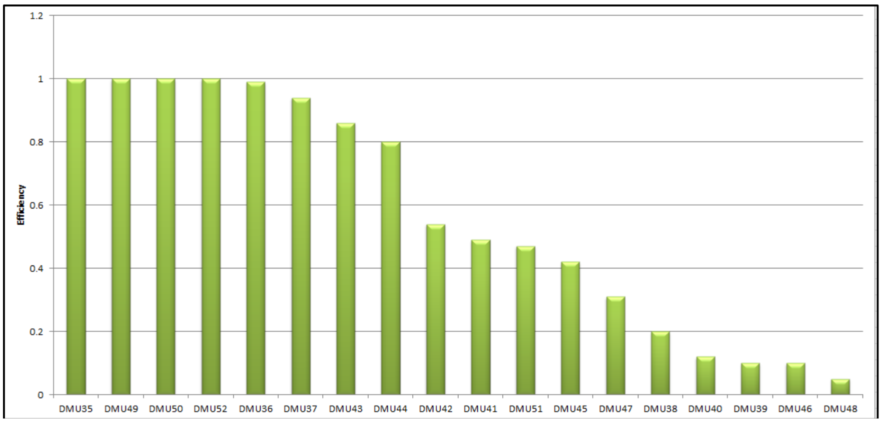

Figure 3: Efficiency of Hydroelectric power plant Decision making unit

Source: The research findings

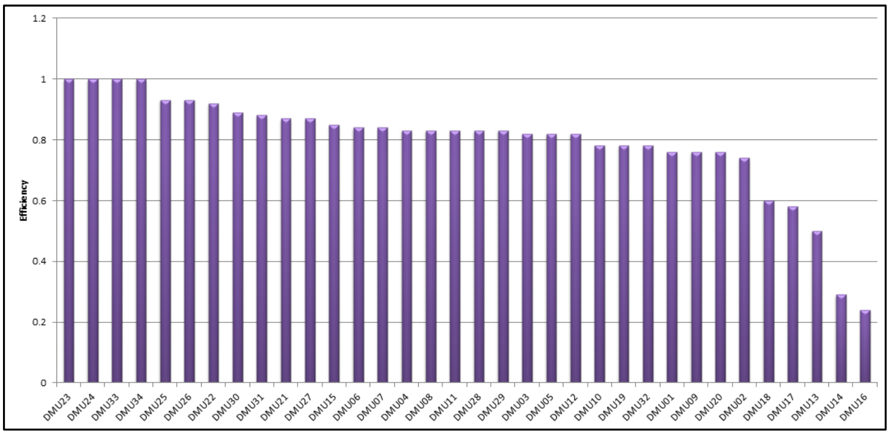

Figure 4: Efficiency of Thermal power plant Decision making unit

Source: The research findings

Fig. 4 and 5 show technical efficiency of power plants in different provinces. Based on the digits, the highest technical efficiency of thermal power plants in 2011 relates to Kish and Kerman provinces with efficiency of 1 and the lowest efficiency belongs to Sistan Baloochestan and Zanjan with efficiency of 58% and 50%, respectively.

Based on Fig.5, in 2011, hydroelectric power plants of Azerbaijan, Esfahan, Khoozestan, and Gilan have higher efficiency; while, thermal power plants in, Bakhtar, Tehran, Fars, Kerman, Mazandaran have higher efficiency.

In case of decreasing inputs and making generation rate fixed in each province (i.e. saving inputs), we can approach efficient frontier. Table 4 and 5 show reduced input for putting on efficient frontier of electricity generation for hydroelectric and thermal power plants in each province in 2011.

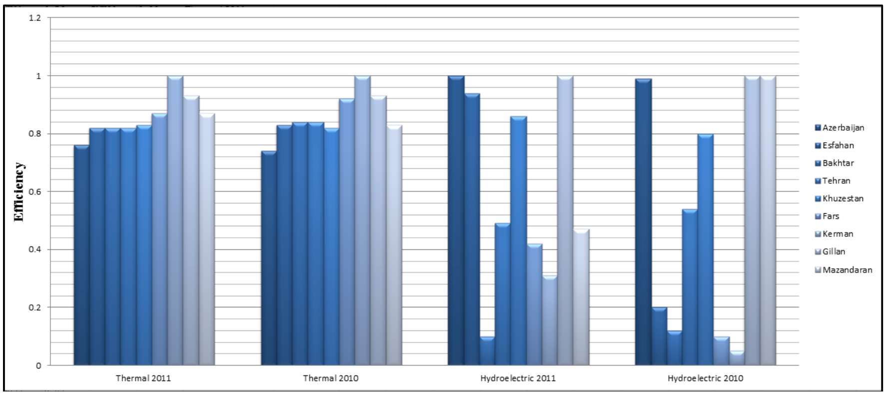

Figure 5: Efficiency of hydro and thermal power plant in 2010-2011 for provinces

Source: The research findings

Table 4. Reduced Input for Thermal Power Plants to Achieve the Efficient Frontier in 2011

Order	Provinces	DMU No.	Maintenance	Labor	Fuel Cost
1	Azerbaijan	DMU01	523.9627	150	37.31625
2	Esfahan	DMU03	312.81	357	30.37595
3	Bakhtar	DMU05	282.5093	114	21.97474
4	Tehran	DMU07	746.244	497	59.94095
5	Khorasan	DMU09	527.5833	396	39.9001
6	Khuzestan	DMU11	252.7493	101	22.85331
7	Zanjan	DMU13	121.82	32	2.575032
8	Semnan	DMU15	49.69	0	0.848972
9	Sistan and Baluchistan	DMU17	251.174	224	21.19143
10	Gharbi	DMU19	239.8653	91	19.72439
11	Fars	DMU21	223.128	73	20.3539
12	Kerman	DMU23	0	0	0
13	Gillan	DMU25	61.92267	94	5.54481
14	Mazandaran	DMU27	173.8747	60	15.31473
15	Hormozgan	DMU29	246.9213	59	20.93267
16	Yazd	DMU31	58.90733	25	4.524232
17	Kish	DMU33	0	0	0

Source: The research findings

Table 5. Reduced Input for Hydroelectric Power Plants to Achieve the Efficient Frontier in 2011

Order	Provinces	DMU No.	Maintenance	Labor	Fuel Cost
1	Azerbaijan	DMU35	0	0	0
2	Esfahan	DMU37	149.12	3	0
3	Bakhtar	DMU39	39.09	71	0
4	Tehran	DMU41	342.77	52	0
5	Khuzestan	DMU43	2112.95	107	0
6	Fars	DMU45	139.25	13	0
7	Kerman	DMU47	47.63	13	0
8	Gillan	DMU49	0	0	0
9	Mazandaran	DMU51	18.46	3	0

Source: The research findings

About explain in fig 4 and table 4,5 for example, to reach efficient frontier in power plants of Fars Province, number of labor force should decrease to 73 people (13%). Also, fuel saving should be 020.4 BTU (or 13%). In case of decrease in any input of Table 4 and 5, supposing fixed electricity generation of any inefficient province, we can achieve efficient frontier.

5. Conclusion

Generation requires input factors. Generation increase results from two methods of increasing generation factors or optimizing generation factors. First step is in efficiency improvement cycle and measurement of productivity.

This study attempted to use DEA method to evaluate efficiency of electricity power plants in different provinces of Iran and offer optimum combination of inputs given the output level of each power plant. Based on our empirical results, the best (thermal or hydroelectric) power plant for each province was suggested. The approach of this study is input oriented because it is assumed that power plants are going to produce a given amount of electricity by minimum amount of inputs Thus, input-oriented approach was used. In this study, in each province, power plants were divided into thermal or hydroelectric types for which technical efficiency was calculated for 2010 and 2011. Thus, different provinces are decision-making units that use 4 units of fuel, labor force, start-up cost, and repair and maintenance costs for electricity generation.

GAMS software was used to measure technical efficiency in different provinces.

- Mean technical efficiency of hydroelectric power plant in 2011 and 2010 are 62% and 53%, respectively.
- Mean technical efficiency of thermal power plant in 2011 and 2010 is 82% and 77%, respectively, revealing an increase in 2011.
- Mean technical efficiency of thermal power plant in both years is higher than efficiency of thermal power plants.
- Thermal power plant of Kerman and Kish in 2010 and 2011 has efficiency of 1.
- Hydroelectric power plants of Gilan and Azerbaijan in 2010 and 2011 has efficiency of 1.
- Technical efficiency of hydroelectric power plants of Bakhtar 2010 and 2010 and Fars and Kerman in 2010 is below 15%.
- The highest technical efficiency of hydroelectric power plants in 2010 belongs to Azerbaijan with efficiency of 1 and the lowest efficiency relates to Bakhtar and Kerman with efficiency of 31% and 10%.
- The highest technical efficiency of thermal power plants in 2011 belongs to Kish and Kerman with efficiency of 1 and the lowest efficiency relates to Sistan Baloochestan and Zanjan with efficiency of 58% and 50%.
- Technical efficiency of hydroelectric power plants in Azerbaijan, Gilan, Esfahan, and Khoozestan is higher than Bakhtar, Fars, Mazandaran, Tehran, and Kerman.
- In case of decreasing inputs and fixing generation of power plants in each province (saving inputs), we can get close to efficient frontier.

Endnotes

1- We used below unit conversion in this study:

$$millioncubicmetresNG \times 10^{-3} = billioncubicmetresNG$$
$$billioncubicmetresNG \times 36 = trillionBtu$$
$$millionlitter \times 10^{3} = kilolitres$$
$$kilolitresGasoil \times 0.839 = tonnesGasoil$$
$$tonnesGasoil \times 7.5 = Barrels$$
$$Barrels \times 42 = gallon\ [U.S.]$$
$$gallon[U.S.]ofdieseloil \times 138\,874.158\,23 = Btu$$
$$Btu \times 10^{-12} = millionBtu$$
$$millionlitter \times 10^{3} = kilolitres$$
$$kilolitresFueloil \times 0.939 = tonnesFueloil$$

$$tonnesFueloil \times 6.7 = Barrels$$
$$Barrels \times 42 = gallon\ [U.S.]$$
$$gallon\ [U.S.]\ of fueloil\ \times 149\,793.010\,97 =\ Btu$$
$$Btu \times 10^{-12} = trillionBtu$$[1]

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Appendix 1. Result of Running the Program in GAMS

DMU No.	Efficiency	Input-Excess				Output-Shortfall	Reference-set
	z	$s(i_1)$	$s(i_2)$	$s(i_3)$	$s(i_4)$	$t(O_1)$	
DMU01	0.76	0.00	45.83	0.00	0.00	0.00	DMU23 DMU24 DMU52
DMU02	0.74	0.00	37.07	0.00	0.00	0.00	DMU23DMU24 DMU52
DMU03	0.82	0.00	0.01	189.48	0.00	0.00	DMU23DMU24
DMU04	0.83	0.00	12.53	246.93	2.12	0.00	DMU23
DMU05	0.82	0.00	6.81	0.00	0.00	0.00	DMU24DMU35 DMU50
DMU06	0.84	0.00	0.00	0.00	0.00	0.00	DMU23DMU24 DMU52
DMU07	0.84	0.00	25.91	141.26	0.00	0.00	DMU24 DMU35
DMU08	0.83	0.00	1.77	190.98	0.00	0.00	DMU24 DMU35
DMU09	0.76	0.00	20.77	120.04	0.00	0.00	DMU24 DMU35
DMU10	0.78	0.00	27.41	143.63	0.00	0.00	DMU24 DMU35
DMU11	0.83	0.00	3.10	0.00	0.00	0.00	DMU23 DMU24 DMU52
DMU12	0.82	0.00	8.04	0.00	0.00	0.00	DMU24 DMU35 DMU50
DMU13	0.50	0.00	9.26	0.00	0.00	0.00	DMU24 DMU35 DMU50
DMU14	0.29	0.00	6.72	0.00	0.00	0.00	DMU24 DMU35 DMU50
DMU15	0.85	0.00	22.54	0.00	0.00	0.00	DMU33 DMU52
DMU16	0.24	0.00	4.09	0.00	0.00	0.00	DMU33 DMU52
DMU17	0.58	0.00	0.75	67.32	0.00	0.00	DMU24 DMU35
DMU18	0.60	0.00	0.00	61.79	0.00	0.00	DMU23 DMU24
DMU19	0.78	0.00	7.66	0.00	0.00	0.00	DMU23 DMU24 DMU52
DMU20	0.76	0.00	15.98	0.00	0.00	0.00	DMU24 DMU35 DMU50
DMU21	0.87	0.00	10.54	0.00	0.00	0.00	DMU23 DMU33 DMU52
DMU22	0.92	0.01	0.00	0.00	1.52	0.00	DMU23 DMU34
DMU23	1.00	0.00	0.00	0.00	0.00	0.00	DMU23
DMU24	1.00	0.00	0.00	0.00	0.00	0.00	DMU24
DMU25	0.93	0.00	0.00	63.23	0.00	0.00	DMU23 DMU24
DMU26	0.93	0.00	0.00	73.33	0.00	0.00	DMU23 DMU24
DMU27	0.87	0.00	14.93	0.00	0.00	0.00	DMU23 DMU33 DMU52
DMU28	0.83	0.00	10.81	0.00	0.00	0.00	DMU23 DMU33 DMU52
DMU29	0.83	0.00	10.73	0.00	0.00	0.00	DMU23 DMU33 DMU52
DMU30	0.89	0.00	14.56	0.00	0.00	0.00	DMU23 DMU33 DMU52
DMU31	0.88	0.00	4.81	0.00	0.00	0.00	DMU24 DMU35 DMU50

DMU No.	Efficiency	Input-Excess				Output-Shortfall	Reference-set
	z	$s(i_1)$	$s(i_2)$	$s(i_3)$	$s(i_4)$	$t(O_1)$	
DMU32	0.78	0.00	8.54	0.00	0.00	0.00	DMU24 DMU35 DMU50
DMU33	1.00	0.00	0.00	0.00	0.00	0.00	DMU33
DMU34	1.00	0.00	0.00	0.00	0.00	0.00	DMU34
DMU35	1.00	0.00	0.00	0.00	0.00	0.00	DMU35
DMU36	0.99	0.00	0.00	2.97	0.00	0.00	DMU35
DMU37	0.94	1.77	0.00	0.00	0.00	0.00	DMU49 DMU52
DMU38	0.20	0.29	0.00	0.00	0.00	0.00	DMU49 DMU52
DMU39	0.10	0.00	0.00	4.35	0.00	0.00	DMU35
DMU40	0.12	0.00	0.00	4.74	0.00	0.00	DMU35
DMU41	0.49	0.00	0.01	0.00	0.00	0.00	DMU49 DMU50
DMU42	0.54	0.00	0.01	0.00	0.00	0.00	DMU49 DMU52
DMU43	0.86	3.30	0.00	0.00	0.00	0.00	DMU49 DMU52
DMU44	0.80	6.27	0.00	0.00	0.00	0.00	DMU49 DMU50
DMU45	0.42	0.00	0.00	0.00	0.00	0.00	DMU49 DMU50
DMU46	0.10	0.00	0.00	0.00	0.00	0.00	DMU35 DMU50
DMU47	0.31	0.00	0.00	0.00	0.00	0.00	DMU35 DMU50
DMU48	0.05	0.00	0.00	0.00	0.00	0.00	DMU35 DMU50
DMU49	1.00	0.00	0.00	0.00	0.00	0.00	DMU49
DMU50	1.00	0.00	0.00	0.00	0.00	0.00	DMU50
DMU51	0.47	0.00	0.00	0.00	0.00	0.00	DMU49 DMU50
DMU52	1.00	0.00	0.00	0.00	0.00	0.00	DMU52

Source: The research findings

Appendix 2. Projection Points

DMU No.	Inputs				Output
	$s(i_1)$	$s(i_2)$	$s(i_3)$	$s(i_4)$	$y(o_1)$
DMU01	1651.98	201.97	472.23	117.67	14866.00
DMU02	1605.07	203.69	512.20	111.25	14406.00
DMU03	1382.71	207.40	551.82	134.27	16752.00
DMU04	1397.95	209.69	547.22	140.43	17345.00
DMU05	1275.04	178.72	516.55	99.13	12994.00
DMU06	1309.52	189.61	525.47	107.40	13929.00
DMU07	3780.79	541.21	1662.69	303.66	39888.00
DMU08	3795.67	567.58	1613.22	325.77	42221.00
DMU09	1691.00	232.88	764.87	127.90	17016.00
DMU10	1725.59	231.43	794.88	125.15	16806.00
DMU11	1263.13	186.36	504.12	114.22	14470.00
DMU12	1244.09	178.57	511.30	100.34	13092.00
DMU13	122.68	9.15	32.61	2.60	449.00
DMU14	73.03	4.23	17.43	0.50	148.00
DMU15	289.35	20.86	0.00	4.95	514.00
DMU16	42.13	2.23	0.00	0.10	30.00

DMU No.	Inputs				Output
	s(i$_1$)	**s(i$_2$)**	**s(i$_3$)**	**s(i$_4$)**	**y(o$_1$)**
DMU17	348.35	51.50	149.42	29.39	3822.00
DMU18	362.67	54.40	148.79	33.44	4239.00
DMU19	872.24	123.18	330.19	71.73	9198.00
DMU20	777.28	100.60	320.04	53.24	7141.00
DMU21	1508.34	215.71	492.19	137.60	16548.00
DMU22	1626.33	243.95	537.80	158.09	18615.00
DMU23	825.15	123.77	323.00	82.89	10238.00
DMU24	837.36	125.60	355.00	72.20	9349.00
DMU25	799.90	119.98	333.10	71.61	9161.00
DMU26	802.42	120.36	330.50	73.43	9329.00
DMU27	1213.47	167.09	416.34	106.89	13282.00
DMU28	1153.44	162.20	391.59	103.98	12746.00
DMU29	1226.82	173.29	293.86	104.02	11627.00
DMU30	1307.67	181.60	257.09	105.17	11317.00
DMU31	434.57	60.37	187.57	33.32	4403.00
DMU32	388.50	49.73	160.09	26.13	3517.00
DMU33	89.31	13.40	0.00	6.93	546.00
DMU34	88.52	13.28	0.00	7.04	550.00
DMU35	88.56	4.43	58.00	0.00	194.00
DMU36	87.65	4.38	57.40	0.00	192.00
DMU37	2233.36	111.75	50.66	0.00	1426.00
DMU38	369.37	18.48	6.63	0.00	229.00
DMU39	4.11	0.21	2.69	0.00	9.00
DMU40	5.02	0.25	3.29	0.00	11.00
DMU41	331.15	16.55	50.12	0.00	356.00
DMU42	364.96	18.24	67.15	0.00	419.00
DMU43	13032.97	651.82	663.61	0.00	9761.00
DMU44	12181.75	609.40	440.17	0.00	8419.00
DMU45	102.67	5.13	9.76	0.00	94.00
DMU46	24.80	1.24	2.46	0.00	23.00
DMU47	21.49	1.07	5.91	0.00	29.00
DMU48	3.18	0.16	1.20	0.00	5.00
DMU49	190.08	9.50	17.00	0.00	171.00
DMU50	190.08	9.50	29.00	0.00	205.00
DMU51	16.10	0.80	2.33	0.00	17.00
DMU52	34.56	1.73	0.00	0.00	19.00

Source: The research findings