International Journal of Applied Operational Research
Vol. 11, No. 4, pp. 91-102, Autumn 2023

Journal homepage: ijorlu.liau.ac.ir

Congestion estimation of selected Iranian electricity generation firms using data envelopment analysis

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Received: 4 May 2023 ; **Accepted:** 2 September 2023

Abstract Since the beginning of the industrial renaissance and the advent of the machine age, the focus and planning of enterprises has been to maximize production. The key and leading model of societies from that time to the present day, manufacturing companies has always been the maximum use of resource minimization that means increasing productivity and efficiency and this will not be achieved unless this end is to improve productivity in the production chain. In energy-producing enterprises, including electricity fixed basic resources such as fuel consumption and labor are used in production, therefore to evaluate the performance of power generation companies, two important factors can be examined. In this study, by presenting a model based on data envelopment analysis the efficiency and congestion of fuel resources and labor force in selected power generation companies in Iran have been investigated. The results show that 15 companies under evaluation during the years 2005-2019 have the highest average total congestion attached to Bakhtar company at 52% and also Yazd and Kerman electricity companies on the frontier of efficiency without congestion. According to the studies, it was found that the congestion in the inputs in matter will cause inefficiency in the unit and deep erosion destruction in the production in restructure in long intervals.

Keyword: Optimization, Efficiency, Congestion, Data Envelopment Analysis; Input, Electricity Generation Company.

1 Introduction

The perspective of modern and developing societies in the world today is a special attention to energy as an important political, strategic, and in accordance with geopolitical situations and economic structure. One of the basic ways of success of countries is to increase the competitiveness of domestic industries with other countries in the region in terms of innovation, improvement of efficiency, and productivity of domestic production. the economic progress and prosperity of the countries can only depend on the use of productive

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[DOI: 10.71885/ijorlu-2023-1-645]

and cheap energy, including electricity, as one of the most important production inputs [1]. The electricity industry is the most important factor in the development of industries with other manufacturing and transformation industries and has a very important strategic role in promoting the economic and industrial goals of a country. Most of Iran's power plants are thermal or combined cycle, and due to the fuel consumption, geographical location, easy access to the energy carrier, and the very low cost of extracting electricity production, it is economical [2]. Since these resources are limited, efficiency in using these resources is an inevitable necessity. Therefore, in the development programs of the country, the governments try to free the price of energy carriers and remove the related subsidies on their agenda, which increases the cost of products and services. For this purpose, the managers and policymakers of all levels of the country's industries are seeking to find a way towards efficiency in using as much energy as possible. In the previous studies, several data envelopment analysis (DEA) researchers (e.g., [3]) have paid attention to the issue of congestion. The managerial issue is defined as evidence of congestion is present when reductions in one or more inputs can be associated with increases in one or more outputs, or proceeding in reverse when increases in one or more inputs can be associated with decreases in one or more outputs, without worsening any other input or output [4]. Congestion is a type of inefficiency and it is said that an increase in one or more inputs causes a decrease in one or more outputs on the contrary, a decrease in one or more inputs causes an increase in one or more outputs without changing other outputs or inputs. Since the input is relatively cost-related and usually a decrease in the input leads to a decrease in the costs.

According to the definition of congestion, a decrease in dense input causes a increase in output or production. Congestion is one of the important and practical topics in DEA and optimization models [5]. In this research, we will try to use the DEA method to determine whether it is possible to optimize the congestion with the current capacity and energy inputs available to the electricity distribution companies and the power grid of the regions to higher production. Therefore, to answer these questions, we must first examine the current situation of Iran's electricity companies from the point of view of congestion and the importance and applicability of the congestion model in selected energy sectors should be shown to experts and manager production.

Pourkazmi [6] evaluated the country's electricity production thermal power plants using the DEA method. The results show that the average efficiency of thermal power plants in the country under the assumption of variable efficiency is 78%, in other words, with the same current situation and with optimal use of the facilities, in the first case, it is possible to produce 36% and in the second case, 23% improve electricity in the country. Emami Meibodi [7] measuring the negative efficiency and productivity in heating and gas power plants and the combined cycle, measuring the technical efficiency of power plants in one year and productivity during some years has paid for 26 active thermal power plants in Iran. The results show that the average technical efficiency of power plants under the assumption of constant and variable efficiency during the years under review was on average equal to 1.5% and scale inefficiency has the greatest impact on technical inefficiency. Qadri [8] evaluated the performance of electricity distribution companies. In this article, 26 selected electricity distribution companies in Iran are evaluated using DEA. According to the results, most of the studied electricity distribution companies have an acceptable performance. Hosni [9] in an article on measuring productivity changes in electricity production management companies using data envelopment analysis and the Malmquist index to evaluate the changes in the total productivity factor in electricity management companies during some years. The results of the evaluation indicate that it has grown at an average rate of 1.023 during the years in question.

[DOI: 10.71885/ijorlu-2023-1-645]

The average change of scale efficiency in the industry is less than 1 indicating that if there is a decline in operational efficiency, it is due to scale inefficiency. Sueyoshi [10] discusses the congestion measurement in DEA by examining the dual formulas related to density in DEA and by introducing the concepts of that economy, the economy of production. As a result, it proposes a method that can be used to investigate the inefficiency that often arises due to congestion in large process industries such as the electricity industry. Wang [11] investigated the environmental efficiency and minimization efficiency measurement of China's thermal power industry. It has used a DEA-based approach to evaluate environmental efficiency and reduce costs in China's thermal power industry that is presented based on the results of new scales of efficiency that help to identify the potential of reducing the pollution of power plants. Abbott [12] examined productivity and efficiency in the Australian electricity industry. The article has analyzed the changes that have occurred in the last 30 years in the Australian electricity industry using the data coverage analysis approach and the Malmquist index during the years 1969-1999. The results show that a significant improvement in the industry started in the mid-1980s, this improvement was more at the beginning of 1990 and until the end of 1999. Waninsky [13] estimated the efficiency of electricity generation in the United States for the years 1991-2004 using data envelopment analysis. The results show that the relative stability in productivity from 1994-2004 at the levels of 0.99-100 is associated with a sharp decrease to the level of 0.95 in the following years. This research predicts that the efficiency for 2010 is equal to 0.80-0.98, which means that the efficiency will decrease more than in the early years.

In the current research, we analyze the performance of the selected energy generation firms in Iran and then we investigate the potential congestion that may exist in those firms. The primary results reveal the congested firm during the study period. Section 2 provides the basic DEA model and section 3 provides the congestion model used in the study. Section 4 performs the case study and section 5 analyzes and interprets the data and results. Section 6 is the conclusion and section 7 provides future research lines.

2 Methodology

There are different definitions of productivity and efficiency in books and research, which are considered from different points of view, but all the teachings state that productivity means the waste of resources and the maximum amount of efficiency from the available resources. The energy sector also enjoys a position in developed societies due to its scope and strategic nature in parent and leading industries. For this purpose, in the electricity industry as a strategic sector of energy, with the increase in the price of fuel materials and its penetration coefficient in other production-consumption and conversion industries, it is an important pillar of countries. So attention to production and productivity chain in this industry has become necessary. One of the new methods of optimization in production factors is the use of the concept of congestion. Congestion is important because it causes inefficiency in the unit under evaluation. The ability to identify and try to eliminate and reduce it leads to more favorable economic efficiency and productivity in the production process. This study is defined based on the DEA method and in non-parametric mode, and to eliminate and reduce the congestion factor and using its control management, productivity in the industry can be increased.

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2.1 DEA

Before 1978, a lot of research had been done to calculate the efficiency of decision making units (DMUs) of a system. Although these methods were good for some special situations, the existence of some problems made their use in the general situation impossible. Farrell was one of the researchers who tried to answer these problems by introducing a production function, but he could not develop his method for the multi-output mode. He introduced the efficiency measure, which later became known as Farrell's efficiency measure. Envelopment analysis of data was expressed by the idea of Farrell [14] in connection with the calculation of efficiency through the production function, which after 20 years of outstanding work by Farrell, Charnes, Cooper and Rhoades, based on the previous work, developed a creative method which was known as the CCR (Charnes, Cooper, Rhodes) model for calculating the relative efficiency of decision-making units.

This model was the basis of a new in operations research (OR) called DEA. Although DEA models have expanded day by day and have become specialized, the basis of all of them can be considered several main models that were designed and explained by the founders of this method, including It is possible to refer to models BCC, CCR, SBM, etc.

DEA also creates many opportunities for collaboration between analysts and data managers. This relationship can be in line with the selection of the input and output of the units under evaluation and how they function and model in relation to the borderline efficiency. In another way, DEA is based on a series of optimizations using linear programming, which is also called non-parametric method. The use of the DEA model for the relative evaluation of the units requires two basic characteristics, the nature of the model and the efficiency to the scale of the model, each of which is explained below.

2.2 Return to the scale of the desired pattern

Return to scale refers to the relationship between the changes in inputs and outputs of a production system. One of the capabilities of the DEA method is the application of different patterns to returns to different scales, as well as the measurement of returns to scale with the scale of units.

Constant Returns to Scale (CRS):

CRS means that every multiple of inputs is the same multiple of outputs of a system. One of the abilities of the DEA method is the application of different models to the efficiency at different scales and also measuring the efficiency at the scale of units.

Variable return to scale (VRS):

VRS is multiple of the inputs can produce the same multiple in the outputs or less or more than that in the outputs, the BCC model assumes variable returns to scale.

3 Congestion in data envelopment analysis

The term congestion or compression in the mathematical programming model occurs when a decrease in one or more inputs causes an increase in one or more outputs or on the contrary. Than congestion occurs when an increase in one or more inputs causes a decrease in one or more outputs or improving other units. Congestion is basically a type of inefficiency, but this inefficiency is different from the concept of technical inefficiency that is already known because technical inefficiency occurs when it is possible to improve some inputs or outputs without other inputs or outputs, but there is a concentration in inputs along with an improvement in at least one of the outputs.

[DOI: 10.71885/ijorlu-2023-1-645]

3.1 Congestion measurement in DEA

Assuming that we have n decision-making units (DMUs) under evaluation, each unit under evaluation includes m inputs is X_{ij} $i = 1, \dots, m, j = 1,2, \dots, n$ which during the production unit process turns into S output is Y_{rj}: $r = 1, \dots, s, j = 1,2, \dots, n$.
In this research, we intend to check the congestion in the inputs, therefore; we use the input-oriented congestion model:
We measure the input congestion for DMU_k in the following two radial models:

$$\begin{aligned} & Min\, \theta \\ & s.t. \\ & -\sum_{j=1}^{n} x_{ij}\, \lambda_J + x_{ik}\theta \geq 0 \\ & \sum_{J=1}^{n} y_{rj}\lambda_j \geq \ y_{rk} \\ & \sum_{j=1}^{n} \lambda_j = 1 \\ & \theta: urs \quad and \quad \lambda_j \geq 0\,, j = 1, \dots, n. \end{aligned} \tag{1}$$

Congestion model:

$$\begin{aligned} & Min\, \beta \\ & s.t. \\ & -\sum_{j=1}^{n} x_{ij}\lambda_j + x_{ik}\beta = 0 \\ & \sum_{j=1}^{n} y_{ri}\lambda_j \geq y_{rk} \\ & \sum_{j=1}^{n} \lambda_j = 1 \\ & \beta = URS \quad and \quad \lambda_j \geq 0\,, j = 1, \dots., n \end{aligned} \tag{2}$$

The variables (β, θ) respectively represent the efficiency level of DEA in two different production conditions and are free in sign, in other words, they can take any positive or negative sign.

To find out whether there is congestion in the unit under evaluation or not, the optimal value of model (3) is θ* and the optimal value of model (4) is β* we consider, since (*) is the optimization symbol, therefore the input congestion (IC) is measured as follows:

$$IC(\theta^*, \beta^*) = {\theta^*}/{\beta^*}$$

1) $IC(\theta^*, \beta^*) < 1$ Occurs in the unit under congestion assessment

2) $IC(\theta^*, \beta^*) = 1$ Congestion does not occur in the unit under evaluation

The following model is used to obtain resources and congestion values:

$$
\begin{aligned}
& Min\ \alpha \\
& s.t. \\
& -\sum_{j=1}^{n} x_{ij}\,\lambda_j + x_{ik}\,\alpha = 0 \qquad (I \in A) \\
& -\sum_{j=1}^{n} x_{ij}\,\lambda_j + x_{ik}\,\alpha \geq 0 \qquad (I \in \bar{A}) \\
& \sum_{j=1}^{n} y_{rj}\,\lambda_j \geq y_{rk} \qquad (r = 1, \ldots, s) \\
& \sum_{j=1}^{n} \lambda_j = 1 \\
& \alpha: URS \quad and \quad \lambda_j \geq 0, j = 1, \ldots, n.
\end{aligned} \tag{3}
$$

Here $A \subseteq \{1, \ldots, m\}$ and $\bar{A}$ is the complementary set of A.

Since congestion does not happen in all inputs, we have two categories of inputs, inputs that have congestion and inputs that do not. Therefore, we set the entries that have congestion equal to zero

4 Case studies: Congestion in electricity production companies

Condensation is a type of inefficiency that may occur during the production process; so that the increase of at least one input causes a decrease in at least one output. Because congestion also shows a kind of inefficiency; so, it is possible to improve efficiency in congestion units by identifying congestion. In this research, to prove this issue, 3 inputs and 2 outputs, which have the most effective effect on the production process of the electricity industry, have been investigated.

Input variables:

1- Internal consumption of produced electricity

2- Feed consumed by power net units

3- Human resources

Output variables:

1- Non special production

2-Special production

-Internal consumption of produced electricity (consumed energy): The amount of electrical energy that is consumed by the auxiliary and equipment of a unit for its direction (either in working mode or in stop mode) during a certain period is called the internal consumption of the unit.

- Consumable feed of power net units (consumable feed): The feed-in sub-categories of the energy network are actually hydrocarbon fuels, including diesel, gas, fuel oil, fuel oil, etc.

- Human resources: The number of employees working in the electricity production network.

-- Non special production company: the total energy production of a company's electricity generators, which is measured in kilowatt-hours or megawatt-hours at the output terminal of the generators during a certain period (for example, one year)

-- Special production of the company: special energy production means the production of non-special electric energy minus the internal consumption of companies in a certain period and is calculated in terms of kilowatt hours or megawatt (MW) hours.

Now according to 3 inputs and 2 outputs and their related data which have been collected for 12 consecutive years with the cooperation of IGMC power net management and Tavanir company and after applying the IC formula on the findings [15,16]. The model patterns (3)

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and (4) check the congestion of each of the inputs, if any, for the decision-making unit under evaluation and we calculate it year by year during the period 2015-2018, and then at the end of the results obtained It will be discussed.

5 Data analysis and interpretation

Table 1 Congestion in the selected electricity production company during the years 2005-2019.

2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	year / state
*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	Azerbaijan
*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	Esfahan
*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	Bakhtar
*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	Sistan and Baluchistan
		*		*				*	*	*	*				Khuzestan
		*	*			*	*	*	*	*	*	*	*	*	Khorasan
*	*		*	*	*	*	*	*	*		*		*	*	Tehran
		*	*	*	*				*	*		*	*	*	Kish
															Yazd
*	*		*	*	*	*	*	*	*	*	*			*	Hormozgan
			*	*	*	*	*	*		*				*	Mazandaran
*		*	*	*	*	*	*	*	*	*	*	*		*	Gilan
															Kerman
									*						Fars
		*		*	*	*		*	*	*	*	*	*	*	West

Source: Research results

Based on the early review of the models used in the research among the 15 selected electricity companies in 2005-2019, the ranking of the congestion and loss of energy carriers in many years for 4 companies in Azerbaijan, Isfahan, Bakhtar, West and Balochistan continues to increase and at other levels, some other companies, including Khorasan, Tehran, West, Kish and Gilan, are in an bad situation in the production process. The production and consumption of this sector of the industry will face serious problems in the 10-year perspective.

In contrast to the undesirable companies mentioned in the research, 3 power plants of Yazd, Kerman and Fars have the highest level of production efficiency in the life cycle of the power net.

[DOI: 10.71885/ijorlu-2023-1-645]

Table 2 Congestion percentage in the selected electricity production company during the years 2005-2019

2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	year / state
0.29	0.43	0.54	0.33	0.13	0.32	0.45	0.62	0.36	0.61	0.43	0.41	0.63	0.23	0.22	Azerbaijan
0.28	0.21	0.13	0.11	0.62	0.14	0.18	0.71	0.18	0.29	0.26	0.32	0.29	0.25	0.18	Esfahan
0.39	0.42	0.59	0.55	0.16	0.49	0.45	0.57	0.40	0.64	0.57	0.58	0.67	0.56	0.74	Bakhtar
0.17	0.52	0.11	0.29	0.11	0.24	0.32	0.41	0.28	0.39	0.25	0.19	0.48	0.18	0.14	Sistan and Baluchistan
0	0	0.15	0	0.26	0	0	0	0.64	0.89	0.54	0.37	0	0	0	Khuzestan
0	0	0.21	0.16	0	0	0.29	0.70	0.17	0.29	0.27	0.25	0.94	0.16	0.35	Khorasan
0.61	0.53	0	0.42	0.13	0.48	0.45	0.75	0.40	0.82	0	0.77	0	0.76	0.85	Tehran
0	0	0.75	0.84	0.15	0.23	0	0	0	0.27	0.35	0	0.34	0.14	0.10	Kish
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Yazd
0.56	0.76	0	0.63	0.53	0.62	0.52	0.59	0.34	0.70	0.61	0.92	0	0	0.79	Hormozgan
0	0	0	0	0.16	0.62	0.49	0.63	0.40	0	0.44	0	0	0	0.27	Mazandaran
0.48	0	0.31	0.34	0.13	0.31	0.45	0.71	0.43	0.83	0.65	0.78	0.20	0	0.73	Gilan
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Kerman
0	0	0	0	0	0	0	0	0	0.37	0	0	0	0	0	Fars
0	0	0.11	0	0.15	0.39	0.41	0	0.37	0.52	0.41	0.26	0.62	0.21	0.19	West

Source: Research results

Table 3 The amount of congestion in the selected Iranian electricity production company during the years 2005-2019

2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	year / State
351.1	1696.2	1490.5	367.6	154.7	400.6	552.6	2626.9	1490.4	2487.6	1690.8	1584.7	1691.6	660.6	529.5	Azerbaijan
2910.2	1990.5	569.8	456.3	2511	577.8	688.5	7553.7	1780.2	3120.6	2643.4	3356.1	2866.3	2408.5	1660.5	Esfahan
1120.9	1203	1980.5	909.4	454.4	1273.5	1246.5	1591.4	1270.8	2182.4	1880.7	1936.6	2286.0	1715.3	2447.2	Bakhtar
170.9	623.7	158.0	403.4	143.7	262.3	269.1	569.1	378	575.3	312	191.0	259.4	183.8	119.1	Sistan and Baluchistan
-	-	705.2	-	844.7	-	-	-	2378.8	2987.7	1612	1135.2	-	-	-	Khuzestan
-	-	2201	663.7	-	-	1109.3	7447.3	1681.3	3120.7	2745.1	2622	9291.0	1541.4	3228.8	Khorasan
6013.2	2598.3	-	1742.2	526.5	1981.0	1721.3	7979.3	3956	8824.1	-	1075.8	-	7321.9	7841	Tehran
-	-	197	229.3	39.8	56.8	-	-	-	94.5	58.8	-	117.6	24.6	17.0	Kish
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Yazd
2101.7	2392.3	-	2707.1	2235.1	2315.7	1693.6	1991.3	1149.9	2263.1	2084.4	3362.6	-	-	2459.3	Hormozgan
-	-	-	-	474.1	1856.3	1313.2	1842.8	1312	-	1586.2	-	-	-	882.6	Mazandaran
267.9	-	191.1	150.6	61.8	187.9	253.6	1599.6	91.6	1814.4	۱٤۳۳.۹	1833	423.4	-	1521.3	Gilan
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Kerman
-	-	-	-	-	-	-	-	-	3484.7	-	-	-	-	-	Fars
-	-	143.4	-	150.5	356.1	758.1	-	909.8	976.1	796.6	450.1	1024.2	355.8	217.2	West

Source: Research results

[DOI: 10.71885/ijorlu-2023-1-645]

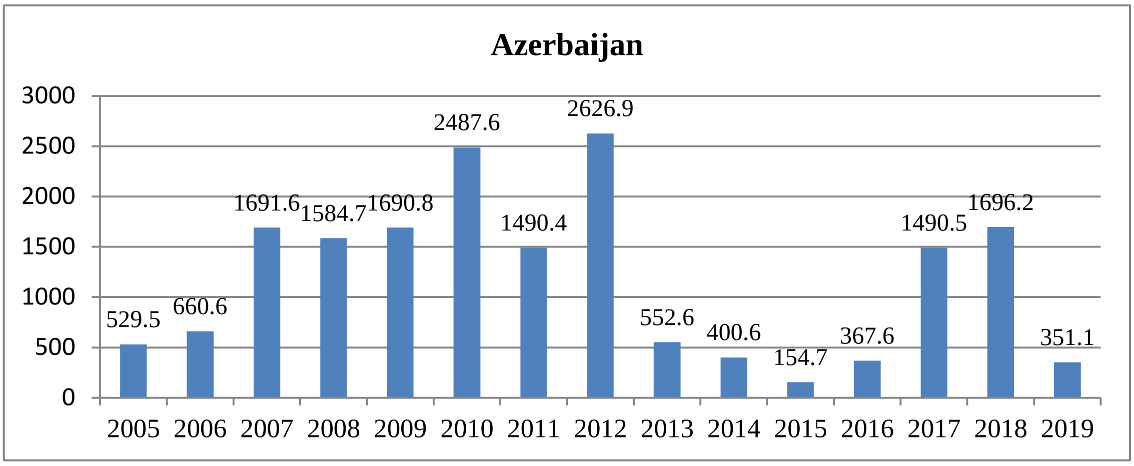

Figure 1 Amount of congestion changes in the Azerbaijan Electricity Production Company

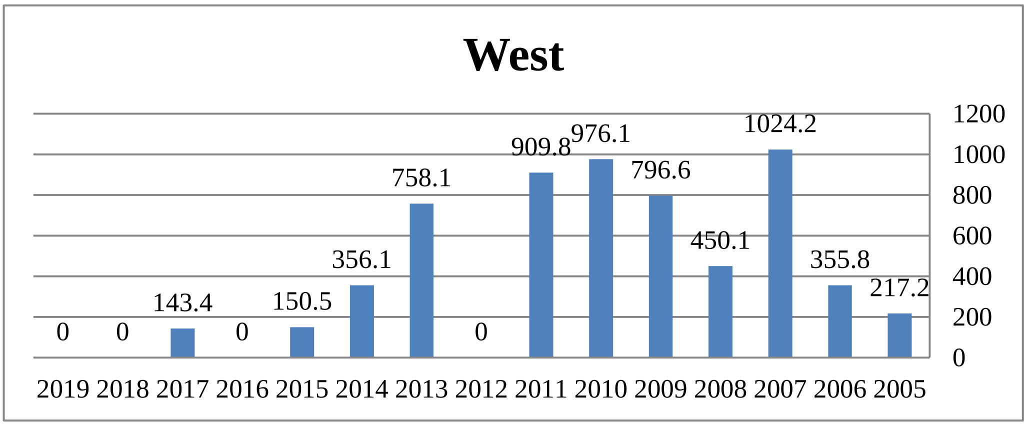

Figure 2 The amount of changes in congestion in West Electricity Production Company

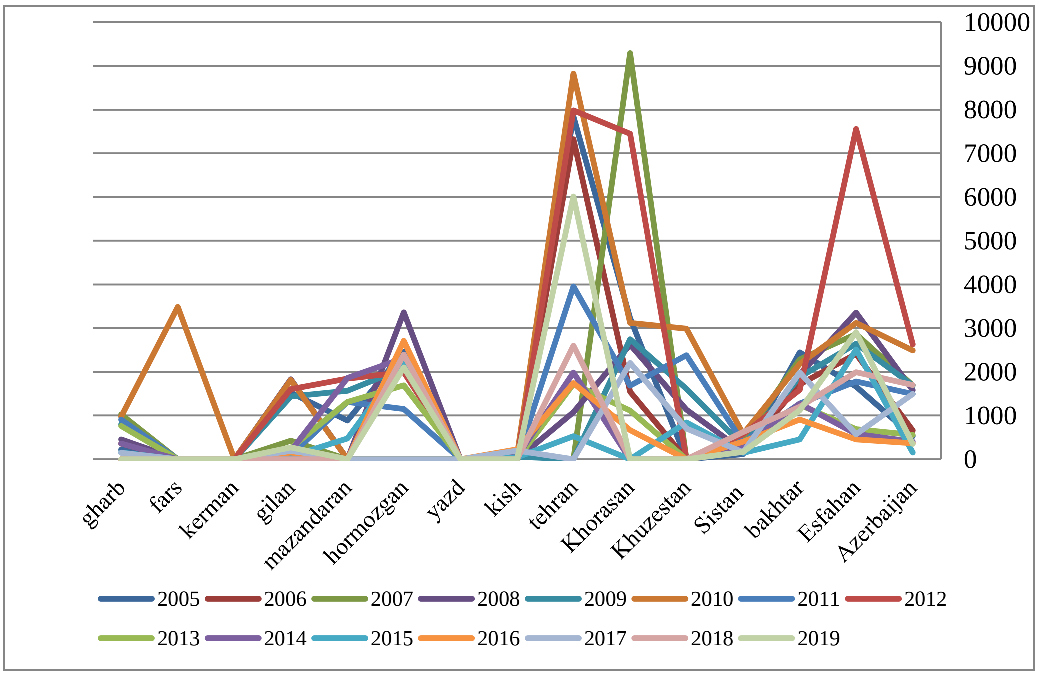

Figure 3 The amount of congestion in selected Iranian electricity production plants

[DOI: 10.71885/ijorlu-2023-1-645]

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Figure 3 can clearly be seen in the studied periods of congestion in regional power companies in different years. Based on the above figure, during the years 2008, 2010, and 2012, most of the regional electricity companies were heavily involved in the problem of congestion in their input units. In the meantime, due to reforms in the production units of the regional subgroup, the Fars electricity company faces a jump in the density of the input grid compared to similar periods, but as a result of the structural reforms in the following years, this amount tends to a significant level of the efficiency limit. The data of this research has been collected and classified from the statistics center of the Ministry of Energy and the Iran Electricity Network Management Company (IGMC). In order to use the presented model, using LINGO 16.1 software and Microsoft Office Excel, the units with relative inefficiency have been identified and their congestion values have been calculated.

Figures 1 and 2 above in the research respectively show the amount of changes in congestion in Azerbaijan and West electricity production companies.

The values presented from the mentioned research model mean the production loss in the considered sectors, which shows significant and non-negligible values from the point of view of the optimization levels of the energy industries sector. According to the examination of the results in Table 2, the average percentage of congestion in electricity production companies during the years in question is in (descending) order:

Bakhtar 0.52, Hormozgan 0.50, Tehran 0.46, Gilan 0.42, Azerbaijan 0.40, Isfahan 0.28,

West 0.24, Khorasan 0.25, Sistan and Baluchistan 0.27, Kish 0.21, Mazandaran 0.20, Khuzestan 0.19, Fars 0.02, Yazd 0.0, Kerman 0.0. As can be seen in the table, the companies of Yazd, Kerman, and Fars are at the best level of border efficiency and the companies of Azerbaijan, Isfahan, Bakhtar, Sistan, and Baluchistan are at the highest level of inefficiency of the congestion during all the production years. Since the congestion causes a decrease in the output by identifying the units under evaluation that have congestion at the desired inlets possible to eliminate or reduce it with less energy (fuel) by identifying the amount of congestion and getting the maximum amount of output.

Similarly, in the ranking of the number of years that the companies show the existence of congestion, the regional company of Bakhtar shows the existence of congestion by the amount of (0.52) with the most recorded year, and further, according to the presence of congestion in many years Azerbaijan companies with a rate of (0.40), Isfahan with a rate of (0.28) and West with a rate of (0.24) are ranked 5 and later, but the regional companies of Hormozgan (0.50), Tehran (0.46) and Gilan (0.42) despite the periodic and cross-sectional congestion of the degree of depth of congestion in production efficiency, which is a more serious warning to policy makers and decision makers in the reforms of infrastructural taste and key input sectors to power plants, including specialist and diversity It requires the consumption of units.

In this model, it has been studied by using logical mathematical relationships and conventional models in DEA using a suitable linear model suitable for the energy industry to determine the level of inefficiency in undesirable inputs which makes the investigations valid.

6 Conclusion

In the present research, the selected companies of Iran's regional electricity net have been evaluated using DEA. The main purpose of this paper is to investigate the presence of congestion in the input (fuel and energy) in 15 selected companies of Iran's regional electricity network by using the DEA method during the years 2005-2019.

According to the findings, 12 companies out of the 15 considered companies have congestion levels at the entrance, which causes a decrease in efficiency and productivity, in other words, the research is about surplus resources that can be ignored, and the existence of this additional amount of inputs is not necessary and their elimination or reduction in periodic conditions will usually be associated with increasing the efficiency of the units. Here too, as it has been found from the results, in different years, there is an input density for most of the units under investigation, which requires attention and correction of the network. The use of DEA models, in addition to determining the level of relative efficiency, determines the weak points of the companies in the target unit and by presenting the level of their inefficiency; it leads the company's policies towards improving productivity and efficiency. Therefore, managers and decision-makers of regional and intermediate electricity companies should carefully investigate the existence of congestion in their units and the necessary solutions to reduce the amount of congestion.

7 Suggestions for future research

As future research issues, we may change the DEA models from input orientation to output orientation, and then investigate the mathematical and economic properties of these dual formulas. Another application of the proposed congestion model is one of the important research topics. For example, we can examine the inefficiencies caused by congestion that often exist in large process industries, such as other sectors of the energy and environmental industries, including water and non-renewable energy. Such research is one of the important future research recommendations in all key sectors of energy and environment.

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