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Local and Global Energy Efficiency Analysis for Energy Production Based on Multi-Plant Generalized Production Technology

MOJTABA GHIYASI[1], BABAK DANESHVAR ROUYENDEGH[2,3], AND YAVUZ SELIM ÖZDEMIR[4]

[1]Faculty of Industrial Engineering and Management Science, Shahrood University of Technology, Shahrud 36147-73955, Iran
[2]Department of Industrial Engineering, Ankara Yıldırım Beyazıt University (AYBU), 06010 Ankara, Turkey
[3]Department of Mechanical and Industrial Engineering, College of Engineering, Sultan Qaboos University (SQU), Muscat 123, Oman
[4]Department of Industrial Engineering, Ankara Science University, 06200 Ankara, Turkey

Corresponding author: Yavuz Selim Özdemir (ysozdemir.phd@gmail.com)

ABSTRACT Power plants plays an important role in term of economic and social affect in all societies. Most of economic sectors and manufacturers are depended in the outcome of power plants in one side and electricity is a vital need of all households and entire society. Therefore, the performance of power plants and consequently their sustainability is crucial concept in the current century. This article proposes a generalized efficiency measurement model for multi-plant firms in terms of returns to scale and number of outputs. This yields to some new indicators for efficiency measurement in an un-communal and communal environment for the local and global analysis. The idea is explained by providing a graphical illustration and numerical example. Proposed models are used for energy efficiency analysis of 46 power plants of 19 provinces in Iran. Local and global aspect of energy efficiency are investigated by using proposed models for aforementioned case study. Primary results are shown that, higher potential energy saving in the communal global environment compared with the local analysis. This highlight the corporation of production electricity units, namely, power plants in this study is a requirement for sustainable energy supply.

INDEX TERMS Energy efficiency, local efficiency measurement, global efficiency measurement, sustainable energy supply, power plants.

I. INTRODUCTION

Data envelopment analysis (DEA) is a mathematical programming based approached for efficiency analysis of a group of decision-making units (DMUs) propose by Charnes et. al. [1] and its origin goes back to the work of Afriat [2] that dealt with the concept of efficiency analysis in an axiomatic manner. It has been used as a powerful and useful approach for the efficiency analysis and performance assessment of different sectors in the real world.

Flexibility of DEA model for considering different managerial and economic factors in one hand and its simplicity for solving on the other hand makes it as an attractive methodology for efficiency analysis. Its origin goes back to Farrell's paper [3] that dealt with estimation of production function for a single output case while DEA models have possibility of considering multiple output. Färe et. al. developed a linear programming model that is capable of analyzing the efficiency of multi plant firms in a DEA framework [4]. Their model is based on a production technology with decreasing returns to scale. After that, same authors extended their previous paper for the limited data [5]. They also used the multi-plant technology for efficiency analysis of multi units [6]. Kao proposed a short run and long run efficiency measures for multi-plant firms that are based on a production technology with decreasing returns to scale and constant returns to scale respectively [7].

The origin paper of multi-plant efficiency measurement is based on a technology with increasing returns to scale properties and it is not able to deal with other types of returns to scale cases. On the other hand, it considers a single output case. The current paper proposes a multi-plant firm modeling based on a generalized production technology capable of dealing with all types of returns to scale cases. As a matter of fact, proposed models in the current paper have variable returns to scale properties. This means that a production unit

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may operate in the deceasing, constant or increasing part of the production set. Moreover, it is extended for considering multiple output too.

Modern economies depend on the reliable and affordable delivery of electricity. Growing demand for electricity can be attributed to the economic structure, climate change, and technology structure.

One of these key strategies and practices is the use of identifying and measuring the efficiency and efficiency of existing executive levels, including refineries, power plants and maternal industries in different parts of the country [8].

In the primary discussions of math planning, efficiency is measured as the ratio of output to input. This implies an initial performance level that describes a system or process that uses the lowest inputs to produce the highest output [9]. Measuring system efficiency and productivity can be a powerful tool for identifying the best solutions, exercises and potential improvements in operational measures and strategies. Energy efficiency is highlighted with its potential to address a number of challenges faced by electricity services. These challenges include increased demand for electricity, reduced operational capacity and reduced system reliability and flexibility [10]. To overcome the system, productivity measurement is applied to the system's performance, so that it identifies sources of technical and operational resources or other influential factors.

DEA has widely usage for efficiency measurement. Efficiency and productivity of Danish biogas power plants measured with the DEA model during the year 1992-2005 [11]. Likewise, Pourkazemi et. al. used classical DEA models for efficiency analysis and ranking of Iranian power plants in country level [12]. Javaheri et. al. utilized classical DEA models for environmental efficiency of thermal and hydroelectric power Plants in Iranian provinces [13]. They found the average of technical efficiency for hydroelectric power plant in 2011 and 2010 are 62% and 53%, respectively and 82% and 77%, for thermal power plant in 2011 and 2010 respectively. Meibodi et. al. analysis the technical efficiency of 26 thermal power plants of Iran in period of 2003-2008 using DEA and Malmquist index [14]. They found average of 76.4 and 92.8 for efficiencies assuming constant and variable returns to scale for the analysis. Same author also investigated the technical and environmental efficiency of 16 selected thermal power plants of Iran during 2011-2015 using DEA [15]. In all national studies on efficiency analysis of Iranian power plants just of the country or province level is considered. In the current paper, we consider both country level and province level in process of efficiency analysis. In this paper, proposed models are utilized for the local and global efficiency analysis of 46 power plants of 19 provinces in Iran.

Section 2 proposes new generalized models for efficiency measurement of multi-plant firm. It continues by providing graphical and numerical example to illustrate proposed models and shows its novelty in comparison with existing models in the literature. Section 3 provides an application of proposed models for efficiency analysis of 46 power plants of 19 provinces in Iran, both in province level and country level.

II. LOCAL AND GLOBAL MULTI-PLANT EFFICIENCY MEASUREMENT

In this section we propose the underlying methodology of a production technology that is capable of assessing the performance of production unit in a local and global collaborative environment; the fact that is ignored in the classical efficiency analysis. Hereafter, the local production activity is called at the plant level and global production activity is called in the firm level.

In fact, the literature gap has a methodological framework for analyzing the local and global performance of production unit without any presumption on the returns to scale properties of the production technology. This aim is done by using proposed models in this section.

Consider that, a single firm that owns plants p_j, $(j \in J)$ and each plant uses m-dimensional input vector $x_j \in \tilde{+}^m$ for producing s-dimensional vector of $y_j \in \tilde{+}^s$.

The input-oriented efficiency of each plant, given the reference technology of T^L as free disposal convex hull of observations may be found by classical Farrell input efficiency measure of $\theta_o^L = \min\left\{\theta \mid (\theta x_o, y_o) \in T^P\right\}$

We can use the following linear programming (1) to find the above efficiency measure:

$$\begin{aligned} \theta_o^L = \; & Min\theta \\ & s.t. \sum\nolimits_{j\in J} \lambda_j x_j \le \theta x_o \\ & \sum\nolimits_{j\in J} \lambda_j y \ge y_o \\ & \sum\nolimits_{j\in J} \lambda_j = 1 \\ & \lambda_j \ge 0; \quad j \in J \end{aligned} \tag{1}$$

Assume n multi-plant firms $f_k, 1 \le k \le n$ that owns plants $p_j, 1 \le j \le |J_k|$, where J_k is the index set of kth firm and $|J_k| = card(J_k)$ is cardinal number of J_k, that is, the number of its plants. Each plant of arbitrary firm f_k consumes m-dimensional input vector $x_j^k \in \tilde{+}^m$ and produce s-dimensional vector of $y_j^k \in \tilde{+}^s$. To construct a reference technology for an arbitrary plant in its firm (f_k), we use the extended technology of Koopman [16] and proposed by Ghiyasi [17] which is denoted as SA (Semi-Additive Postulate). This technology for the classical Farrell input efficiency measure of $\theta_o^{CL} = \min\left\{\theta \mid (\theta x_o, y_o) \in T^f\right\}$. One may solve the following linear programming to find this measure:

$$\begin{aligned} \theta_o^{CL} = \; & Min\theta \\ & s.t. \sum\nolimits_{j\in J_k'} \lambda_j^k x_j^k \le \theta x_o^k \\ & \sum\nolimits_{j\in J_k'} \lambda_j^k y_j^k \ge y_o^k \\ & \sum\nolimits_{j\in J_k'} \lambda_j^k = 1 \\ & \lambda_j^k \ge 0; \quad j \in J_k' \end{aligned} \tag{2}$$

where J_k' is the extended index set of kth firm that includes all subset of J_k except empty set. The above model estimates the efficiency of under evaluation plant in the competitive environment in the operating firm. This unit has to compete not only with the existing operating plants in the firm but also other potential aggregated firm that can be performed communally.

The advantage of using SA contrasted with Koopman's technology is that the former technology does not impose any restriction on returns to scale of the technology. This technology considers variable returns to scale that can be decreasing, constant or increasing returns to scale for the production technology. In other words, it is generalized reference technology in terms of returns to scale. In other words, we SA production technology provides collaborative and of course more competitive environment (for rivals) compared with its classical peer, that is, the BBC model. This fact is mathematically shown and proved by the following proposition.

Proposition 1: The optimal value of the linear programming model (2) is less than or equal to the optimal value of the linear programming model (1), that is, $\theta_o^{CL} \leq \theta_o^{L}$.

Proof: The feasible region of model (2) is based on a production space constructed with original DMUs that shape the production space of model (1) plus all possible aggregated DMUs. Therefore, the feasible region of model (1) is a subset of feasible region of model (2). This implies that optimal value of model (2) is less than or equal to the optimal value of model (1) or $\theta_o^{CL} \leq \theta_o^{L}$ (Q.E.D.).

In order to have a global performance assessment we consider all production activities as a reference technology, that is, the free disposal convex hull of all reference technology that yields to the following (3) linear programming:

$$\begin{aligned} \theta_o^G = \ & Min\theta \\ & s.t. \ \sum_{k=1}^{n} \sum_{j\in J_k} \lambda_j^k x_j^k \leq \theta x_o^k \\ & \sum_{k=1}^{n} \sum_{j\in J_k} \lambda_j^k y_j^k \geq y_o^k \\ & \sum_{k=1}^{n} \sum_{j\in J_k} \lambda_j^k = 1 \\ & \lambda_j^k \geq 0; \quad 1 \leq k \leq n, \ j \in J_k \end{aligned} \tag{3}$$

In order to consider the collaborative environment in the global analysis we consider free disposal convex hull of collaborative technologies that yields to the following (4) linear programming:

$$\begin{aligned} \theta_o^{CG} = \ & Min\theta \\ & s.t. \ \sum_{k=1}^{n} \sum_{j\in J_k'} \lambda_j^k x_j^k \leq \theta x_o^k \\ & \sum_{k=1}^{n} \sum_{j\in J_k'} \lambda_j^k y_j^k \geq y_o^k \\ & \sum_{k=1}^{n} \sum_{j\in J_k'} \lambda_j^k = 1 \\ & \lambda_j^k \geq 0; \quad 1 \leq k \leq n, \ j \in J_k \end{aligned} \tag{4}$$

The model, which is given above, is based on free disposal hull of extended technology of all firms. In fact, the performance of an under-evaluation plant is measured in its competitive firm plus all other operating firms. This model provides more competitive environment compared with the model of (2). The under-evaluation plant faces more rivals in this model, a group of plants in its firm and other plants in other firms.

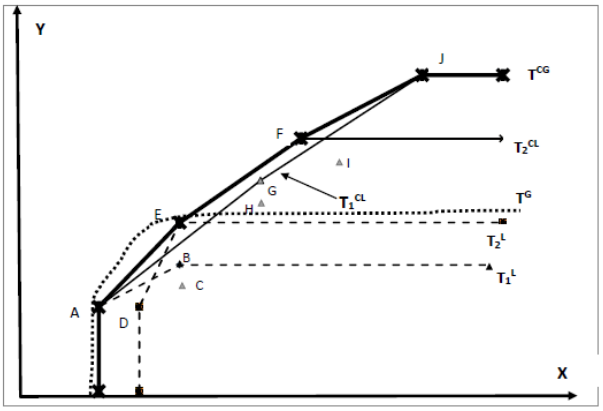

FIGURE 1. Single input-output illustration of proposed models.

In order to illustrate proposed models, assume two firms. The first firm owns three plants A, B and C and the second firm owns two plants D and E for the single input-output case. figure 1 illustrates the proposed models. Dashed lines T_1^L starts from X-axis and segment A-B and extends from B horizontally. Dashed lines T_2^L starts from X-axis and segment D-E and horizontally extends from B. Global frontier T^G starts from passes from A and E and continues from E horizontally. This production space is approximately shown by the rounded dote curve. Extended reference technology of T_1^{CL} is determined by the solid line and starts from X-axis and segment A-G-J and horizontally extends from J. Input-output bundle of G is sum of A and B, that is, G=A+B and J is sum of three bundle of A and B and C, that is, J=A+B+C. Another bundle, that are interior and are not on the frontier, are H and I. They are sum of A and C and sum of B and C respectively, namely, H=A+C, I=B+C. The extended reference technology of T_2^{CL} is determined by solid line made by D, E and F. In fact, it starts from X-axis and segment D-E-F and horizontally extends from F, where F is sum of D and E, that is, F=D+E. The free disposal convex hull of all bundles shapes the reference technology of all firms, that is, T^{CG}. Input-output bundles of A, E, F and J shapes this frontier that is the thick solid line.

Consider only the first firm and extended reference technologies in figure 2. The following efficiency indicators can be measured at different levels:

Local efficiency: $LE\ (x_oy_o) = x_o/x_1 = \theta_o^L$
Global efficiency: $GE\ (x_oy_o) = x_o/x_2 = \theta_o^G$
Communal local efficiency: $CLE\ (x_oy_o) = x_o/x_3 = \theta_o^{CL}$
Communal global efficiency: $CGE\ (x_oy_o) = x_o/x_4 = \theta_o^{CG}$
These indicators are illustrated in figure 2.

The first measure that is $PE = \theta_o^p$ is based on the dashed plant efficiency frontier of T_1^p. The second measure of θ_o^f is

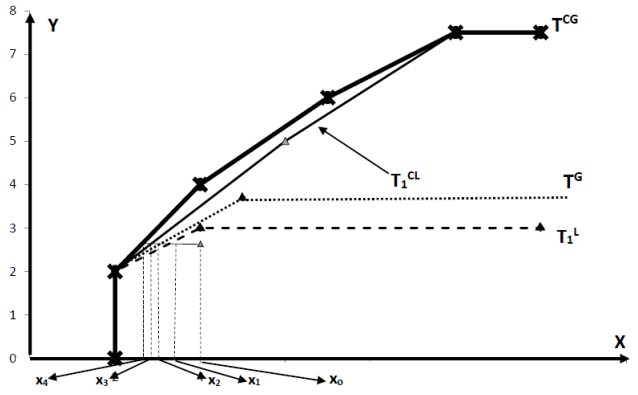

FIGURE 2. Multi-plant firms efficiency measures.

computed regarding to the firm efficiency frontier of T_1^f. The third measure of θ_o^{p-f} is computed based on the plant-firm efficiency frontier of T_1^{p-f}.

Proposition 2: The optimal value of the linear programming model (3) is less than or equal to the optimal value of the linear programming model (1), that is, $\theta_o^G \leq \theta_o^L$.

Proof: Regarding to the fact that the feasible region of linear programming model (3) is constructed based on free disposal convex hull of all firm's extended reference technology we can say that feasible region of model (3) is a subset of the feasible region of model (1). This guarantees a higher or equal optimal value for model (1), in contrasted with model (3). Therefore, we can conclude the optimal value of the linear programming model (3) is less than or equal to the optimal value of the linear programming model (1).

Proposition 3: The optimal value of the linear programming model (4) is less than or equal to the optimal value of the linear programming model (2), that is, $\theta_o^{CG} \leq \theta_o^{CL}$.

Proof: It is straightforward following the structure of proof of proposition 2. (Q.E.D.)

Remark: Considering proposition 1, proposition 2 and proposition 3, we conclude the following relationship between all proposed efficiency indicators (5).

$$\theta_o^{CG} \leq \theta_o^{CL} \leq \theta_o^{L}; \quad (Q.E.D) \tag{5}$$

This is a rational result since an arbitrary DMU has more rival in the competitive environment of its firm and even more in the whole industry that yields a lower or equal efficiency in the global and communal environment level. It is important fact is that the above remark does not guarantee any relationship between θ_o^{CL} and θ_o^{G}. This fact can also be seen in the following numerical example.

It is important to note that the technology of both model (1) and model (2) and consequently model (3) and model (4) are possible to consider all type of returns to scale cases, that are decreasing, constant, increasing and variable returns to scale. For more details of these properties for model (1) see chapter 4 of [18] and more details of aforementioned properties on model (2) can be seen on section 3.3 of [17]. Compared with the relevant existing models in the literature, that is, the multi plants models of [4], our models are generalized in terms of the returns to scale properties. As mentioned, any type of returns to scale properties are assumed in our models that deal with the decreasing, constant, increasing as variable returns to scale.

TABLE 1. Input-Output of numerical example.

	Firm A		Firm B			Firm C		
Plant	A1	A2	B1	B2	B3	C1	C2	C3
Input	2	4	1	2	2	2	4	5
Output	3	4	2	1,5	1	2	3	1

TABLE 2. Plant efficiency, Firm efficiency and plant-firm efficiency report.

DMUs	Local Efficiency	Global Efficiency	Communal Local Efficiency	Communal Global Efficiency
A1	1.0000	1.0000	1.0000	1.0000
A2	1.0000	1.0000	1.0000	0.7500
B1	1.0000	1.0000	1.0000	1.0000
B2	0.3750	0.5000	0.5000	0.5000
B3	0.2500	0.5000	0.5000	0.5000
C1	1.0000	0.5000	1.0000	0.5000
C2	1.0000	0.5000	0.8333	0.5000
C3	0.2000	0.2000	0.4000	0.1000

A. A NUMERICAL EXAMPLE

Assume a single input-output case of three firms with some plant as shown in Table 1. We estimate the local efficiency of LE, global efficiency of GE, communal local efficiency of CLE and communal global efficiency of CGE of all units using linear programming model (1), (2), (3) and (4) respectively. The result is reported in Table 2.

Observe, for instance the second plant of firm B, namely B2 that its efficiency decreases in each level. DMU C2 has the same situation as B2, but with different magnitudes. On the other hand, we see A1 that has a consistent efficiency in all levels like DMU B3. DMU A2 has a lower efficiency in the firm level in contrasted with plant level, but it is consistent in the plant-firm level.

In order to compare the primary result of proposed models with the models of (Färe & Primont, 1984), we run their model for this example and report the results in the table 3. The result of this report is based on the decreasing returns to scale assumption, since [4] is limited to this type of returns to scale. Therefore, we observe less values compared with peers in our model. It is also important to point out that we have one extra index, that is, global efficiency index compared with [4].

III. ENERGY EFFICIENCY AND PERFORMANCE MEASUREMENT OF IRANIAN POWER PLANTS

In this section, proposed approach for economic input-output performance assessment were applied for 46 power plants in 21 provinces. Provinces are assumed as plants in the local level and country is assumed as firm in the global level. Total assets and total energy consumption that include gas and

TABLE 3. Plant efficiency, Firm efficiency and plant-firm efficiency report.

DMUs	Plant Efficiency	Firm Efficiency	Communal Plant Efficiency	Communal Firm Efficiency
A1	1.0000	1.0000	1.0000	1.0000
A2	1.0000	1.0000	1.0000	1.0000
B1	1.0000	1.0000	1.0000	1.0000
B2	0.3750	0.3750	0.3750	0.3750
B3	0.2500	0.2500	0.2500	0.2500
C1	1.0000	0.5000	1.0000	1.0000
C2	1.0000	0.5000	0.8333	0.8333
C3	0.2000	0.1000	0.2000	0.2000

TABLE 4. Summary statistics of data.

Variable Type	Input	Input	Output
Variable name	Total assets	Total energy consumption	Electricity production
Mean	760,6957	4532730	754238,0
Standard error	508,7195	3267759	664627,8
Min	42,0000	133367	2622,3
Max	2043,0000	12885126	2936547,0

gasoline are assume as inputs and electricity production is assumed as output. Table 4 reports the descriptive static of the data. The local and global analysis is performed in the province and country level respectively.

Considering classical production technology in the local level analysis we find the result of energy efficiency reported in the second column of Table 5. There are only four inefficient power plants in the local efficiency analysis that show very low discrimination power of analysis. The same analysis is done in the classical environment for the whole country. The results are reported in the third column of the Table 5. This yields to higher discrimination power compared with local efficiency report. In both previous efficiency analysis the corporation between power plants are ignored. All power plants, especially those that are located in the same province, are jointly in charge of electricity supply of the region. Considering this fact in the process of efficiency analysis, the efficiency report is given in the fourth column of Table 5 in the province level. Compare the first local efficiency analysis with the later local efficiency analysis (column #2 and column #4 of Table 5).

This causes more discrimination power in the competitive efficiency analysis compared with the normal local efficiency analysis. The last column of Table 4 reports the global efficiency measures of power plants in the competitive environment. Compared with the normal global efficiency report, we get lower efficiency measures and find higher discrimination power in the global efficiency measures. The average of efficiency measure are 0.3776 and 0.44402 in the normal and competitive global efficiency analysis.

Considering the classical model of [4] we have three peer indicators in out paper, namely, local efficiency, communal local efficiency and communal global efficiency. We have one more indicator in our paper that was not dealt in [4].

TABLE 5. Efficiency analysis of 46 power plants.

Power Plants/ Efficiency	Local Efficiency Measure	Global Efficiency Measure	Communal Local Efficiency Measure	Communal Global Efficiency Measure
P1	1,000000	0.428265	1,000000	0.164503
P2	1,000000	0.066484	1,000000	0.123588
P3	0,959100	0.189447	0.954800	0.119400
P4	0,637100	0.508361	0.637100	0.064956
P5	1,000000	0.609391	1,000000	0.171216
P6	1,000000	0.929477	1,000000	0.377753
P7	0,931500	0.888721	0.857900	0.139789
P8	0,189400	1,000000	0.189400	0.004485
P9	1,000000	0.125217	1,000000	0.099566
P10	1,000000	0.276447	1,000000	1,000000
P11	1,000000	0.445640	1,000000	0.065265
P12	1,000000	0.407750	1,000000	0.225102
P13	1,000000	0.708202	1,000000	0.531885
P14	1,000000	1,000000	1,000000	0.045352
P15	1,000000	0.420035	1,000000	0.428167
P16	1,000000	1,000000	1,000000	0.009196
P17	1,000000	0.251227	0.908000	0.203271
P18	1,000000	0.145183	1,000000	0.031271
P19	1,000000	0.153444	1,000000	0.193484
P20	1,000000	0.416554	1,000000	0.272434
P21	1,000000	0.016177	1,000000	1,000000
P22	1,000000	0.313283	0.567000	0.171376
P23	1,000000	0.756325	1,000000	0.135023
P24	1,000000	0.674342	1,000000	0.099181
P25	1,000000	0.067775	0.961500	0.505110
P26	1,000000	0.065168	1,000000	1,000000
P27	1,000000	0.973944	1,000000	0.308166
P28	1,000000	1,000000	1,000000	0.505824
P29	1,000000	0.171908	1,000000	1,000000
P30	1,000000	1,000000	0.189300	0.177136
P31	1,000000	0.050748	1,000000	0.110367
P32	1,000000	0.112866	1,000000	1,000000
P33	1,000000	0.237254	1,000000	1,000000
P34	1,000000	0.289006	1,000000	0.653580
P35	1,000000	0.206935	1,000000	1,000000
P36	1,000000	0.233024	0.987700	0.366323
P37	1,000000	0.274281	0.921600	0.235705
P38	1,000000	0.207654	1,000000	0.839932
P39	1,000000	0.842279	0.800000	0.421080
P40	1,000000	0.627178	1,000000	0.592822
P41	1,000000	0.690393	1,000000	0.464133
P42	1,000000	0.339346	1,000000	0.770776
P43	1,000000	0.326224	1,000000	0.054523
P44	1,000000	0.338731	1,000000	0.281735
P45	1,000000	0.209689	1,000000	0.207574
P46	1,000000	0.430746	1,000000	0.202638

TABLE 6. Efficiency analysis of 46 power plants.

Power Plants/ Efficiency	Peer for Local Efficiency Measure	Peer for Communal Local Efficiency Measure	Peer for Communal Global Efficiency Measure
P1	1,000000	1,000000	0.164503
P2	1,000000	0.985421	0.122548
P3	0,959100	0.938450	0.118454
P4	0,637100	0.636541	0.064956
P5	1,000000	1,000000	0.171216
P6	1,000000	1,000000	0.377753
P7	0,931500	0.856510	0.139789
P8	0,189400	0.187054	0.004464
P9	1,000000	1,000000	0.099566
P10	1,000000	1,000000	1,000000
P11	1,000000	0.984142	0.062354
P12	1,000000	1,000000	0.225102
P13	1,000000	1,000000	0.531885
P14	1,000000	1,000000	0.045352
P15	1,000000	0.971413	0.427541
P16	1,000000	1,000000	0.009196
P17	1,000000	0.872254	0.202547
P18	1,000000	1,000000	0.031271
P19	1,000000	1,000000	0.193484
P20	1,000000	1,000000	0.272434
P21	1,000000	0.978445	0.978456
P22	1,000000	0.566540	0.171376
P23	1,000000	1,000000	0.135023
P24	1,000000	1,000000	0.099181
P25	1,000000	0.945816	0.504518
P26	1,000000	1,000000	1,000000
P27	1,000000	1,000000	0.308166
P28	1,000000	0.984557	0.485515
P29	1,000000	1,000000	1,000000
P30	1,000000	0.189300	0.177136
P31	1,000000	0.984410	0.104571
P32	1,000000	1,000000	1,000000
P33	1,000000	1,000000	1,000000
P34	1,000000	0.970445	0.641459
P35	1,000000	1,000000	1,000000
P36	1,000000	0.985740	0.364959
P37	1,000000	0.921600	0.235705
P38	1,000000	1,000000	0.834854
P39	1,000000	0.800000	0.421080
P40	1,000000	1,000000	0.592822
P41	1,000000	1,000000	0.464133
P42	1,000000	0.995147	0.764874
P43	1,000000	1,000000	0.054523
P44	1,000000	1,000000	0.281735
P45	1,000000	1,000000	0.207574
P46	1,000000	0.984614	0.198724

TABLE 7. Potential input saving in normal and competitive analysis.

Power plants	Potential total assets saving in normal environment	Potential total consumption saving in normal environment	Potential total assets saving in competitive environment	Potential total consumption saving in competitive environment
P1	451,0992	464328,5	659,2068	678539,3
P2	46,6758	117922,7	43,8206	110709,3
P3	201,0171	350643,5	218,3887	380945,7
P4	458,2078	381166,9	871,4608	724937,6
P5	189,0545	210875,5	401,1313	447430,5
P6	113,9658	207095,3	1005,5510	1827257,0
P7	106,1601	90864,0	820,6416	702399,5
P8	0,0000	0,0	1030,3590	1047743,0
P9	171,4574	136670,8	176,4850	140678,4
P10	703,2939	4830,0	0,0000	0,0
P11	231,7224	195193,4	390,7190	329125,6
P12	383,7780	471115,9	502,1342	616407,0
P13	555,2925	699885,0	890,8231	1122784,0
P14	0,0000	0,0	1813,8320	544003,4
P15	757,4348	998886,6	746,8141	984880,3
P16	0,0000	0,0	959,0981	581338,3
P17	662,6644	848020,3	705,1053	902332,4
P18	102,5780	92571,5	116,2474	104907,5
P19	409,7329	403412,5	390,3539	384332,4
P20	746,8113	390804,6	931,2844	487339,0
P21	41,3206	348503,5	0,0000	0,0
P22	679,8502	1116175,0	820,3378	1346827,0
P23	232,4662	242831,4	825,1881	861981,6
P24	234,4737	214417,1	648,5896	593109,9
P25	72,7135	685504,1	38,6014	363913,5
P26	70,1124	33302,4	0,0000	0,0
P27	42,2892	40003,1	1122,8460	1062145,0
P28	0,0000	0,0	1009,6010	709214,1
P29	135,8071	270575,0	0,0000	0,0
P30	0,0000	0,0	785,0127	1420016,0
P31	44,6148	49865,2	41,8127	46733,3
P32	385,9034	1351471,0	0,0000	0,0
P33	257,0454	2000,2	0,0000	0,0
P34	412,3767	180681,4	200,9237	88034,0
P35	507,5615	104810,7	0,0000	0,0
P36	497,0002	516614,9	410,6227	426828,3
P37	518,1633	724975,7	545,7067	763512,4
P38	521,3634	521721,5	105,3249	105397,3
P39	149,8346	65031,5	549,9744	238701,0
P40	283,3446	121321,8	309,4552	132501,8
P41	258,8318	122766,8	447,9845	212484,0
P42	356,7533	651016,7	123,7809	225879,9
P43	309,9370	83941,7	434,9196	117791,4
P44	661,2688	87638,6	718,2649	95192,4
P45	202,3197	56619,5	202,8610	56771,0
P46	740,0297	1170043,0	1036,5710	1638897,0

However, those peer indicators have some limitations in the returns to scale properties of the production technology. We consider a generalized assumption for the returns to scale properties of the technology by VRS and all other types of returns to scale may be considered and utilized easily.

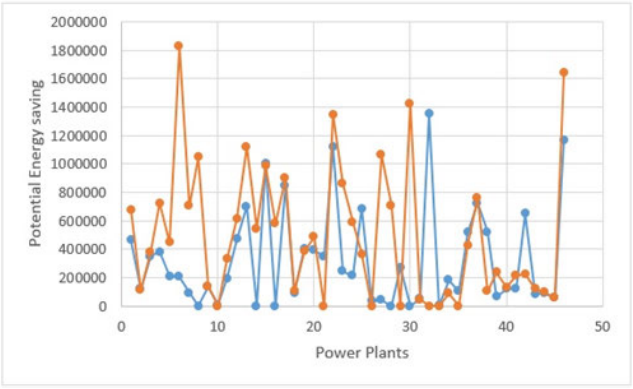

FIGURE 3. Potential possible energy saving of all power plants in the normal and competitive environment.

See [17] for more details on the returns to scale of extended production technology. To make a comparison we provide table 6 that reports these peer indicators for the data set. For the first indicator, that is, local efficiency measure both methods consider the same assumption of returns to scale and therefore the results are identical. However, turning into the communal environment we find different results. As it is expectable, the efficiency score gauged by peer indicators of [4] are not greater than their peers in our analysis. As mentioned this is expectable since the former assumed decreasing and the later assumed variable returns to scales for the production technology.

In another analysis we measure the wasted input (potential of input saving) in both environments, namely, normal and competitive environment of global level. Table 7 reports this analysis. Observe 491826.5639 potential of energy consumption saving in the competitive analysis versus 322306.9321 potential of energy consumption saving in the classical efficiency analysis environment. These reports clarify the status of power plants in the local and global setting. It suggests the competitive setting not only in the local but also in the global setting. Observe the mean saving potential in the classical local environment by 26263.23 versus mean potential saving value of 79879.41 in the competitive and communal local environment. This fact may encourage managers to improve their performance on using resources for producing electricity. This fact can be seen in the reported value of potential energy consumption in the competitive and communal environments. Finally, the results show the importance of global analysis versus local analysis in the performance assessment of power plants.

Figure 3 also provides a graphical illustration of potential energy saving of all power plants in the normal and competitive environment. We observe higher potential improvement in the competitive environment for most of power plants. This is an expectable observation since a production unit has more rival that may have better performance and therefore there exist more rooms for improvement to survive in the competitive environment. It is important that we consider two input in our analysis and we also considered radial measure of efficiency. Thus, the potential improvement for the first input, the total asset, can also be performed and considered to have a full picture of potential input saving for power plants.

IV. CONCLUSION

In all production technologies that consist of internal production units (multiple-plant firms) there are some internal link and collaboration within the production space. Thus, in order to have an overall perspective of the efficiency characteristic we should consider aforementioned links. The current paper propose a new index based on DEA models for measuring the efficiency measures of a production unit in both plant (local) level and firm (global) level. Compared with the existing models in the literature, the proposed models are generalized in the returns to scale assumption. In fact, all different types of returns to scale (increasing, decreasing and constant) may hold in the production technologies associated with the proposed models. A real-world application shows the strength and potential of proposed models in the practice. Primary result emphasizes on corporation of power plants in this study that encourage more improvement which is a requirement for sustainable energy supply.

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MOJTABA GHIYASI received the Ph.D. degree in production economics and operations research. He is currently an Assistant Professor with the Faculty of Industrial Engineering and Management. He is also working with the Faculty of Industrial Engineering and Management Science, Shahrood University of Technology. His research interests include productivity and efficiency analysis, production economic, data envelopment analysis, stochastic frontier analysis, energy economics, environmental economics, stochastic and fuzzy programming, and health economics.



BABAK DANESHVAR ROUYENDEGH (B.ERDEBILLI) was a Research Fellow with Toronto University, Canada, from 2011 to 2012. He held a postdoctoral position with Auburn University, USA, from 2015 to 2016. He is currently an Associate Professor with the Department of Industrial Engineering, Ankara Yıldırım Beyazıt University (AYBU). His work has been published in high-impact journals, such as the *International Journal of Production Research*, *Journal of Testing and Evaluation*, and *Annals of Operations Research*. His main teaching and research interests include performance measurement, fuzzy set, linear programming, and multi-criteria decision-making. He is a member of INFORMS and MCDM. He was awarded the Grant by the Scientific and Technological Research Council of Turkey (TÜBİTAK). He is also serving as the Editor for the *Journal of Turkish Operations Management* and the Academic Editor for the *Applied Computational Intelligence and Soft Computing*.



YAVUZ SELIM ÖZDEMIR received the B.S. degree in industrial engineering, the M.S. degree in computer engineering, and the Ph.D. degree in modelling and design of engineering systems. He is currently an Assistant Professor with the Department of Industrial Engineering, Ankara Science University. He is also working with the Faculty of Engineering and Architecture, as the Chair of the Department of Industrial Engineering. His research interests include multi-criteria decision-making, fuzzy logic, intellectual capital, performance measurement, linear programming, and heuristic optimization. He is also serving as the Editor of the *Researcher* Journal.