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Evaluating the Efficiency of Power Companies Using Data Envelopment Analysis Based on SBM Models: A Case Study in Power Industry of Iran

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ABSTRACT

Data Envelopment Analysis (DEA) is one of the most powerful and useful instrument to evaluate the efficiency of DMU's. To measure the relative efficiency of multi-sector DMU's, it is essential to focus on the activities which relate these sectors together. The electrical firms or companies usually include different parts or sectors and focusing on the efficiency of each part enables us to evaluate the efficiency of the complex in a better way. In this paper, using the network DEA based on SBM approach we have measured the efficiency of electrical firms or companies in Iran.

1. Introduction

Competitive environment leads the producers to promote their manufacturing systems with more efficient and effective design in a short time [1-6]. Therefore, designing an efficient manufacturing system was an important and controversial issue in the past decades [7-12]. Performance measuring is a matter of management to understand the past achievements of a unit, and planning for future development of that unit is [13, 14]. Due to the vital role and effect on economic growth and the main factors which affect economic growth, the electricity industry is a dynamic and effective industry. Due to the electricity is a wide spreading energy, it can be considered as one of the main factors that will pave the way to economic development.

Data Envelopment Analysis (DEA) is one of the common ways to measure efficiency. DEA is a mathematical programming model to evaluate the decision making units that use the multiple inputs to produce multiple outputs. One weakness of these models is ignoring the intermediate production or domestic activities or transplantation. In real world problems there are some decision making units whose procedures contain two or more different stages. Such DMU's involves some intermediate products that traditional DEA models do not consider to them [15]. Network DEA models consider the

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relationship and dependencies between the internal processes and intermediate products to determine the efficiency of these units [16, 17].

Power industry is divided into three division of production, transmission, and distribution division that each of them is essential. These three sections are connected together and they have the responsibility of providing the electrical energy for domestic and industrial uses. To calculate the efficiency of the power companies, considering the dependencies and relationships between these three parts is essential. Many previous studies on the use of DEA in evaluating the efficiency and performance of power generating companies in some countries have been done, for example, Olatubi and Dismukes [18], Lam and Shiu [19], Nag [20], Sueyoshi and Goto [21], and Sueyoshi et al. [22]. There are also some other studies conducted in background efficiency of transmission and distribution, for example, Pahwa et al. [23], Sanhueza et al. [24], Azadeh et al. [25], and Asgrell and bogetoft [26]. Hjalmarsson and Veiderpass [27] in Sweden and Bagdadioglu et al. [28] in Turkey did some studies on the efficiency of power companies. In these studies, no evidence of a difference in performance between public and private companies was found. Førsund and Kittelsen [29] in 1998 studied on the trend of productivity growth of Norwegian electricity dispatch industry and in year 2001 Filippini et al. [30] examined the economic efficiency of 50 companies of Swiss electricity dispatch in 1996 to 1998.

2. Network DEA with SBM

Suppose there are n DMU's (j=1,…, n) that any of them consists of q sectors p=1,…, q . Sectors are linked together in series form. Sector p of DMU_j has m_p inputs and s_p outputs. x_{ij}^{p} indicates input i of sector p from DMU_j and shows output r of sector p from DMU_j and is the intermediate product from sector p-1 to the sector p in DMU_j. The production possibility set $\left\{x_{ij}^{p}, y_{rj}^{p}, z_j^{(p-1,p)}\right\}$ is defined as follows [16, 31]:

$$
\begin{aligned}
& x_{ik}^{p} \geq \sum_{j=1}^{n} x_{ij}^{p} \lambda_j^{p} && \forall i \in M_p, \quad p=1,...,q \\
& y_{rk}^{p} \leq \sum_{j=1}^{n} y_{rj}^{p} \lambda_j^{p} && \forall r \in S_p, \quad p=1,...,q \\
& z_k^{(p-1,p)} = \sum_{j=1}^{n} z_j^{(p-1,p)} \lambda_j^{p} && \text{input to p} \\
& z_k^{(p-1,p)} = \sum_{j=1}^{J} z_j^{(p-1,p)} \lambda_j^{p-1} && \text{outputs from p-1} \\
& z_k^{(p,p+1)} = \sum_{j=1}^{n} z_j^{(p,p+1)} \lambda_j^{p+1} && \text{input to p+1} \\
& z_k^{(p,p+1)} = \sum_{j=1}^{n} z_j^{(p,p+1)} \lambda_j^{p} && \text{outputs from p} \\
& \sum_{j=1}^{n} \lambda_j^{p} = 1 \qquad p=1,...,q \\
& \lambda_j^{p} \geq 0 \quad \forall (j,p) \qquad i \in M_p = \{m_1,...,m_q\} \quad r \in S_p = \{s_1,...,s_q\}.
\end{aligned}
\tag{1}
$$

Where, λ_j^p shows the intensity vector corresponding to division k of DMU_j.

Noteworthy, the model above follows variable returns to scale property for production and removing constraint $\sum_{j=1}^{n} \lambda_j^p = 1\,;\ \forall p$ converts it to a model with constant return to scale property.

Hence for DMU_k it can be defined as follows:

$$x_{ik}^{p} = \sum_{j=1}^{n} x_{ij}^{p} \lambda_j^p + s_i^{p-} \qquad \forall i \in M_p,\quad p=1,...,q$$

$$y_{rk}^{p} = \sum_{j=1}^{n} y_{rj}^{p} \lambda_j^p - s_r^{p+} \qquad \forall r \in S_p,\quad p=1,...,q$$

$$e\lambda^p = 1 \qquad p=1,...,q\,.$$

Where, s_r^{p+} and s_i^{p-} shows respectively slack vectors for outputs and inputs.

2.1 Efficiency

The input oriented relative efficiency for DMU_k is obtained by computing the following linear programming problem [16].

$$\theta_k^* = \underset{\lambda^p, S_i^{p-}}{Min} \quad \sum_{p=1}^{q} w^p \left[1 - \frac{1}{m_p} \left(\sum_{i=1}^{m_p} \frac{s_i^{p-}}{x_{ik}^{p}} \right) \right],$$

subject to (1).

Where shows the relative weight of importance for sector p and $\sum_{p=1}^{q} w^p = 1$, $w^p \geq 0$ $(\forall p)$.

DMU_k in optimality has the following values:

$$x_k^{p*} \leftarrow x_k^p - s_k^{p-*} \quad (p = 1,...,q)$$
$$y_k^{p*} \leftarrow y_k^p + s_k^{p+*} \quad (p = 1,...,q)$$
$$z_k^{(p,p+1)^*} \leftarrow z_k^{(p,p+1)} \lambda^{k*}.$$

In optimality if $\theta_k^* = 1$ then DMU_k is an overall input oriented efficient unit.

2.2 Divisional Efficiency

Using in optimality the divisional efficiency is obtained as follows [16, 32]:

$$\theta_k^{p*} = 1 - \frac{1}{m_p} \left(\sum_{i=1}^{I_p} \frac{s_i^{p-*}}{x_{ik}^{p}} \right) \quad p=1,...,P.$$

The following relationship is established for the overall and divisional efficiency.

$$\theta_k^* = \sum_{p=1}^{q} w^p \theta_k^{p*}.$$

The following notations are used in this article.

ρ_k	Total efficiency of DMU_k in Model.
θ	Efficiency in input oriented model.
φ	Efficiency in output oriented model.
λ_j^p	Intensity vector of division p in DMU_j.
x_{ij}^p	Input i of division p in DMU_j.
y_{rj}^p	Output r of division p in DMU_j.
$z_j^{(p-1,p)}$	The intermediate product that is sent to DMU_{p-1} to DMU_p p-1.
s_i^{p-}	Surplus variable of input I of sector p.
s_r^{p+}	Slack variable of output r of sector p.
i	Input، $i = 1,...,m$.
r	Output، $r = 1,...,s$.
j	DMU، $j = 1,...,n$.
p	DMU's sectors، $p = 1,...,q$.
u_r	Weight of input r.
v_i	Weight of input i.

3. A Case Study in the Power Industry

Due to good relationship with all the infrastructure and the factors affecting the economic growth, the electrical industry is a dynamics and effective industry. Due to the wide sweeping power, it can be considered one of the key-factors that pave the way to economic development of the country. The infrastructure of the power company is that different units can be connected in series [16, 31].

Power industry is divided into three divisions of production, transmission, and distribution for each division that is essential. These three divisions are connected and have the responsibility of providing electrical energy for domestic and industrial uses. In continue we study a case study on electricity companies.

3.1 The Examined Data on Power Companies

Figure Below shows the model studied in this research, a power company that its various sections are linked in series.

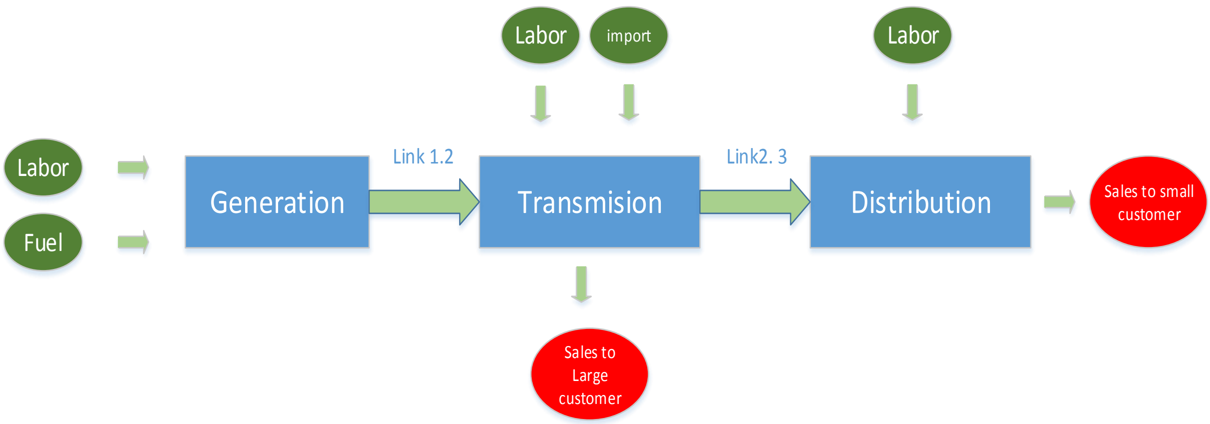

Fig. 1. Network structure of a power company.

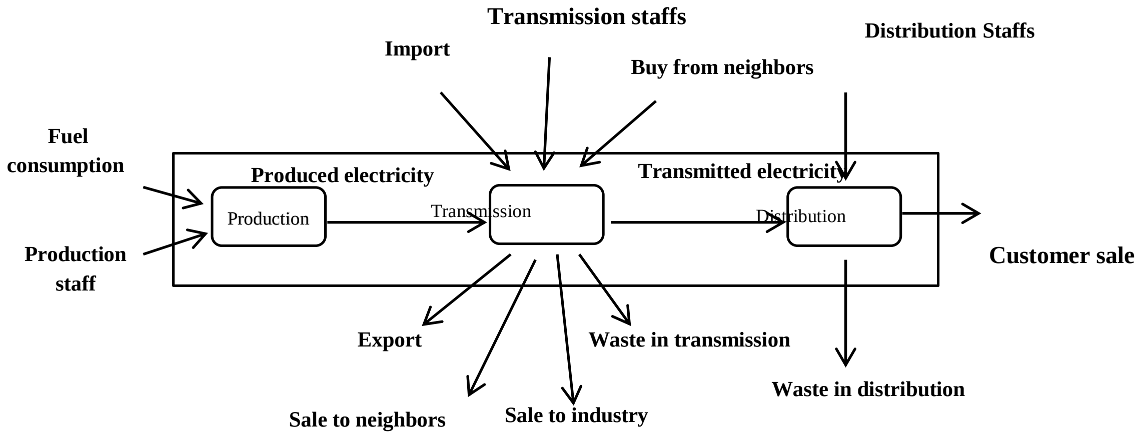

Fig. 2. The structure of a power company in series.

As mentioned, the power companies in this research consist of generation, transmission, and distribution divisions, which are in series connected . The electricity is generated by the thermal power plants, hydro power, combined cycle, and other products. We consider the fuels used in power generation division as input.

Fuels used in power plants are the oil, natural gas and oil furnace. Natural gas is measured in Cubic meters; diesel and furnace oil are measured in units of liters. To Measure these fuels in the same units, we use the following formula (Industry DATABASE water, electricity, petroleum, and energy).

(Cubic meters of natural gas) $\times$8600= kilo calorie.

(Liter of oil) $\times$ 9232= kilo calorie.

(Liter of oil furnace) $\times$ 9790= kilo calorie.

So, using the above conversion, all fuels are measured in a single unit.

We introduce the production staff as the next input in the manufacturing division. The production staff consists of the hydroelectric power plant personnel and the production management firms. The electric energy or Net production of production division is conducted to the transmission division and is considered as an intermediate product of production and transmission divisions. The transmission division, in addition to electrical energy, which is considered as the intermediate product, has three other inputs.

We consider the Amount of electrical energy received from external neighbors as imports and the amount of electrical energy from neighbor companies as ‘neighbor receiving’. We name the personnel who are occupied in the transmission network as ‘transmission personnel’. In this paper we consider the amount of energy sales to large industries, sending electrical energy to foreign countries for export sales to neighboring companies, and wasting energy during the process as outputs. Finally, as an intermediate product, some electrical energy is conducted to the distribution division. In distribution division, the intermediate product and distribution personnel are considered as inputs and sales to small customers including the power subscribers across the country; the public places are considered as outputs. Wasted energy in distribution division is also considered as another output.

3.2 Results

In this section, using the data from 16 regional electricity companies in Iran in year 1392 and applying Lingo software, the problem has solved and the results are described in tables and graphs. The obtained efficiency in case ignoring the intermediate links (Blackbox model) will be compared to the model which considers the links between sectors (Network SBM).

Firstly, the Blackbox problem is solved and in this case, the intermediate products are not considered. The efficiency scores in the table above were reported. Then the problem is considered in NSBM form. In this case, the different sectors of the company are linked together with the intermediate products and the weights of importance for all sectors (Wp) are identical.

Table 1. *Regional power companies’ efficiency in cases Blakbox and NSBM.*

Regional Power company	**Blakbox**	**NSBM**
Azerbaijan	*0.569968*	*0.46349*
Esfahan	*1*	*0.8818*
Bakhtar	*1*	*0.686574*
Tehran	*1*	*1*
Khorasan	*1*	*0.724691*
Khuzestan	*1*	*1*
Zanjan	*1*	*0.821904*
Semnan	*1*	*1*
Sistan	*0.507888*	*0.512906*
Gharb	*1*	*0.691345*
Fars	*1*	*0.960551*
Kerman	*1*	*0.792537*
Gilan	*1*	*0.700972*
Mazandaran	*0.512717*	*0.528394*
Hormozgan	*1*	*0.808348*
Yazd	*1*	*0.805476*
Average	*0.911911*	*0.773687*

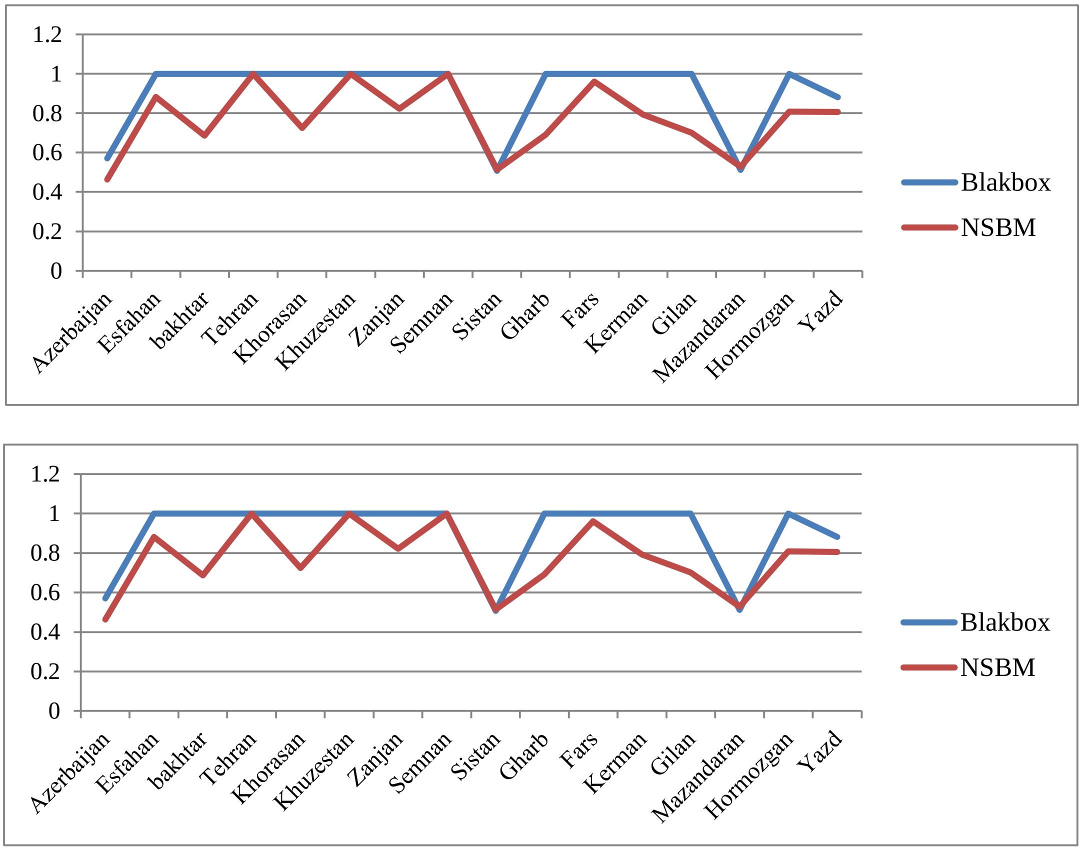

Fig. 3. *NSBM and comparison of the efficiency in cases Blackbox.*

In the following, we evaluate the performance of companies; their overall efficiency will be compared.

As shown in Fig. 3, in the Blackbox model efficiency scores tend to be higher than the NSBM. In Blakbox model, 3 of the 16 companies are inefficient and 13 companies are efficient. But in NSBM, only three companies have been recognized as efficient and 13 companies are inefficient.

As we said above, the overall efficiency is obtained by weighted sum of the efficiency of other sectors using equation below.

$$\theta_k^* = \sum_{p=1}^{q} w^p \theta_k^{p*}.$$

According to the table above average efficiency of transmission sector is more efficient than other sectors and the production sector compared to other sectors is inefficient.

Table 2. *Division efficiency of electrical company.*

Regional power company	Overall efficiency	Production sector	Transmission sector	Distribution sector
Azerbaijan	*0.4634899*	*0.5049541*	*0.5468112*	*0.3387044*
Esfahan	*0.881799633*	*0.6453989*	*1*	*1*
bakhtar	*0.686574367*	*0.4394697*	*1*	*0.6202534*
Tehran	*1*	*1*	*1*	*1*
Khorasan	*0.724691067*	*0.5498454*	*1*	*0.6242278*
Khuzestan	*1*	*1*	*1*	*1*
Zanjan	*0.8219043*	*0.521052*	*1*	*0.9446609*
Semnan	*1*	*1*	*1*	*1*
Sistan	*0.512906167*	*0.3259178*	*0.8194037*	*0.393397*
Gharb	*0.691344633*	*0.5600104*	*1*	*0.5140235*
Fars	*0.960551367*	*1*	*1*	*0.8816541*
Kerman	*0.792537433*	*0.680066*	*1*	*0.6975463*
Gilan	*0.7009715*	*0.6234954*	*1*	*0.4794191*
Mazandaran	*0.5283941*	*0.5953027*	*0.5281434*	*0.4617362*
Hormozgan	*0.808348067*	*0.6398743*	*1*	*0.7851699*
Yazd	*0.805476067*	*0.6101509*	*1*	*0.8062773*
Average	*0.773686788*	*0.6684711*	*0.930897394*	*0.721691869*

4. Conclusion

DEA is a powerful instrument to measure the relative efficiency of decision making units. In the real world problems, DMUs usually have multi sectors and follow a network structure. So, focusing on the functionality of different sectors of these networks plays an essential role to evaluate the efficiency of the DMU. The electrical companies that are very important in developing country followed the network structure. The SBM network model is a more stringent model than Blackbox and led to more accurate results. The importance of the power industry in developing countries insisted the need for more accurate conclusion of the performance of the industry. Hence using the network DEA based on SBM approach the relative efficiency of this industry in Iran was evaluated.

References

[1] Alavidoost, M. H. (2017). *Assembly line balancing problems in uncertain environment: a novel interactive fuzzy approach for solving multi-objective fuzzy assembly line balancing problems*. LAP LAMBERT Academic Publishing.

[2] Alavidoost, M. H., Tarimoradi, M., & Zarandi, M. F. (2015). Fuzzy adaptive genetic algorithm for multi-objective assembly line balancing problems. *Applied soft computing*, *34*, 655-677.

[3] Tarimoradi, M., Alavidoost, M. H., & Zarandi, M. F. (2015). Comparative corrigendum note on papers “Fuzzy adaptive GA for multi-objective assembly line balancing” continued “Modified GA for different

types of assembly line balancing with fuzzy processing times": differences and similarities. *Applied soft computing*, *35*, 786-788.

[4] Alavidoost, M. H., Babazadeh, H., & Sayyari, S. T. (2016). An interactive fuzzy programming approach for bi-objective straight and U-shaped assembly line balancing problem. *Applied soft computing*, *40*, 221-235.

[5] Alavidoost, M. H., Zarandi, M. F., Tarimoradi, M., & Nemati, Y. (2017). Modified genetic algorithm for simple straight and U-shaped assembly line balancing with fuzzy processing times. *Journal of intelligent manufacturing*, *28*(2), 313-336.

[6] Alavidoost, M. H., & Nayeri, M. A. (2014). Proposition of a hybrid NSGA-II algorithm with fuzzy objectives for bi-objective assembly line balancing problem. *Tenth international industrial engineering conference*.

[7] Alavidoost, M. H., Tarimoradi, M., & Zarandi, M. F. (2018). Bi-objective mixed-integer nonlinear programming for multi-commodity tri-echelon supply chain networks. *Journal of intelligent manufacturing*, *29*(4), 809-826.

[8] Babazadeh, H., Alavidoost, M. H., Zarandi, M. F., & Sayyari, S. T. (2018). An enhanced NSGA-II algorithm for fuzzy bi-objective assembly line balancing problems. *Computers & industrial engineering*, *123*, 189-208.

[9] Zarandi, M. F., Tarimoradi, M., Alavidoost, M. H., & Shakeri, B. (2015, August). Fuzzy approximate reasoning toward Multi-objective optimization policy: deployment for supply chain programming. *2015 annual conference of the north american fuzzy information processing society (nafips) held jointly with 2015 5th world conference on soft computing (WConSC)*(pp. 1-6). Redmond, WA, USA: IEEE.

[10] Zarandi, M. F., Tarimoradi, M., Alavidoost, M. H., & Shirazi, M. A. (2015, August). Fuzzy comparison dashboard for multi-objective evolutionary applications: an implementation in supply chain planning. *2015 annual conference of the north american fuzzy information processing society (nafips) held jointly with 2015 5th world conference on soft computing (WConSC)*(pp. 1-6). Redmond, WA, USA: IEEE.

[11] Nemati, Y., & Alavidoost, M. H. (2018). A fuzzy bi-objective MILP approach to integrate sales, production, distribution and procurement planning in a FMCG supply chain. *Soft computing*, 1-20.

[12] Nemati, Y., Madhoushi, M., & Alavidoost, M. H. (2017). *Modeling of S&OP in a large scale dairy supply chain*. Scholar's Press.

[13] Kao, C. (2014). Network data envelopment analysis: a review. *European journal of operational research*, *239*(1), 1-16.

[14] Shahrasbi, A., Shamizanjani, M., Alavidoost, M. H., & Akhgar, B. (2017). An aggregated fuzzy model for the selection of a managed security service provider. *International journal of information technology & decision making*, *16*(03), 625-684.

[15] Mahmoudabadi, M. Z., Azar, A., & Emrouznejad, A. (2018). A novel multilevel network slacks-based measure with an application in electric utility companies. *Energy*, *158*, 1120-1129.

[16] Shermeh, H. E., Najafi, S. E., & Alavidoost, M. H. (2016). A novel fuzzy network SBM model for data envelopment analysis: a case study in Iran regional power companies. *Energy*, *112*, 686-697.

[17] Emrouznejad, A., & Yang, G. L. (2018). A survey and analysis of the first 40 years of scholarly literature in DEA: 1978–2016. *Socio-Economic planning sciences*, *61*, 4-8.

[18] Olatubi, W. O., & Dismukes, D. E. (2000). A data envelopment analysis of the levels and determinants of coal-fired electric power generation performance. *Utilities policy*, *9*(2), 47-59.

[19] Lam, P. L., & Shiu, A. (2001). A data envelopment analysis of the efficiency of China's thermal power generation. *Utilities policy*, *10*(2), 75-83.

[20] Nag, B. (2006). Estimation of carbon baselines for power generation in India: the supply side approach. *Energy policy*, *34*(12), 1399-1410.

[21] Sueyoshi, T., & Goto, M. (2012). Data envelopment analysis for environmental assessment: comparison between public and private ownership in petroleum industry. *European journal of operational research*, *216*(3), 668-678.

[22] Sueyoshi, T., Goto, M., & Ueno, T. (2010). Performance analysis of US coal-fired power plants by measuring three DEA efficiencies. *Energy policy*, *38*(4), 1675-1688.

[23] Pahwa, A., Feng, X., & Lubkeman, D. (2003). Performance evaluation of electric distribution utilities based on data envelopment analysis. *IEEE transactions on power systems*, *18*(1), 400-405.

[24] Sanhueza, R., Rudnick, H., & Lagunas, H. (2004). DEA efficiency for the determination of the electric power distribution added value. *IEEE transactions on power systems*, *19*(2), 919-925.

[25] Azadeh, A., Amalnick, M. S., Ghaderi, S. F., & Asadzadeh, S. M. (2007). An integrated DEA PCA numerical taxonomy approach for energy efficiency assessment and consumption optimization in energy intensive manufacturing sectors. *Energy policy*, *35*(7), 3792-3806.

[26] Agrell, P. J., & Bogetoft, P. (2005). Economic and environmental efficiency of district heating plants. *Energy policy*, *33*(10), 1351-1362.

[27] Hjalmarsson, L., & Veiderpass, A. (1992). Productivity in Swedish electricity retail distribution. *The Scandinavian journal of economics*, S193-S205.

[28] Bagdadioglu, N., Price, C. M. W., & Weyman-Jones, T. G. (1996). Efficiency and ownership in electricity distribution: a non-parametric model of the Turkish experience. *Energy economics*, *18*(1-2), 1-23.

[29] Førsund, F. R., & Kittelsen, S. A. (1998). Productivity development of Norwegian electricity distribution utilities. *Resource and energy economics*, *20*(3), 207-224.

[30] Filippini, M., Wild, J., & Kuenzle, M. (2001). Scale and cost efficiency in the Swiss electricity distribution industry: evidence from a frontier cost approach. *CEPE working paper*, *8*.

[31] Tone, K., & Tsutsui, M. (2009). Network DEA: A slacks-based measure approach. *European journal of operational research*, *197*(1), 243-252.