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APPLICATION OF THE DATA ENVELOPMENT ANALYSIS METHOD FOR EVALUATING OPERATION OF TECHNICAL SYSTEMS

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Abstract

The paper describes theoretical foundations of the Data Envelopment Analysis method. The peculiarities of its application at enterprises of the heat supply system of the fuel and energy complex are considered. The Charnes, Cooper and Rhodes model of the Data Envelopment Analysis method is studied and analyzed. The paper describes the application of the Charnes, Cooper and Rhodes model with constant economies of scale for the heat supply system, i.e., for combined heat and power plants and boiler houses. Inputs and outputs indicators for the enterprises under consideration are studied and determined. The thermal power of the equipment and fuel equivalent consumption are selected as two inputs. The supply of thermal energy to the heating system is selected as one output. The efficiency indicators of 27 combined heat and power plants and boiler houses were calculated applying the Charnes, Cooper and Rhodes model of the Data Envelopment Analysis method. The orientation of the Charnes, Cooper and Rhodes model is selected to increase the output. The thermal energy supply to the heating system is considered. Firms with a maximum efficiency that is equal to 1 were identified according to the results of calculations applying the Data Envelopment Analysis method. For the rest of the firms, whose efficiency indicators turned out to be less than 1, changes in output indicators were calculated to achieve maximum efficiency. This made it possible to increase the enterprises' efficiency of the studied sample.

Keywords: Data envelopment analysis, charnes, cooper and rhodes model, heat supply system, combined heat and power plant, boiler house

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1. Introduction

Any organizations need to ensure the proper development and efficiency constantly in accordance with modern trends and directions of scientific and technological development. Decision makers (DM) need to ensure the adaptability of the organization to such changes due to rapidly changing environmental factors. Constant monitoring and evaluation of the enterprise's efficiency as well as the constant process of increasing competitiveness are becoming one of the main areas of work for decision makers. In the current economic situation, methods for evaluating and improving the efficiency of enterprises are gaining more and more popularity. The previous studies by Pokushko et al. (2019) analyzed various efficiency evaluation methods. The Data Envelopment Analysis (DEA) method can be noted as one of the most efficient methods taking into account the carried-out analysis. Accordingly, the authors believe that it seems to be important and scientifically in demand to conduct a study on this method application to evaluate and improve the efficiency of organizations. It will be quite relevant for the heat supply system. It will be possible to solve theoretical and practical problems that there exist in the industry contributing to an increase in the efficiency of the studied technical system and have the possibility of their implementation at enterprises. The results of the study are within the framework of the world strategy for scientific and technological development.

2. Problem Statement

Solving efficiency problems for complex technical systems is not a simple process. These systems have a complex structure and they are accompanied by production processes that require an understanding of the specifics of this activity. It is difficult for an engineering staff that does not know properly modern methods to improve efficiency to optimize processes based on information technology. It is difficult to apply these methods for employees in the field of information technology who can use them without mastering the specifics of production processes. Therefore, there is a need to conduct such scientific research to resolve this kind of problems for complex technical systems.

3. Research Questions

The following sections will describe the peculiarities of the DEA method to apply them at enterprises of the heat supply system in the fuel and energy complex of Russia. The Charnes, Cooper and Rhodes (CCR) model of the DEA method will be considered. Its application for the heat supply system, namely for combined heat and power plants (CHPs) and boiler houses is described. Indicators of inputs and outputs for the enterprises under study investigated and determined. Efficiency indicators of the analyzed sample are calculated. Indicators of inputs and outputs for CHPs and boiler houses for maximum efficiency of these facilities are calculated as well.

4. Purpose of the Study

The objective of the study is to improve efficiency indicators of the heat supply system of the fuel and energy complex based on the DEA method. In accordance with this objective, the following tasks will be solved:

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- describe peculiarities of the DEA method for its application at enterprises of the heat supply system;
- consider the Charnes, Cooper and Rhodes (CCR) model of the DEA method;
- describe the application of the CCR model for the heat supply system, namely for combined heat and power plants (CHPs) and boiler houses;
- study and determine input and output indicators for the enterprises under consideration;
- calculate efficiency indicators of the analyzed sample;
- calculate input and output indicators for CHPs and boiler houses to achieve maximum efficiency.

5. Research Methods

The DEA method is a non-parametric method. Founders of this method are Charnes et al. (1978). The DEA method is an optimization mathematical programming method for generalizing Farrell's (1957) technical efficiency indicators with a single input/single output or multiple input/multiple output. The method builds a relative efficiency evaluation as a ratio of the virtual output to a virtual input of the studied objects. The efficiency frontier is constructed for the studied sample based on the indicators of inputs and outputs of efficient objects. The method helps to calculate the indicators of inputs and outputs of inefficient sample objects to achieve the efficiency frontier.

The formula for calculating efficiency (Ef) according to the DEA method can be generally represented as:

$$Ef = min\frac{\sum_{i=1}^{m} V_i X_{i_0}}{\sum_{r=1}^{s} U_r Y_{r_0}} \quad (1)$$

Here:

$$0 \leq \frac{\sum_{i=1}^{m} V_i \, X_{i_j}}{\sum_{r=1}^{s} U_r Y_{r_j}} \geq 1,$$

j = 1,2,…n, r = 1,2…s, i = 1,2…m, $U_r, V_i \geq \varepsilon$.

As one can see their formulas, the efficiency of the objects of the studied sample lies within a range from 0 to 1.

The method has found wide application for evaluation the efficiency of homogeneous objects. Thus, DEA has become a new tool in practice-oriented study to measure technical efficiency. Since the DEA method had been developed, a large number of scientific papers have been published such as Xie et al. (2018), Jablonsky et al. (2018), Bod'a et al. (2018), Malik et al. (2018), Fu (2018). The method has found application in many areas, for example, publications of Fu (2018), Jablonský (2018), Emrouznejad et al. (2014), Foroughi and Shureshjani (2017).

In this study, we apply the DEA method to evaluate the efficiency of the heat supply system of the fuel and energy complex of Russia at enterprises. The objects of the study sample are combined heat and power plants (CHPs) and boiler houses. In this study, we apply the CCR model. This model is applied with a constant effect of scale.

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Now consider inputs and outputs for the objects under study. CHPs and boiler houses process fuel, providing the proper capacity of the equipment and, as a result, generate thermal energy. Therefore, it is advisable to take these three indicators for inputs and outputs. Thus, the model will have two inputs, i.e., thermal power of the equipment (Gcal/h) is input (x1) and consumption of reference fuel (thousand t.o.e./year) is input (x2), and one output, i.e., supply of thermal energy to network (thousand Gcal) is output (y1). We select a model with a focus on output to increase the supply of thermal energy. Table 1 presents initial data on the inputs and outputs of the study sample. The sample includes of 27 enterprises. For clarity, the paper presents only a part of objects.

Table 1. Initial Data of Indicators of Inputs and Outputs of the Studied Sample

Firm	Output (y1)	Input (x1)	Input (x2)
1	3860	1405	672
2	1378	752	384
3	4023	1497	706
4	4194	1405	730
5	1180	752	355
6	3305	1497	584
7	3825	1405	673
8	1244	712	308
9	3355	1447	595
10	3986	1405	694
11	1719	712	366
12	2894	1447	434
13	3379	1405	598

6. Findings

Now, calculate the performance indicators of enterprises under study applying the DEA method. Calculate the efficiency indicators according to the CCR model with a focus on the output to increase the output, i.e., supply of thermal energy. Table 2 presents the obtained efficiency indicators for the studied sample.

Table 2. Efficiency Indicators for the Studied Sample

Firm	Technical efficiency	Peers	Lambda weight
1	0.949	23; 25	0.538; 0.518
2	0.611	23; 25	0.144; 0.406
3	0.936	23; 25	0.606; 0.525
4	0.985	23; 25	0.202; 0.820
5	0.546	23; 25	0.265; 0.302
6	0.854	25; 26	1.021; 0.154
7	0.940	23; 25	0.512; 0.543
8	0.637	23; 25	0.114; 0.440
9	0.868	23; 25	1.062; 0.082
10	0.963	23; 25	0.398; 0.645
11	0.802	23; 25	0.124; 0.396
12	0.965	26	0.923

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13	0.884	23; 25	0.921; 0.178

Table 2 demonstrates that none of the companies presented in the Table has a maximum efficiency indicator that is equal to 1. The maximum efficiency indicator in this Table is 0.949 belongs to firm No.1. The minimum efficiency indicator presented in Table 2 is 0.546 and belongs to firm No. 5. According to table 2, firms with maximum efficiency indicators that are equal to 1 are firm No. 23, firm No. 25, firm No. 26. They are samples for all other firms presented in Table 2.

Now, calculate inputs and outputs for inefficient enterprises so that they can reach the efficiency frontier, i.e., become efficient. Present a summary Table 3, where the indicators of inputs and outputs for the studied sample and their deviations are calculated to achieve efficiency indicators that are equal to 1.

Table 3. Indicators of inputs and outputs for the studied sample and their deviations to achieve performance indicators that are equal to 1

Firm	Output (y1)	Radial movement	Input(x1)	Slack movement	Input (x2)	Slack movement
1	4065.728	205.728	1405	-	672	-
2	2256.574	878.574	752	-	384	-
3	4298.862	275.862	1497	-	706	-
4	4257.599	63.599	1405	-	730	-
5	2160.638	980.638	752	-	355	-
6	3872.218	567.218	1497	-	584	-
7	4069.036	244.036	1405	-	673	-
8	1952.695	708.695	712	-	308	-
9	3866.085	511.085	1447	-	595	-
10	4138.506	152.506	1405	-	694	-
11	2144.567	425.567	712	-	366	-
12	2999.217	105.217	1297.383	-149.617	434	-
13	3820.926	441.926	1405	-	598	-

According to data from Table 3, the CCR model of the DEA method made it possible to calculate input and output indicators for the studied sample to achieve the maximum efficiency that is equal to 1. The third column presents Radial movement by outputs of the enterprises under consideration. Output indicators are calculated based on the output-oriented model. Table 3 demonstrates that all output indicators vary, since in the presented Tables all firms have efficiency indicatorы less than 1. Therefore, output indicators of all these firms require an increase in order to achieve maximum efficiency. For example, firm No. 1 with a maximum efficiency of 0.949 requires an output increase of 205.728 to achieve maximum efficiency of 1. Firm No. 5 with the minimum efficiency score, 0.546 requires an increase in output by 980.638 to achieve maximum efficiency that is equal to 1. Input rates remain low for the exit-oriented model. Except for firm No. 12 that has Slack movement on entry (x1). This input must be reduced by 149.617 for this firm to hit the efficiency frontier.

7. Conclusion

Thus, the objective of this study was fully achieved. The efficiency indicators of the heat supply system of the fuel and energy complex were improved based on the application of the DEA method. In accordance with this objective, the following tasks will be solved:

- peculiarities of the DEA method for its application at enterprises of the heat supply system was described;
- CCR model of the DEA method was considered;
- application of the CCR model for the heat supply system, namely for CHPs and boiler houses was described;
- indicators of inputs and outputs for the enterprises under consideration were studied and determined;
- efficiency indicators of the analyzed sample were calculated;
- indicators of inputs and outputs for CHPs and boiler houses to achieve maximum efficiency were calculated.

The study calculated the efficiency indicators of 27 CHPs and boiler houses according to the output-oriented CCR model of the DEA method. Firms with maximum efficiency of one were identified. For the rest of the firms, whose performance indicators turned out to be less than one, changes in output indicators were calculated to achieve maximum efficiency. Thus, the calculated indicators of inputs and outputs made it possible to increase the efficiency of enterprises of the studied sample.

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References

Bod'a, M., Dlouhý, M., & Zimková, E. (2018). Unobservable or omitted production variables in data envelopment analysis through unit-specific production trade-offs. *Central European Journal of Operations Research, 26*(4), 813-846. https://doi.org/10.1007/s10100-018-0561-8

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research, 2*(6), 429-444. https://doi.org/10.1016/0377-2217(78)90138-8

Emrouznejad, A., Banker, R., Miranda Lopes, A. L., & Rodrigues de Almeida, M. (2014). Data Envelopment Analysis in the public sector. *Socio-Economic Planning Sciences, 48*(1), 2-3. https://doi.org/10.1016/j.seps.2013.12.005

Farrell, M. J. (1957). The Measurement of Productive Efficiency. Journal of the Royal Statistical Society. *Series A (General), 120*(3), 253. https://doi.org/10.2307/2343100

Foroughi, A. A., & Shureshjani, R. A. (2017). Solving generalized fuzzy data envelopment analysis model: a parametric approach. *Central European Journal of Operations Research, 25*(4), 889-905. https://doi.org/10.1007/s10100-016-0448-5

Fu, J. (2018). Two-stage data envelopment analysis with undesirable intermediate measures: an application to air quality improvement in China. *Central European Journal of Operations Research, 26*(4), 861-885. https://doi.org/10.1007/s10100-018-0564-5

https://doi.org/10.15405/epct.23021.6
Corresponding Author: M. Pokushko
Selection and peer-review under responsibility of the Organizing Committee of the conference
eISSN: 2672-8834

Jablonsky, J. (2018). Ranking of countries in sporting events using two-stage data envelopment analysis models: a case of Summer Olympic Games 2016. *Central European Journal of Operations Research, 26*(4), 951-966. https://doi.org/10.1007/s10100-018-0537-8

Jablonský, J., Emrouznejad, A., & Toloo, M. (2018). Special issue on data envelopment analysis. *Central European Journal of Operations Research, 26*(4), 809-812. https://doi.org/10.1007/s10100-018-0584-1

Malik, M., Efendi, S., & Zarlis, M. (2018). Data Envelopment Analysis (DEA) Model in Operation Management. *IOP Conference Series: Materials Science and Engineering, 300*, 012008. https://doi.org/10.1088/1757-899x/300/1/012008

Pokushko, M., Stupina, A., Medina - Bulo, I., Dresvianskii, E., & Karaseva, M. (2019). Application of data envelopment analysis method for assessment of performance of enterprises in fuel and energy complex. *Journal of Physics: Conference Series, 1353*(1), 012140. https://doi.org/10.1088/1742-6596/1353/1/012140

Xie, Q., Li, Y., Wang, L., & Liu, C. (2018). Improving discrimination in data envelopment analysis without losing information based on Renyi's entropy. *Central European Journal of Operations Research, 26*(4), 1053-1068. https://doi.org/10.1007/s10100-018-0550-y