ISSN 1829–0043

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ВЕСТНИК

ИНЖЕНЕРНОЙ АКАДЕМИИ АРМЕНИИ

СБОРНИК НАУЧНО-ТЕХНИЧЕСКИХ СТАТЕЙ

PROCEEDINGS

OF ENGINEERING ACADEMY OF ARMENIA

SCIENTIFIC AND TECHNOLOGICAL COLLECTED ARTICLES

XIV

ՀԱՏՈՐ **ТОМ** **VOLUME#**

№ 1

ԵՐԵՎԱՆ **ЕРЕВАН** **YEREVAN**

2017

UDC 62.691.4.003.1 ECONOMICS AND MANAGEMENT

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ASSESSING EFFICIENCY OF MAJOR ARMENIAN POWER PLANTS BY MEANS OF DEA APPROACH*

The assessment of major Armenian power plants' performance efficiency is given. As a method of efficiency evaluation, Data Envelopment Analysis is selected, which is one of the most widespread used techniques for solving this kind of problems. A dual linear programming problem is solved for achieving results which shows that out of five major power plants only Yerevan Thermal Power Plant has an efficiency rating less than 1. Furthermore, Efficiency Reference Set for Yerevan Thermal Power Plant is defined and techniques for increasing efficiency are suggested.

Keywords: *Data Envelopment Analysis, linear programming, performance efficiency, electricity production.*

Introduction. In modern economy among various management problems a particular interest represent efficiency related problems. That interest is reasoned by facts that efficiency has a direct impact on the performance both on state and corporate level. Efficient management of production process, personnel or finances is a crucial key to further successes. Conversely, inefficiencies in the mentioned areas may have a negative impact on the overall performance and consequently lead to insufficient results in a business perspective.

Energy production and supply sector is not an exclusion with respect to impact of efficiency problems. This sector is among the most important driving forces of any economy. Functioning of economy's other branches is highly dependent on this sector. Furthermore, this sector is of crucial importance for common people. Thus, companies engaged in this sector are required to pay significant attention to their overall performance efficiency, as operation in energy sector is related to very high input costs. Therefore, efficient management of inputs is vital for energy companies and should be organized properly.

For Armenia, energy sector is of even more importance. This country doesn't possess major energy sources (oil, natural gas) and imports them from Russia and Iran. This makes production of power even costly. Therefore, it is necessary for Armenian power plants to keep their performance efficiency in a proper level in order to avoid additional expenses in production process. In this study, an attempt is made to classify five major Armenian power plants according to their performance efficiency. As a method of evaluation, Data Envelopment Analysis approach is selected. It is believed that the results of this study will give a clear picture about efficiency of Armenian major power plants, allow to compare those plants in terms of efficiency and make judgements in a management level.

Methodology and data. In order to assess efficiency of power plants and compare them, one of the most commonly used techniques is decided to apply – Data Envelopment Analysis (DEA) – which for the first time was proposed by Charnes, Cooper and Rhodes in 1978 [1]. Sherman and Zhu (2006) consider DEA as a quite powerful tool for benchmarking. Originally, this approach was developed for evaluating non-profit and public organizations. In comparison with other productivity management techniques, DEA has a methodological advantage – it is based on linear programming methods. Such a basis of DEA makes many managers to refrain from using it as it requires additional efforts and knowledge. Moreover, there can be problems with proper understanding of this method. There were several cases, when managers got weak results and blamed DEA technique, while the true problem was its misunderstanding [2].

The results of this kind of analysis can be interpreted in the following order [2].

At first, efficiency scores are generated and studied units are classified according to those scores. Units which have efficiency score equal to 1 are considered as relatively efficient. At this point, it is worth mentioning that efficiency score of 1 doesn't necessarily imply best possible management practice. It only indicates best existing management practice. On the contrary, units which have efficiency rating less than 1 are classified as inefficient. These units are considered strictly inefficient in comparison with other units.

Next step represents construction of Efficiency Reference Set (ERS) for each unit. Basically, ERS allows to compare inefficient units against relatively efficient ones. Moreover, ERS gives an opportunity to construct a mixture of operating techniques for inefficient ones and consequently increase their efficiency.

Mathematically DEA model for n studied units can be represented by means of two linear programming problems: maximization and minimization problems. The first one, which is also called "multiplier model", is given by the following model [1] - [3]:

$$\text{Maximize } \theta = \frac{u_1 y_{1o} + u_2 y_{2o} + \ldots + u_s y_{so}}{v_1 x_{1o} + v_2 x_{2o} + \ldots + v_m x_{mo}} = \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}}. \qquad (1)$$

Subject to the following constraints:

$$\text{SU}_1 \quad \frac{u_1 y_{11} + u_2 y_{21} + \ldots + u_s y_{s1}}{v_1 x_{11} + v_2 x_{21} + \ldots + v_m x_{m1}} = \frac{\sum_{r=1}^{s} u_r y_{r1}}{\sum_{i=1}^{m} v_i x_{i1}} \le 1\ , \qquad (2)$$

* Current paper was developed in the framework of the project SYNERGIA – Sustainable and Systematized Energy Efficiency in Armenia.

$$\text{SU}_2 \quad \frac{u_1 y_{12}+u_2 y_{22}+\ldots+u_s y_{s2}}{v_1 x_{12}+v_2 x_{22}+\ldots+v_m x_{m2}} = \frac{\sum_{r=1}^{s} u_r y_{r2}}{\sum_{i=1}^{m} v_i x_{i2}} \leq 1 \, , \tag{3}$$

$$\text{SU}_3 \quad \frac{u_1 y_{13}+u_2 y_{23}+\ldots+u_s y_{s3}}{v_1 x_{13}+v_2 x_{23}+\ldots+v_m x_{m3}} = \frac{\sum_{r=1}^{s} u_r y_{r3}}{\sum_{i=1}^{m} v_i x_{i3}} \leq 1 \, , \tag{4}$$

...

$$\text{SU}_o \quad \frac{u_1 y_{1o}+u_2 y_{2o}+\ldots+u_s y_{so}}{v_1 x_{1o}+v_2 x_{2o}+\ldots+v_m x_{mo}} = \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}} \leq 1 \, , \tag{5}$$

...

$$\text{SU}_j \quad \frac{u_1 y_{1j}+u_2 y_{2j}+\ldots+u_s y_{sj}}{v_1 x_{1j}+v_2 x_{2j}+\ldots+v_m x_{mj}} = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \, , \tag{6}$$

$$u_1, \ldots, u_S > 0, v_1, \ldots, v_m \geq 0 \, , \tag{7}$$

where *j* is the number of service units (SU) being compared in the DEA analysis, *SUj* is a service unit number j, θ is an efficiency rating of the service unit being evaluated by DEA, y_{rj} is an amount of output *r* generated by service unit j, x_{ij} is an amount of input *i* used by service unit j, *i* is the number of inputs used by the SUs, *r* - the number of outputs generated by the SUs, u_r- coefficient or weight assigned by DEA to output *r* and v_i is a coefficient or weight assigned by DEA to input *i* [2].

By solving the above introduced linear programming problem, the set of *u* and *v* coefficients will be obtained, which represent highest efficiency ratio of output and inputs that is possible to obtain for a unit under evaluation. The meaning of the constraints is that when the same *u* and *v* coefficients are applied to all units, no one will be more efficient than 100% [2].

In order to run a DEA model in a program package, above introduced equations are reformulated in the following way [2].

$$\text{Maximize}\theta = u_1 y_{1o} + u_2 y_{2o} + \ldots + u_s y_{so} (= \textstyle\sum_{r=1}^{s} u_r y_{ro}) \tag{8}$$

subject to the following constraints [2]:

$$v_1 x_{1o} + v_2 x_{2o} + \ldots + v_m x_{mo} (= \textstyle\sum_{i=1}^{m} v_i x_{io}) = 1 \, , \tag{9}$$

$$u_1 y_{1j} + u_2 y_{2j} + \ldots + u_s y_{sj} \leq v_1 x_{1j} + v_2 x_{2j} + \ldots + v_m x_{mj} \, . \tag{10}$$

Inequality (10) can be introduced also in the following form [2]:

$$\sum_{r=1}^{s} u_r y_{\text{rj}} \leq \sum_{i=1}^{m} v_i x_{\text{ij}} \, . \tag{11}$$

Therefore, DEA model actually assumes solving next linear programming problem [2]:

$$\text{Maximize} \textstyle\sum_{r=1}^{s} u_r y_{ro} \tag{12}$$

subject to:

$$\sum_{r=1}^{s} u_r y_{\text{rj}} - \sum_{i=1}^{m} v_i x_{\text{ij}} \leq 0, j = 1, \ldots, n \, , \tag{13}$$

$$\textstyle\sum_{i=1}^{m} v_i x_{\text{io}} = 1 \, , \tag{14}$$

$$u_r, v_i \geq 0 \, . \tag{15}$$

This study employs the second method of DEA model estimation - solving a dual linear programming problem which can be represented as follows [1] - [3]:

$$\text{Minimize}\theta \tag{16}$$

subject to:

$$\textstyle\sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta x_{io} \, , i = 1,2, \ldots, m \, , \tag{17}$$

$$\sum_{j=1}^{n} \lambda_j y_{\text{rj}} \geq y_{\text{ro}}, r = 1,2, \ldots, s \, , \tag{18}$$

$$\lambda_j \geq 0, j = 1,2, \ldots, n \, . \tag{19}$$

This model aims at minimizing efficiency rating subject to the following constraints: inputs of the unit under evaluation are greater than or equal to the weighted sum of other units' inputs (Equation (18)) and output of service unit under evaluation is less than or equal to the weighted sum of other units' outputs (Equation (19)). λs represent the weights. Those units that have non-zero λ weights form the ERS. This model is also called "envelopment model".

As it was already mentioned in the Introduction, this study analyses efficiency of five major Armenian power plants. Those plants are: Armenian Nuclear Power Plant (ANPP), Yerevan Thermal Power Plant (YTPP), Hrazdan Thermal Power Plant (HTPP), Vorotan Hydro Power Plant (VHPP) and Sevan-Hrazdan Hydro Cascade (SHHC). The DEA model developed in this study assumes one output and four inputs. As an output physical production of the plants is taken (electricity production in *mln. kWh*) while input variables are the volume of fixed assets (in *mln. AMD*), cost of production (in *mln. AMD*), return on equity (ROE) and return on assets (ROA). All data except for output data are taken from plants' annual financial reports of 2015 [4-8]. Output data are obtained from Electricity Reports provided by Public Services Regulatory Commission of Armenia [9]. ROA and ROE are calculated as ratio of Net Profit to Assets and Equity respectively.

The following table reports information about output and input data (Table 1).

Table 1

Output and inputs employed in DEA model

Plants	Output	Inputs			
	Electricity production (*mln. KWh*)	Fixed assets (*mln. AMD*)	Cost of production (*mln. AMD*)	ROA (%)	ROE (%)
Yerevan TPP	1,594.6	127,707.2	61,907.3	-3.1	-50.4
Hrazdan TPP	546.8	1,166.5	19,971.7	5.7	7.6
Armenian NPP	2,787.7	61,473.1	27,883.4	-1.1	-2.2
Vorotan HPP	915.9	70,958.4	1,781.9	-6.6	-120.0
Sevan-Hrazdan Cascade	453.4	17,874.4	2,381.9	-0.3	-1.7

Source: [4] - [9]

It can be seen from the table that out of five major power plants only Hrazdan TPP had positive returns both on assets and equity in 2015. The most expensive production was occurred in Yerevan TPP while the cheapest one in Vorotan HPP. Among these five plants, the leader in terms of electricity production was Armenian NPP which produced 2,787.7 *mln. kWh* electricity in 2015.

The results. As it has been already mentioned, efficiency of studied power plants was assessed by solving a dual linear programming problem. The results are presented in the Table 2.

Table 2

The results of DEA model

Plants	Efficiency score (θ)	Efficiency reference sets (λs)				
		λ_1	λ_2	λ_3	λ_4	λ_5
Yerevan TPP	0.34	0	0.07	0.46	0.14	0.33
Hrazdan TPP	1	0	1	0	0	0
Armenian NPP	1	0	0	1	0	0
Vorotan HPP	1	0	0	0	1	0
Sevan-Hrazdan Cascade	1	0	0	0	0	1

Source: Authors' own calculations

Table reports that four out of five studied power plants have an efficiency score of 1 meaning that they demonstrate 100% performance efficiency. Only one plant – Yerevan TPP – got a score equal to 0.34 which indicates that this plant is only 34% efficient as another four plants. Therefore, it is possible to conclude that there are serious management problems in that particular plant which led to an inefficient performance.

The table also provides an information on ERS for each plant. For those ones which have an efficiency score equal to 1, ERS consists only by themselves, therefore optimal λs for those plants are also equal to 1. The story is different for Yerevan TPP. The ERS for this plant consists of Hrazdan TPP, Armenian NPP, Vorotan HPP and Sevan-Hrazdan Hydro Cascade. Respective coefficients indicate mixture of techniques applied by those four plants, adoption of which would allow Yerevan TPP to increase its efficiency to 100%. In more detail, that mixture represents a hypothetical plant inputs which are calculated by multiplying respective coefficients by output and inputs of a respective plant (Table 3). These coefficients provide an information for managers on possible directions of improvements which can result in an increase of performance efficiency.

Table 3

Construction of ERS for Yerevan TPP

Output & inputs	Output & inputs of Hrazdan TPP			Output & inputs of Armenian NPP			Output & inputs of Vorotan HPP			Outputs and inputs of Sevan-Hrazdan Hydro Cascade			ERS for Yerevan TPP
Output													
Electricity production		546.8			2,787.7			915.9			453.4		1594.6
Inputs													
Fixed assets	0.07*	1,166.5	+	0.46*	61,473.1	+	0.14*	70,958.4	+	0.33*	17,874.4	=	43918.1
Cost		19,971.7			27,883.4			1,781.9			2,381.9		15254.3
ROA		4.5			-1.0			-3.3			-0.3		-1.1
ROE		6.0			-2.0			-60.1			-1.7		-17.3

Source: Authors' own calculations

According to the coefficients provided in Table 4, Yerevan TPP should be able to increase its efficiency up to 100% by reducing fixed assets to 43,918.1 *mln. AMD*, production costs to 15,254.3 *mln. AMD*, while increasing ROA to -1.1% and ROE to -17.3%. The level of output will remain the same. The last column of Table 4 gives an information about excess inputs utilized by Yerevan TPP.

Table 4

Inefficiency in Yerevan TPP

Output and inputs	ERS for Yerevan TPP	Actual output and inputs of Yerevan TPP	Column (2) – Column (1)
Electricity production (*mln. kWh*)	1,594.6	1,594.6	0.0
Fixed assets (*mln. AMD*)	43,918.1	127,707.2	83,789.1
Cost of production (*mln. AMD*)	15,254.3	61,907.3	46,653.0
ROA (%)	-1.1	-3.1	-2.0
ROE (%)	-17.3	-50.4	-33.1

Source: Authors' own calculations

Conclusion. In this paper an attempt was made to assess efficiency of five major Armenian power plants with the help of DEA modelling approach. In the analysis, electricity production (in physical values) of plants was taken as an output, while inputs were the volume of fixed assets, production costs and also two financial coefficients – ROA and ROE. In order to get efficiency scores, a dual linear programming problem was solved. The results indicated that only Yerevan TPP had an efficiency different from 100% (only 34%). Moreover, applied modelling technique allowed to define Efficiency Reference Set for that plant which contained Hrazdan TPP, Armenian NPP Vorotan HPP and Sevan-Hrazdan Hydro Cascade.

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09.11.2016.

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ՀՀ ԳԼԽԱՎՈՐ ԷԼԵԿՏՐԱԿԱՅԱՆՆԵՐԻ ԱՐԴՅՈՒՆԱՎԵՏՈՒԹՅԱՆ ԳՆԱՀԱՏՈՒՄԸ ՏՎՅԱԼՆԵՐԻ ՊԱՐՓԱԿՄԱՆ ԵՂԱՆԱԿՈՎ

Տրված է ՀՀ գլխավոր էլեկտրակայանների գործունեության արդյունավետության գնահատումը: Որպես գնահատման մեթոդ կիրառվել է Տվյալների պարփակման եղանակը: Վերջինս նմանատիպ խնդիրների լուծման ամենատարածված մեթոդներից մեկն է: Արդյունքները ստացվել են երկակի գծային ծրագրման խնդրի լուծման միջոցով: Համաձայն արդյունքների՝ ուսումնասիրված հինգ կայաններից միայն Երևանի ջերմային էլեկտրակայանի համար է ստացվել 1-ից փոքր արդյունավետության գործակից: Բացի այդ, համապատասխան մեթոդների օգնությամբ սահմանվել է տվյալ կայանի արդյունավետ բազմությունը, ինչպես նաև առաջարկվել են արդյունավետության բարձրացմանն ուղղված որոշ քայլեր:

Առանցքային բառեր. *տվյալների պարփակման եղանակ, գծային ծրագրում, գործունեության արդյունավետություն, էլեկտրաէներգիայի արտադրություն:*

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ОЦЕНКА ЭФФЕКТИВНОСТИ ОСНОВНЫХ ЭЛЕКТРОСТАНЦИЙ АРМЕНИИ МЕТОДОМ АНАЛИЗА СРЕДЫ ФУНКЦИОНИРОВАНИЯ

Дается оценка эффективности деятельности основных электростанций Армении. Оценка выполнена методом анализа среды функционирования, являющимся одним из самых распространенных методов решения задач данного вида. Согласно результатам, полученным решением двойственной задачи линейного программирования, из пяти основных станций только для Ереванской ТЭС определен коэффициент эффективности меньше единицы. Более того, с помощью соответствующих методов определено эффективное множество данной станции, а также предложены некоторые шаги для повышения ее эффективности.

Ключевые слова: *анализ среды функционирования, линейное программирование, эффективность деятельности, производство электроэнергии.*

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