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Research Article

Efficiency Assessment of Hydroelectric Power Plant in Turkey by Data Envelopment Analysis (DEA)

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Abstract

Renewable energy resources are being increasingly used, because reserves of fossil energy sources are limited, they lead to environmental problems, economic and political reasons in foreign dependency and price instabilities. Hydroelectric power is a clean and renewable energy source. This power is a source having Turkey's largest renewable energy potential. Hydroelectric power plants (HEPP) are the plants constructed to use the flow energy of water and to produce electricity. This energy source becomes even more important, since approximately 20.81% of the energy consumed in Turkey is met by HEPPs. In this study, the efficiency assessment of 51 HEPPs constructed in Turkey was carried out by Data Envelopment Analysis (DEA). In accordance with this purpose, three input variables and two output variables were defined. Efficiency-measurement was performed using CCR model developed by Charnes, Cooper and Rhodes. The improvement rates that inefficient power plants should perform input and output variables in order to reach the efficiency limit, were determined by DEA method. Therefore, the efficiency of HEPPs with 32% of Turkey's total installed power was tried to measure using DEA model in this study. In the application, DEA model was used separately for 51 HEPPs and the models were solved using GAMS package program. When the results obtained were examined, it was observed that 19,61% of HEPPs were operating effectively. Suggestions for improvement were offered for inefficient HEPPs.

Keywords: Renewable energy, Hydroelectric power plants, Efficiency analysis, Data envelopment analysis, Performance evaluation

Türkiyedeki Hidroelektrik Santrallerin Etkinliklerinin Veri Zarflama Analizi (VZA) ile Değerlendirilmesi

Öz

Fosil enerji kaynaklarının rezervlerinin sınırlı olması, çevre sorunlarına, dışa bağımlılıkta ekonomik ve siyasi nedenlere yol açması ve fiyat istikrarsızlıkları gibi nedenlerden dolayı yenilenebilir enerji kaynakları kullanımı gittikçe artmaktadır. Hidroelektrik enerji temiz ve yenilenebilir bir enerji kaynağıdır. Bu enerji Türkiye'nin en büyük yenilenebilir enerji potansiyeline sahip olan bir kaynaktır. Hidroelektrik santraller (HES) ise, suyun akış enerjisinden faydalanılarak, elektrik enerjisi elde etmek için kurulan santrallerdir. Türkiye'de tüketilen enerjinin yaklaşık %20,81'inin HES'lerden karşılanması bu enerji kaynağını daha da önemli hale getirmektedir.

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Bu çalışmada, Türkiye'deki kurulu 51 adet HES'in etkinlikleri Veri Zarflama Analizi (VZA) kullanılarak değerlendirilmiştir. Bu amaç doğrultusunda, üç girdi iki çıktı değişkeni belirlenmiştir. Etkinlik ölçümü, Charnes, Cooper ve Rhodes'un geliştirdiği CCR modeli kullanılarak gerçekleştirilmiştir. VZA yöntemiyle, etkin olmayan santrallerin etkinlik sınırına ulaşabilmeleri için girdi ve çıktı değişkenlerinde gerçekleştirmeleri gereken iyileştirme oranları saptanmıştır. Sonuç olarak bu çalışmada, Türkiye toplam kurulu gücünün %32'sine sahip HES'lerin etkinlikleri VZA modeli kullanılarak ölçülmeye çalışılmıştır. Uygulamada VZA modeli 51 adet HES için ayrı ayrı çalıştırılmış ve GAMS paket programı kullanılarak modeller çözülmüştür. Elde edilen sonuçlar incelendiğinde, HES'lerin %19,61'inin etkin bir şekilde çalıştığı gözlenmiştir. Etkin olmayan HES'ler için ise geliştirmeye yönelik öneriler sunulmuştur.

Anahtar Kelimeler: Yenilenebilir enerji, Hidroelektrik enerji santralleri, Etkinlik analizi, Veri zarflama analizi, Performans değerlendirme.

1. Introduction

The energy consumption realized with each passing day because of the industrialization and rapid population growth in Turkey as well as in the entire World, has been above the expected level. Turkey are largely dependent on outside financial sources, because the available sources could not meet the energy needs. Turkey should detect and make clean and renewable energy production methods available in the fastest time as an alternative to fossil fuels with common usage areas due to concerns caused by both environment and dependence. The fact that renewable energy is nonconsumable, it can renew itself continuously, it is environmentally friendly in harmony with nature and most importantly, that the most worried high cost problem can be solved with developing technology, increases the demand and investments for these sources. The number of the constructed renewable energy plants is increasing with each passing day in Turkey. 35.91% of the energy produced in Turkey is provided by renewable sources (hydro, wind, solar and geothermal). When hydraulic sources taking the most important place in Turkey's renewable energy sources are examined; Turkey's theoretical hydroelectric potential is 1% of that of the World and Turkey's economic potential is 16% of that of Europe. Turkey produced 58.4 billion kWh of electricity from hydropower plants in 2017. As of end-June 2018, 636 HEPPs in operation with total installed capacity of 27,912 MW corresponds to 32% of the total installed capacity of Turkey. The energy generated from hydraulic sources constitutes 20.08% of the total energy generation.

HEPPs are the plants that produce electricity after the water is stored from stream bed and lowered from a certain elevation to create falling water and this falling water causes the turbine to spin. In other words, HEPPs convert the gravitational potential energy of the water to kinetic energy first and then to the electric energy via generator motor (Koçhan Arı, 2013). Hydroelectric power plants; are domestic sources that are environment-friendly, clean, renewable, high-efficiency, without fuel expenses, long-lasting, with very low operating expense and not dependent on outside financial sources. HEPP becomes more important since it has the highest share among renewable energy sources in energy generation.

Turkey's hydroelectric power potential map is shown in Figure 1. Starting from this, the performances of 51 hydroelectric power plants in Turkey were evaluated by DEA in this study. Efficient and inefficient plants were determined with respect to their performances and it is revealed which parameter value should be changed how much in order to make inefficient plants be effective (Energy Atlas, 2019a).

Figure 1. Map of Turkey's Hydroelectric power plants (Energy Atlas, 2019a)

DEA is a method used to measure relative efficiency. The method evaluates both objectives and possible consequences in problems including multiple inputs and multiple outputs. Efficiency measurement enables to determine where the enterprise is located in the current competitive environment and shows how well the output will be produced from the present inputs (Kaya et al. 2010).

Considering the current studies on DEA, it can be seen that it is applied to the following fields: measure to efficiency radiotherapy treatments (Ehrgott et al. 2018), measure to efficiency of collective floodplain aquaculture (Bayazid et al. 2019), analysis of efficiency and production volume in an armament manufacturer (de Souza et al. 2018), identifying efficient construction sites in terms of safety (Nahangi et al. 2019), hotels performance evaluation (Ang et al. 2018), efficiency in the environmental management of plastic wastes

(Gobbi et al. 2019), identification of efficient dairy farms (Siafakas et al. 2019), efficiency in the Brazilian banking system (Henriques et al. 2018), evaluating the sustainability of national logistics performance (Rashidi and Cullinane 2019), regional tourism efficiency (Chaabouni 2019), assessment of the Global Food Security Index (Chen et al. 2019), assessing China's agricultural water use efficiency (Geng et al. 2019), eco-efficiency of centralized wastewater treatment plants in industrial parks (Hu et al. 2019), inventory-related costs in green supplier selection (Dobos and Vörösmarty 2019), the university teaching performance evaluation (Zhang and Shi 2019), outsourcing performance quality assessment (Pournader et al. 2019), performance measurement of Turkish electric distribution companies (Petridis et al. 2019), efficiency analysis of emergency departments (Akkan et al. 2019). Studies conducted on energy using DEA method are given in Table 1:

Table 1. Energy studies conducted by DEA

Author(s)	***Application area***
Sarıca and Or 2007	*Efficiency assessment of Turkish power plants (65 thermal, hydro and wind power plants)*
San Cristóbal 2011	*Evaluate the efficiency of Renewable Energy technologies*
Özyiğit et al. 2011	*Efficiency assessment of energy sources for electricity generation in Turkey*
Mobtaker et al.2012	*Optimization of energy required for alfalfa production*
Lins et al. 2012	*11 alternative energy sources for energy analysis*
Li-bo and Tao 2014	*The Evaluation and Selection of Renewable Energy Technologies in China*
Emre and Ömürgönülşen 2015	*Measurement of the relative efficiency of wind power plants (wpp) in the Marmara region*
Ervural et al. 2016	*Energy Efficiency Evaluation of Provinces in Turkey*
Arabi et al. 2016	*Measurement of technical and financial efficiency of different types of energy sources*
Amid et al. 2016	*Analyze energy efficiency for broiler production*
Wu et al. 2016	*Efficiency assessment of wind farms in China (42)*
Ömürgönülşen et al. 2016	*Efficiency analysis of wind power plants in Turkey (61)*
Sağlam 2017	*Assessment of the productive efficiency of large wind farms in the United States (236 wind*
Eroğlu and Seçkiner 2017	*Performance analysis in wind farms*
Ervural et al. 2018	*Assess the sustainable energy efficiency*
Longo et al. 2018	*Energy efficiency at wastewater treatment plants*
Sağlam 2018	*Performance assessment of utility-scale wind farms in Texas*
Zheng et al. 2018	*Evaluating the efficiency of energy conservation measures in energy service companies in*
Mohseni et al. 2018	*Mitigation of environmental impacts and enhancement of energy efficiency in grape*
Hosseinzadeh-Bandbafha et	*Optimization of energy consumption of dairy farms*
Gökgöz and Güvercin 2018	*Energy security and renewable energy efficiency*
Pambudi and Nananukul 2019	*Wind turbine site selection in Indonesia*
Zhao et al. 2019	*The provincial energy efficiency of China*
Gong et al. 2019	*The efficiency of sustainable operations*
Nadimi and Tokimatsu 2019	*Evaluation of the energy system*
Jha and Singh 2019	*Performance evaluation of Indian states in the renewable energy sector*
Zeng et al. 2019	*Evaluation of renewable energy technical plans*

As can be seen in Table 1, there are so many studies conducted on the energy field using DEA method. Moreover, by using DEA method, the difference between the current studies on HEPPs effeciency measurement and our study are as follows: In the study of de França et al. (2017), it is emphasized that the electricity generated by HEPPs in Brazil is very important for economic growth. For this purpose, the most effective company was determined by DEA and linear regression model using financial statements of 11 companies. Therefore, they stated that the efficiency of the company was obtained by combining the smaller contribution margin value with different rates of other variables. In the study of Jha and Shrestha (2006), the performances of hydroelectric power plants in Nepal was evaluated using DEA. The technical and scale efficiencies of 50 decision units were calculated using 4-year data. In the study of Barros (2008), with the data of 2001-2004, the performance evaluation was performed taking values of number of workers, capital, operational costs, investment as input and values of production in MWh, capacity utilisation as % of total as output for 25 hydroelectric plants. Wu and Yan (2011) suggested a new model for power generation optimization of hydro power plants and performed efficiency analysis using historical and optimal data for cascaded hydro power plants based on efficiency index. Wu et al. (2011) included DEA in electromagnetism-like mechanism and solved the multi-objective optimization problem for 8 hydroelectric power plants. With this model, total energy generation and the final water storage for regulating reservoir are maximized, the sum of bias squares of final water storage, the total water consumption and the total water spillage of the last hydroelectric plant values are minimized. In the study of Sözen et al. (2012), with DEA and Window analysis, capacity usage factor, installed capacity, water collection at the dam reservoir values were used as input in Model 1 for 10 hydro-power plants and the efficiency analysis was performed taking net generation value. In Model 2, water collection at the dam reservoir, gross generation and operational costs values were taken as input, and unit cost was taken as output. In the study of Jiekang et al. (2014), DEA was included in electromagnetism-like mechanism and a new multipurpose scheduling model was suggested to achieve the optimal balance between water volume and quantity of electricity for production. A test system with eight hydroelectric power plants was used to verify this new method. In the study of Calabria et al. (2018), the performances of 81 hydro power plants were evaluated by DEA method considering four indicators (annual operation and maintenance costc per installed capacity, availability factor, Failure rate, Average time to repair).

This study is different from the studies mentioned above with regard to the amount and types of input/output, the model used together with DEA, the number of plants of which efficiency is measured, the different scenarios established, the region and place where it is applied, etc. In this study, the efficiency of 51 HEPPs constructed in Turkey was assessed using CCR model of DEA. In accordance with this purpose, values of “Installed power”, “Production capacity (year)” were used as input variables; “Amount of water use for electricity generation”, “Electricity generation amount (year)” and “the average number of people whose energy needs are met” were used as output variables. Efficiency-measurement was performed using CCR model developed by Charnes, Cooper and Rhodes. The improvement rates that inefficient power plants should perform input and output variables in order to reach the efficiency limit, were determined by DEA method.

The remainder of the study is organized as follows: the methodology describing DEA in detail, is the application section where HES efficiencies are assessed and Discussion and Conclusion section where the results finally obtained are construed.

2. Methodology

2.1. *The Data Envelopment Analysis (DEA) method*

DEA is a method formulated by Charnes et al. under the name of constant return scale-CRS in 1978 and named by first letters of Charnes, Cooper and Rhodes (CCR). The basic logic of DEA method is to measure the distance of each Decision-making unit (DMU) from the limit defined as the quantitative efficiency limit and to reveal the efficiency level (Charnes et al. 1978). Then, variable return scale-VRS of DEA was developed by Banker et al. in 1984 and this method was named by first letters of Banker, Charnes and Cooper (BCC). In cases where inputs and outputs measured in multiple and different scales or with a different unit of measure make comparison difficult, DEA that aims to measure the relative performance of decision-making units and that is a linear-based technique is one of the most frequently used non-parametric methods (Emre 2014).

DEA method determines “the best” observation that produces the most output composition using the least input composition in any observation set before measuring DMU efficiency. Then it accepts this limit as “reference” and measures the distance of inefficient DMUs to this limit. The solution is made using a linear programming technique for each method. If efficiency value is “1”, the result is efficient, if efficiency value is different from “1”, the result is inefficient.

DEA models are classified in two ways. They are constant return model (CCR) and variable return model (BCC) according to the scale; while they are input-oriented and output-oriented according to model. According to the constant return assumption, a unit increase in inputs will result in a unit increase in outputs. According to the variable return assumption, a unit increase in inputs will not result in an increase in the same rate. The purpose of input-oriented models is to hold outputs constant and to minimize inputs, while the purpose of output-oriented models is to hold inputs constant and to maximize outputs.

Since the total efficiency of the power plants was examined in our study and the efficiency score was tried to be determined according to the maximum output which could be generated against a certain input, the input-oriented CCR model was used (Özden 2008):

$$Enk\ \theta_k - \varepsilon \sum_{i=1}^{m} S_i^{-} - \varepsilon \sum_{r=1}^{s} S_r^{+} \quad (2.1)$$

$$S_i^{-} = \theta_k X_{ik} - \sum_{j=1}^{n} X_{ij}\lambda_j \qquad i = 1, \dots m \quad (2.2)$$

$$S_r^{+} = \sum_{j=1}^{n} Y_{rj}\lambda_j - Y_{rk} \qquad r = 1, \dots s \quad (2.3)$$

$$\lambda_{jk}, S_i^{-}, S_r^{+} \geq 0 \qquad j = 1, \dots, n \quad (2.4)$$

Y_{rj}: the rth output of DMU$_j$

X_{ij}: the i[th] input of DMU$_j$

λ_j: the model variables

S_i^-: the value of slack for the i[th] input

S_r^+: the value of slack for the r[th] output

θ_k: the efficiency in input orient ($0 \leq \theta_k \leq 1$)

ε : a very small number

In the model given above, the equation (2.1) shows the value of the objective function for a DMU. EquationS (2.2 and 2.3) are used to find the values of idle variables for the inputs and outputs. Equation (2.4) refers to the sign constraint. If both of the following conditions are met, DMU is efficient.

1. $\theta_k = 1.0$
2. All slack variables (S_i^-, S_r^+) are zero.

If $\theta_k < 1.0$ and, all slack variables (S_i^-, S_r^+) ≠0, it is concluded that DMU is relatively inactive.

3. Application

In this study, technical efficiencies of 51 HEPPs (Energy Atlas, 2019b), which are in operation as of April 2019 and of which information can be accessed, were calculated using DEA. HEPP capacity in Turkey selected as sample, is the running capacity that provides electricity to network as of April 2019. The data published on the official website of Hydroelectric Energy Atlas were taken as a basis in this study, because it provides the most comprehensive and current data available for use in Turkey. Accordingly, HEPPs are seen to concentrate in Southeast Anatolia, Eastern Black Sea, Eastern Anatolia and Aegean regions where there are plenty of rivers and lakes.

DEA was chosen as the work description. We can list the reasons for this as measuring efficiency relatively in DEA, considering more than one factor which cannot be measured with the same unit, revealing the strengths and weaknesses of the units. In the section about DEA of the study, in other words, the analysis part was made by using GAMS package program.

The determination of the input and output variables in DEA application, as well as the accessibility of the data required for the selected variables are of great importance. In this study, studies in the literature were used to determine input and output variables. The definition of these variables is shown in Figure 2. Data were collected for each power plant for the specified variables. Input and output values were determined for each HEPP. Some of these are shown in Table 2. Because of data privacy, the names of the power plants are coded with numbers. Regional data are available for power plants.

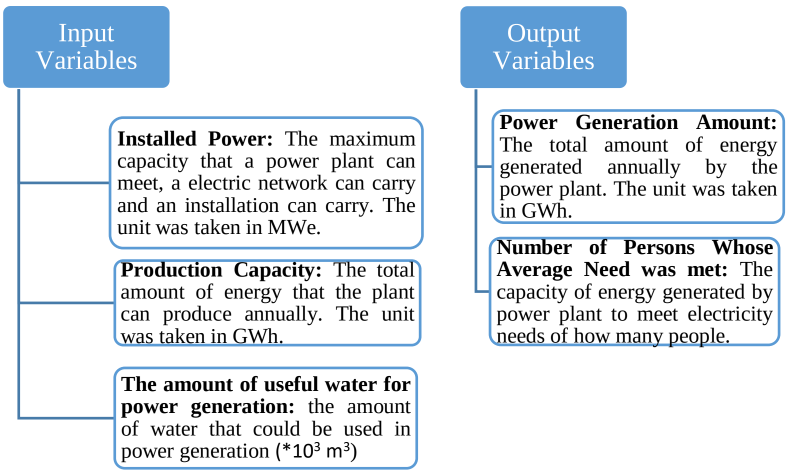

Figure 2. The definition of input and output variables

Table 2. Input and Output Values of HEPPs

HEPP No	City	S_1^-	S_2^-	S_3^-	S_1^+	S_2^+
		Installed Power Mwe	**Generation capacity /annual GWh**	**Amount of useful water for power generation (*10^3 m^3)**	**Amount of Power Generation /annual GWh**	**Number of Persons Whose Average Need was met**
1	Şanlıurfa	2405	8100	11.169.800	6831	2.063.706
2	Diyarbakır	1800	7500	4.353.110	6668	2.014.597
3	Elazığ	1330	6600	13.927.400	5795	1.750.733
4	Samsun	702,55	1632	2.892.000	922	278.541
5	Artvin	669,6	2118	963.000	1328	401.257
6	Antalya	540	1620	76.487	1207	364.578
7	Sinop	513	1468	1.402	804	243.043
8	Osmaniye	510	1669	302.000	1459	440.692
9	Samsun	500	1217	636.062	1140	344.310
10	Adana	310,66	966,53	300.540	736	222.328
11	Karaman	302,4	1187	1.747	763	230.407
12	Artvin	300,6	1039	150.781	822	248.298
13	Kahramanmaraş	283,5	725	747.900	648	195.821
14	Eskişehir	278,4	400	221.425	421	127.243
15	Çorum	210,8	473	136.600	364	110.079
16	Diyarbakır	198,48	483	816.600	330	99.798
17	Gaziantep	189	652	89.672	406	122.718
18	Bingöl	170	413	690.200	457	137.993
19	Adana	168,9	596	720.000	473	142.901
20	Ankara	160	300	942.250	317	95.738
21	Mersin	159,38	528	65.468	340	102.746
22	Osmaniye	138	569	1.146.250	597	180.469
23	Kırşehir	128	300	2.035.120	186	56.150
24	Kahramanmaraş	124	515	1.440.600	479	144.679
25	Sivas	120	332	1.033.260	326	98.566
26	Artvin	115	444	19.800	395	119.305
27	Diyarbakır	110	298	239.825	190	57.526
28	Gümüşhane	103	322	80.800	245	74.100
29	Kayseri	100	422	2.076.000	356	107.543
30	Erzurum	96	313,898	12.000	205	61.875
31	Diyarbakır	94,5	146	1.655.080	107	32.439
32	Adana	89,42	203,14	23.000	140	42.169
33	Gümüşhane	85	198	62.700	151	45.550
34	Ankara	76	250	56.946	117	35.256
35	Manisa	69	80	765.308	113	34.035
36	Samsun	69	350	28.090	305	92.047
37	Denizli	62	150	821.580	112	33.850
38	Samsun	56,4	257	45.750	179	53.973
39	Kırıkkale	54	190	140.761	112	33.733
40	Aydın	48	80	361.600	105	31.697
41	Antalya	48	220	72.400	151	45.650
42	Neşehir	47	166,04	66.000	135	40.729
43	Burdur	46,4	206	6.300	149	45.093
44	Karaman	38	120	12.500	68	20.452
45	Ankara	38,89	122	4.675	105	31.800
46	Sivas	32	102	22.617	91	27.589
47	Burdur	32	142	824.634	105	31.784
48	Denizli	28,72	88,12	78.000	66	19.968
49	Tokat	27	100	855.257	86	25.988
50	Erzurum	20,9	36	307.100	21	6.320
51	Erzincan	15	51	132.182	43	12.980

4. Results and Discussion

In this section, the results obtained by DEA are discussed. For each HEPP, VCR model for CCR input was studied in GAMS package program. The mathematical model given in Section 2 is solved in GAMS package program and $\boldsymbol{\theta}$ and **S** values of each DMU are obtained and the values obtained are shown in Table 3. When the results of 51 HEPPs are examined, it is seen that 10 power plants (power plants numbered as 7, 11, 14, 18, 22, 26, 35, 36, 40 and 45) are generating effectively. Suggestions will be given in the discussion section in order to enable other power plants to become effective.

Table 3. GAMS results of HEPPs

DMU	$\boldsymbol{\theta}$	S	DMU	$\boldsymbol{\theta}$	S
1	0,822	- - - 1,559 -	26	1	- - - - -
2	0,954	- - - 5,259 -	27	0,639	- - - 0,472 -
3	0,989	- - 1,203E+11 5,005 -	28	0,822	- - - 0,321 -
. . .	. . .	. . .	. . .	. . .	. . .
11	1	- - - - -	48	0,752	- - - 0,130 -
12	0,871	- - - 0,054 -	49	0,804	- - 5,103E+05 - 5,828
13	0,868	- - - 0,399 -	50	0,449	- - 67081,440 - 19,785

The efficiency values of the hydroelectric power plants are shown in pie chart (Figure 3). In the graph, the majority of the hydroelectric power plants, in other words, the efficiency values of, 43.14% were in the range of 0.7-0.9, but the efficiency of only one HEPP fell below 0.5. 19.61% of the plants were efficient.

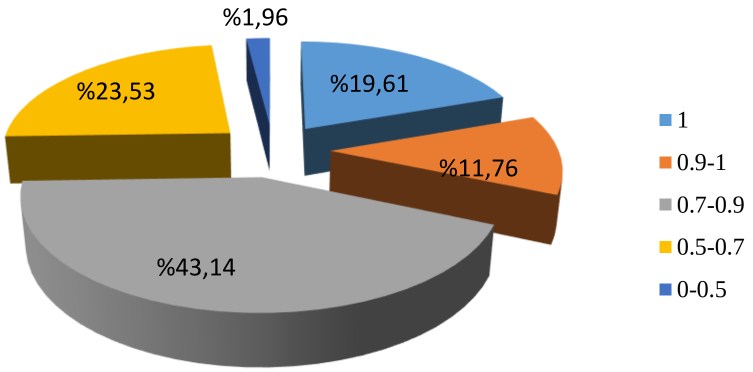

Figure 3. Efficiency values of HEPPs

Firstly, DEA model was operated separately for 51 HEPPs using GAMS package program and the efficiency values of each power plant were measured. Then, it was examined why inefficient plants (θ_k < 1.0 and S_i^-, S_r^+ ≠0) were not efficient using GAMS package program dual results. Table 4 shows S_i^- and S_r^+ results of some inefficient HEPPs. Using this Table, it is calculated how much improvement should be done in inputs and outputs to ensure HEPPs to be efficient. For instance, improvement rates for inefficient 51th HEPP are calculated as follows: amount of useful water for power generation is 132.182 (*10^3 m^3), and S_3^- for 51th HEPP 8532,424 (*10^3 m^3). In other words, the capacity of %6,5 ((8532,424/132.182)*100) is not used. In this regard, amount of useful water for power generation should be increased by %6,5 in order to make 51st HEPP be efficient.

Table 5 shows improvement rates for inefficient plants.

Table 4. GAMS dual results

Plants/Slack variables	S_1^-	S_2^-	S_3^-	S_1^+	S_2^+
1	-	-	-	1,559	-
2	-	-	-	5,259	-
3	-	-	1,203E+11	5,005	-
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
31	-	-	4,773E+05	0,504	-
32	18,776	-	-	-	120,718
33	-	-	-	-	69,408
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
50	-	-	67081,44	-	19,785
51	-	-	8532,424	-	15,481

Table 5. Improvement rates for inefficient plants

Plants/Slack variables	S_1^-	S_2^-	S_3^-	S_1^+	S_2^+
1	-	-	-	%0,02	-
2	-	-	-	%0,08	-
3	-	-	%0,00	%0,09	-
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
31	-	-	%0,00	%0,47	-
32	%20	-	-	-	%0,29
33	-	-	-	-	%15
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
50	-	-	%22	-	%0,31
51	-	-	%6,5	-	%0,12

When Table 5 is taken into consideration, it is seen that the amount of Power Generation should be improved by 0,02% for HEPP No. 1. This means that the annual production amount of plant No. 1 is normally 6831 GWh. The plant does not work effectively as is. If plant No.1 generates annually 6833 GWh power by increasing the amount of annual power generation by 0,02%, the power plant will become efficient. Another example, when we consider the power plant No. 33, the reason why the power plant is ineffective is due to the number of people whose average energy needs are met. Therefore, the number of people whose energy needs are met should be increased by 15% to make the power plant to be efficient. Normally, the power plant meets the needs of 45,550 people as is. If plant No. 33 can meet the energy needs of 45,619 people, it will become efficient.

5. Conclusions

About one-third of Turkey’s energy supply is provided by Hydraulic energy among the renewable energy sources including nonconsumable solar, geothermal, biomass, wind and water that Turkey has. The theoretical hydroelectric potential of our hydraulic sources, which takes the most important place in the renewable energy potential of our country, is 433 billion kWh and the technically evaluable potential is 216 billion kWh and the economic hydroelectric energy potential is 140 billion kWh/year. The present HEPPs corresponds to 32% of Turkey’s total installed capacity.

It is assumed that hydroelectric power plants are one of the least harmful energy production methods. During the operation phase, no toxic waste is produced and as is, greenhouse gas emissions (CO2) are relatively low compared to the power plants using fossil fuels in energy production. Therefore, it is the most widely used form of renewable energy together with solar, wind and geothermal sources in recent years.

For these reasons, the performance assessment for existing 51 HEPPs in Turkey was performed using DEA method and GAMS package programming in this study. It will be necessary to obtain maximum benefit from the inputs and to change the input combinations if necessary in order to ensure the high efficiency of the plants being evaluated. High efficiency will provide an economic return and it will be necessary to measure efficiency and to make comparisons between certain periods in order to reach this point.

When the results obtained were examined, it was observed that 80,39% of 51 HEPPs were not operating effectively. The reason why inefficiency rate is high is that most of the available input amounts cannot be converted to output. In general, when 51 HEPPs data are examined, although there is a large amount of useful water that can be used in energy production, it is not used effectively. The factors causing inefficiencies (climate change, operating and maintenance costs, number of employees, etc.) in ineffective plants should be determined by on-site inspection. The performance measurement of these plants should be performed in certain periods and it should be determined how and to what extent the output changes and what the parameters that affect this change are.

Future studies may make calculations and compare the results for BBC and CCR models from DEA models. In this study, the efficiencies of HEPPs were also measured, it is possible to calculate the efficiency value for different power plant types. Researchers may measure the efficiencies of plants by increasing input and output values.

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