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Abstract—**The growing demand for electricity energy requires expansion and improvement of the appropriate capacities of thermal power plants. In order to provide the stable and sustainable electricity production as well as to improve the sustainable development of each mining company, optimal coal supplier selection for thermal power plant has a great significance and represents the core of this study. There are many reasons for coal supplier selection for thermal power plant. Some of them are related to decreasing the cost of electricity production, enhancing market competitiveness, establishing a balanced quantity and quality of ore delivery to power plant etc. In this paper, we have developed a new model of optimal coal supplier selection for thermal power plant based on MCRAT method. The model was tested as hypothetical example related to coal supplier selection for thermal power plant.**

Keywords - coal supplier selection, multi – criteria decision – making, MCRAT method, objective criteria weights

I. Introduction

Coal represents one of the strategically most important energy raw material, both in the world and in our country. Coal plays a vital role in electricity production. The economy and energy development of each country largely depends on stable electricity production. In Serbia, coal is primary applied for electricity production and represents a crucial factor in sustainable development of the country. In the world, about 40% of electricity is produced by coal combustion, while in Serbia, even 70% of electricity is produced by coal combustion in thermal power plants.

Thermal power plant is a key facility at each coal mine. The main role of each thermal power plant is referred on electricity production obtained by coal combustion. The type of coal that used for burning can vary from lignite to brown coal depending on target attribute value required by thermal power plant. Coal, used for combustion in thermal power plant, is characterized by the following attribute values (criteria) such as: calorific value, ash, sulphur and moisture content. In addition to the above coal quality attributes, we should not forget the economic attribute of coal such as the coal price on the market. Based on these main attributes (criteria) that characterize each coal types, coal supplier can be selected for sustainable delivery to thermal power plant.

Several authors in mining industry have dealt with multi – criteria decision – making optimization and applied different mathematical methods and new approaches for coal supplier selection for thermal power plant [1-4].

In this paper, multi – criteria decision – making method called MCRAT method is applied for optimal coal supplier selection for thermal power plant. Also, we have applied a novel objective method for criteria weights determination, Method based on the Removal Effects of Criteria (MEREC) and compare results with a traditional Shannon’s entropy method. The rest of this paper is organized as follows. In Section 2, detailed description of the multi – criteria decision – making method (MCRAT method) is represented including description of methods for objective criteria weights determination (Shannon’s entropy method and MEREC method). Section 3 is referred on numerical example where hypothetical situation is tested. Finally, conclusions about the developed model and obtained results are discussed in Section 4.

II. Multi – Criteria Decision – Making Model

The most suitable way to describe the problem of alternative ranking is the decision-making matrix, abbreviated decision matrix:

$$D=\left[x_{ij}\right]_{m\times n}=\\ =\begin{bmatrix} A/C & C_1 & C_2 & \dots & C_n \\ A_1 & x_{11} & x_{12} & \dots & x_{1j} \\ A_2 & x_{21} & x_{22} & \dots & x_{2j} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_m & x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix}, \quad (1)$$

where:

$A=\left[A_1,A_2,\dots,A_m\right]$ – a given set of alternatives,

$C=\left[C_1,C_2,\dots,C_n\right]$ – a given set of criteria,

m – the total number of alternatives

n – the total number of criteria

$\left[x_{ij}\right]_{m\times n}$ – an assessment of alternative Ai with respect to a set of criteria.

The procedure of the multiple criteria ranking by alternative trace (MCRAT) method [5] is composed of the following steps:

Step 1: Normalization of input data

Normalization is a process of transforming different dimensions of input data into compatible scale i.e., unity interval [0,1]. For that purpose, we applied a simple linear normalization technique, and it is described as follows:

For the benefit criteria:

$$r_{ij}=\frac{x_{ij}}{max_i\left(x_{ij}\right)},\ \forall i\in\left[1,2,\dots,m\right]\wedge j\in S_{max}\ , \quad (2)$$

For the cost criteria:

$$r_{ij}=\frac{min_i\left(x_{ij}\right)}{x_{ij}},\ \forall i\in\left[1,2,\dots,m\right]\wedge j\in S_{min}\ , \quad (3)$$

where:

S_{max} – a set of benefit criteria

S_{min} – a set of cost criteria

The normalized decision matrix R is formed as:

$$R=\left[r_{ij}\right]_{m\times n}=\\ =\begin{bmatrix} A/C & C_1 & C_2 & \dots & C_n \\ A_1 & r_{11} & r_{12} & \dots & r_{1j} \\ A_2 & r_{21} & r_{22} & \dots & r_{2j} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_m & r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix}\frac{1}{2}. \quad (4)$$

Step 2: Weighted normalization

For each normalized assessment r_{ij} do the weighted normalization as follows:

$$u_{ij}=w_j r_{ij},\forall i\in\left[1,2,\dots,m\right],\forall j\in\left[1,2,\dots,n\right]. \quad (5)$$

The outcome of weighted normalization is weighted normalized matrix:

$$U=\left[u_{ij}\right]_{m\times n}=\\ =\begin{bmatrix} A/C & C_1 & C_2 & \dots & C_n \\ A_1 & u_{11} & u_{12} & \dots & u_{1j} \\ A_2 & u_{21} & u_{22} & \dots & u_{2j} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_m & u_{m1} & u_{m2} & \dots & u_{mn} \end{bmatrix}. \quad (6)$$

Step 2.1: Shannon's entropy method

One of the most used methods for determining the criteria weights is Shannon's entropy method. Entropy is a measure of uncertainty in the information formulated using probability theory. This method provides a help the decision maker to reduce subjectivity during criterion weight assignment. Shannon and Weaver [6] proposed the entropy concept and this concept has been upgraded by Zeleny [7] for deciding the objective criteria weights. Entropy contains the following steps:

Step 2.1.1: Construct the initial decision-making matrix as follows:

$$\left(A/C\right)=\left[x_{ij}\right]_{mxn}=$$
$$=\begin{bmatrix} A/C & C_1 & C_2 & \cdots & C_n \\ A_1 & x_{11} & x_{12} & \cdots & x_{1n} \\ A_2 & x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_m & x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}, \quad (7)$$

where:

x_{ij} – represents the evaluation of the alternative i with respect to criterion j,

m – the number of alternatives,

n – the number of criteria.

Step 2.1.2: Construct the normalized matrix r_{ij} using following Eq.:

$$r_{ij}=\frac{x_{ij}}{\sum_{i=1}^{m}x_{ij}} . \quad (8)$$

Step 2.1.3: Value of the entropy e_j is calculated as follows:

$$e_j=-k\sum_{i=1}^{m}r_{ij}ln\ a_{ij} , \quad (9)$$

where:

$k=\frac{1}{lnm}$ – a constant that guarantees $0\le e_j\le 1$.

m – a total number of alternatives.

Step 2.1.4: The degree of divergence d_j is determined using following Eq.:

$$d_j=1-e_j . \quad (10)$$

Step 2.1.5: The objective weight for each criterion w_j is calculated as follows:

$$w_j=\frac{d_j}{\sum_{j=1}^{n}d_j} . \quad (11)$$

Step 2.2: MEREC method

This method was developed by [8] for obtaining the objective criteria weights determination in multi – criteria decision – making problems. This novel idea for criteria weights determination represents the Method based on the Removal Effects of Criteria (MEREC). MEREC is created by the following steps:

Step 2.2.1: Construct the initial decision – making matrix with input data

$$X=\left[x_{ij}\right]_{nxm}=\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix}, \quad (12)$$

where are:

n – the number of alternatives,

m – the number of criteria.

Step 2.2.2: Normalization of the initial decision – making matrix

for beneficial (maximization) criteria:

$$r_{ij}=\frac{\min\limits_{i=1,2,\ldots,n} x_{ij}}{x_{ij}} . \quad (13)$$

for non – beneficial (minimization) criteria:

$$r_{ij}=\frac{x_{ij}}{\max\limits_{i=1,2,\ldots,n} x_{ij}} . \quad (14)$$

Step 2.2.3: Calculation the overall performance of the alternative S_i:

$$S_i=\ln\left(1+\left(\frac{1}{m}\sum_j\left|\ln\left(r_{ij}\right)\right|\right)\right) . \quad (15)$$

Step 2.2.4: Calculate the performance of the alternatives by removing each criterion $S_{ij}^{'}$:

$$S_{ij}^{'} = \ln\left(1+\left(\frac{1}{m}\sum_{k,k\neq j}\left|\ln\left(r_{ik}\right)\right|\right)\right), \quad k = 1,2,\ldots,m \quad (16)$$

Step 2.2.5: Compute the summation of absolute deviations E_j :

$$E_j = \sum_i \left|S_{ij}^{'} - S_i\right| . \quad (17)$$

Step 2.2.6: Final criteria weights determination w_j:

$$w_j = \frac{E_j}{\sum_k E_j},\ k = 1,2,\ldots,m . \quad (18)$$

Step 3: Optimal alternative determination

Determine each element of the optimal alternative as follows:

$$q_j = max\left(u_{ij} | 1 \le j \le n\right),\ \forall i \in [1,2,\ldots,m] . \quad (19)$$

Optimal alternative is represented by the following set:

$$Q = \left\{q_1, q_2, \ldots, q_j\right\}, j = 1,2,\ldots,n . \quad (20)$$

Step 4: Decomposition of the optimal alternative

This step implies decomposition of the optimal alternative in the two subsets or two components. The set Q can be represented as the union of the two subsets:

$$Q = Q^{max} \cup Q^{min} . \quad (21)$$

If the k represents the total number of benefit criteria, then $h = n - k$ represents the total number of cost criteria. Hence, the optimal alternative is defined as:

$$Q = \left\{q_1, q_2, \ldots, q_k\right\} \cup \left\{q_1, q_2, \ldots, q_h\right\}; \quad k + h = j . \quad (22)$$

Step 5: Decomposition of the alternative

Similarly, to the Step 4 we perform decomposition of each alternative:

$$U_i = U_i^{max} \cup U_i^{min}, \forall i \in [1,2,\ldots,m] , \quad (23)$$

$$U_i = \left\{u_{i1}, u_{i2}, \ldots, u_{ik}\right\} \cup \left\{u_{i1}, u_{i2}, \ldots, u_{ih}\right\}, \quad \forall i \in [1,2,\ldots,m] . \quad (24)$$

Step 6: Magnitude of component

For each component of the optimal alternative, calculate the magnitude defined by:

$$Q_k = \sqrt{q_1^2 + q_2^2 + .. + q_k^2} , \quad (25)$$

$$Q_h = \sqrt{q_1^2 + q_2^2 + .. + q_h^2} . \quad (26)$$

The same approach is applied for each alternative.

$$U_{ik} = \sqrt{u_{i1}^2 + u_{i2}^2 + \ldots + u_{ik}^2}, \forall i \in [1,2,..,m] , \quad (27)$$

$$U_{ih} = \sqrt{u_{i1}^2 + u_{i2}^2 + \ldots + u_{ih}^2}, \forall i \in [1,2,..,m] . \quad (28)$$

Step 7: Multiple-Criteria Ranking by Alternative Trace (MCRAT) [5]

Create the matrix F composed of optimal alternative components:

$$F = \begin{bmatrix} Q_k & 0 \\ 0 & Q_h \end{bmatrix} . \quad (29)$$

Also, create the matrix G_i composed of alternative components:

$$G_i = \begin{bmatrix} U_{ik} & 0 \\ 0 & U_{ih} \end{bmatrix}, \forall i \in [1,2,\ldots,m] . \quad (30)$$

If T_i is a matrix obtained by the product of matrix F and G_i:

$$T_i = F \times G_i = \begin{bmatrix} t_{11;i} & 0 \\ 0 & t_{22;i} \end{bmatrix}, \forall i \in [1,2,\ldots,m] . \quad (31)$$

Then, trace of the matrix T_i is as follows:

$$tr\left(T_i\right) = t_{11;i} + t_{22;i}, \forall i \in [1,2,\ldots,m] . \quad (32)$$

Alternatives are now ranked according to the descending order of $tr(T_i)$.

III. Numerical Example

Management of the coal mining company is faced with a problem of coal supplier selection for thermal power plant. The thermal power plant was built 35 years ago, with total power capacity of about 400 MW and an annual coal delivery of nearly 3.5 million tons of coal. As currently coal reserves near thermal power plant are almost exhausted, there is a need to find a new coal supplier for existing thermal power plant. In order to provide the stable and sustainable electricity production as well as to improve the sustainable development of the company, optimal coal supplier must be selected for the thermal power plant. Note that the example is hypothetical. Detailed description of the input parameters of alternatives and criteria is represented in Table I. Coal supplier 1, coal supplier 2…, coal supplier 7 are represented as a set of alternatives $A_1, A_2, \ldots, A_7$. Calorific value, ash content, sulphur content, moisture content and price are represented as a set of criteria $C_1, C_2, \ldots, C_5$.

Calorific value is one of the most important criteria of each coal type that indicates the fuel quality. It is mainly used to select the coal type based on quality. Calorific value can be defined as the amount of heat released during the complete combustion of 1 kg of coal. It can be defined in kJ/kg or MJ/kg units. This criterion, as the rest of criteria, is quantitative. It is the only positive attribute of coal and should be maximized.

Ash content also has important role in coal type selection based on quality. If the percentage of ash in coal sample is high, it means that it will cause the larger amounts of slag and dust during combustion. Since this is a negative characteristic of coal, this criterion should be minimized. It can be shown in % units.

Sulphur content, as well as ash content, represents the parameter that has a significant impact on coal quality. High percentage of sulphur in coal sample implies high emissions of air pollutants and concentrations of harmful substances in the air, primarily sulphur oxides. Due to the unfavorable impact on environment, this criterion should be minimized. It can be shown in % units.

Moisture content represents important criterion that affects the coal quality. When the percentage of moisture content in coal sample increases, then calorific value decreases and vice versa. The presence of moisture in coal sample requires his drying which increases the total costs and additional negative consequences. It can be shown in % units. Due to all negative characteristics, this criterion should be minimized.

Price, such as calorific value, is one of the key attributes that influence the coal type selection as well as coal supplier selection for thermal power plant. Electricity price directly depends on coal price. Large variations and fluctuations of coal price on the market have an extremely negative impact on stable electricity production. Price is defined in EUR/t units. It is tendency for the lowest possible price, so this criterion should be minimized.

The procedure for criteria weights determination by Shannon's entropy method is well – known and often used while detailed calculation process of MEREC method is shown in the following Equations and Tables.

Based on Step 2.2 using (13) – (14), normalization of the input data is performed and obtained values are shown in Table II.

TABLE I. DETAILED DESCRIPTION OF THE INPUT PARAMETERS OF ALTERNATIVES AND CRITERIA.

A/C	C_1 (MJ/kg)	C_2 (%)	C_3 (%)	C_4 (%)	C_5 (EUR/t)
	max	*min*	*min*	*min*	*min*
A_1	7.90	17.75	0.96	46.13	70.00
A_2	8.40	18.83	1.03	43.41	80.00
A_3	7.40	19.40	0.45	46.20	50.00
A_4	14.20	17.12	1.25	28.00	130.00
A_5	13.80	13.21	1.00	30.21	120.00
A_6	6.00	19.28	0.88	44.33	105.00
A_7	7.80	17.40	1.02	45.00	110.00

TABLE II. NORMALIZED DECISION – MAKING MATRIX.

A/C	C_1	C_2	C_3	C_4	C_5
	max	*min*	*min*	*min*	*min*
A_1	0.7595	0.9149	0.7680	0.9985	0.5385
A_2	0.7143	0.9706	0.8240	0.9396	0.6154
A_3	0.8108	1.0000	0.3600	1.0000	0.3846
A_4	0.4225	0.8825	1.0000	0.6061	1.0000
A_5	0.4348	0.6809	0.8000	0.6539	0.9231
A_6	1.0000	0.9938	0.7040	0.9595	0.8077
A_7	0.7692	0.8969	0.8160	0.9740	0.8462

The overall performance of the alternative S_i is calculated by 15. Detailed calculation process for the alternative S_1 is shown in (33). The same procedure is valid for other alternatives from S_2 to S_7.

$$S_1 = \ln\left(1+\left(\frac{1}{5}\left(\begin{array}{l}|\ln(0.7595)|+\\+|\ln(0.9149)|+\\+|\ln(0.7680)|+\\+|\ln(0.9985)|+\\+|\ln(0.5385)|\end{array}\right)\right)\right) = \\ = 0.2229 \quad .(33)$$

The performance of the alternatives by removing each criterion S_{ij}' is calculated by (16). Two detailed numerical examples (for $S_{12}'$and S_{64}') are represented in (34) and (35) to describe this step of calculation process. S_{12}' is the overall performance of the A_1 related to the removal of C_2 , while S_{64}' is the overall performance of the A_6 related to the removal of C_4. The same calculation process is valid for other alternatives and obtained values are shown in Table III.

$$S_{12}' = \ln\left(1+\left(\frac{1}{5}\left(\begin{array}{l}|\ln(0.2751)|+\\+|\ln(0.2640)|\\+|\ln(0.0015)|\\+|\ln(0.6190)|\end{array}\right)\right)\right) = \\ = 0.2086 \quad , (34)$$

$$S_{64}' = \ln\left(1+\left(\frac{1}{5}\left(\begin{array}{l}|\ln(0.0000)|+\\+|\ln(0.0062)|+\\+|\ln(0.3510)|+\\+|\ln(0.2136)|\end{array}\right)\right)\right) = \\ = 0.1081 \quad . (35)$$

TABLE III. VALUES OF PERFORMANCE OF THE ALTERNATIVES BY REMOVING EACH CRITERION S_{ij}'.

A/C	*C1*	*C2*	*C3*	*C4*	*C5*
A1	0.1779	0.2086	0.1797	0.2227	0.1186
A2	0.1434	0.1952	0.1679	0.1899	0.1173
A3	0.3332	0.3628	0.2095	0.3628	0.2202
A4	0.1179	0.2409	0.2604	0.1801	0.2604
A5	0.2009	0.2717	0.2960	0.2655	0.3170
A6	0.1155	0.1144	0.0509	0.1081	0.0767
A7	0.0963	0.1238	0.1070	0.1383	0.1135

The summation of absolute deviations E_j is computed by (17). Detailed calculation process for E_1 is represented in (36). The same calculation process is valid for each corresponding criteria from E_2 to E_5.

$$\begin{array}{l}E_1 = |0.1779-0.2229|+\\+|0.1434-0.2001|+|0.3332-0.3628|+\\+|0.1179-0.2604|+|0.2009-0.3286|+.\\+|0.1155-0.1155|+|0.0963-0.1429| =\\ = 0.4481\end{array} \quad (36)$$

Finally, criteria weights are determined by (18), and obtained values are shown in Table IV.

Graphical review of obtained criteria weights is represented in Fig. 1. Spearman's rank correlation coefficient between criteria weights obtained by Shannon's entropy and MEREC is $r = 0.9862$. The high level of correlation shows that both methods can be successfully used for criteria weights determination.

TABLE IV. CRITERIA WEIGHTS OBTAINED BY SHANNON'S ENTROPY AND MEREC METHOD.

	C1	*C2*	*C3*	*C4*	*C5*
Shannon entropy	0.3314	0.0448	0.2214	0.1161	0.2863
MEREC	0.2985	0.0771	0.2410	0.1105	0.2729

Using (5) we obtained weighted normalized decision – making matrix for both methods for criteria weights determination. The values are shown in Table V and Table VI.

By applying (19), optimal alternative is determined for both methods for criteria weights determination. Results are shown in Table VII and Table VIII.

TABLE V. WEIGHTED NORMALIZED DECISION MATRIX USING SHANNON'S ENTROPY METHOD.

A/C	C_1	C_2	C_3	C_4	C_5
	max	*min*	*min*	*min*	*min*
A_1	0.1844	0.0333	0.1038	0.0705	0.2045
A_2	0.1960	0.0314	0.0967	0.0749	0.1789
A_3	0.1727	0.0305	0.2214	0.0704	0.2863
A_4	0.3314	0.0346	0.0797	0.1161	0.1101
A_5	0.3221	0.0448	0.0996	0.1076	0.1193
A_6	0.1400	0.0307	0.1132	0.0733	0.1363
A_7	0.1820	0.0340	0.0977	0.0722	0.1301

TABLE VI. WEIGHTED NORMALIZED DECISION MATRIX USING MEREC METHOD.

A/C	C_1	C_2	C_3	C_4	C_5
	max	*min*	*min*	*min*	*min*
A_1	0.1661	0.0574	0.1130	0.0671	0.1949
A_2	0.1766	0.0541	0.1053	0.0713	0.1705
A_3	0.1556	0.0525	0.2410	0.0670	0.2729
A_4	0.2985	0.0595	0.0868	0.1105	0.1049
A_5	0.2901	0.0771	0.1085	0.1024	0.1137
A_6	0.1261	0.0528	0.1233	0.0698	0.1299
A_7	0.1640	0.0585	0.1063	0.0688	0.1240

TABLE VII. OPTIMAL ALTERNATIVE USING SHANNON'S ENTROPY METHOD.

Opt. A/C	C_1	C_2	C_3	C_4	C_5
	max	*min*	*min*	*min*	*min*
Q	0.3314	0.0448	0.2214	0.1161	0.2863

TABLE VIII. OPTIMAL ALTERNATIVE USING MEREC METHOD.

Opt. A/C	C_1	C_2	C_3	C_4	C_5
	max	*min*	*min*	*min*	*min*
Q	0.2985	0.0771	0.2410	0.1105	0.2729

TABLE IX. DECOMPOSITION OF THE OPTIMAL ALTERNATIVE USING SHANNON'S ENTROPY METHOD.

Opt. A/C	C_1	C_2	C_3	C_4	C_5
	max	*min*	*min*	*min*	*min*
Q^{max}	0.3314	-	-	-	-
Q^{min}	-	0.0448	0.2214	0.1161	0.2863

TABLE X. DECOMPOSITION OF THE OPTIMAL ALTERNATIVE USING MEREC METHOD.

Opt. A/C	C_1	C_2	C_3	C_4	C_5
	max	*min*	*min*	*min*	*min*
Q^{max}	0.2985	-	-	-	-
Q^{min}	-	0.0771	0.2410	0.1105	0.2729

Using (21), decomposition of the optimal alternative is obtained for both methods for criteria weights determination. The values are shown in Table IX and Table X.

By applying (23), decomposition of alternatives is represented for both methods for

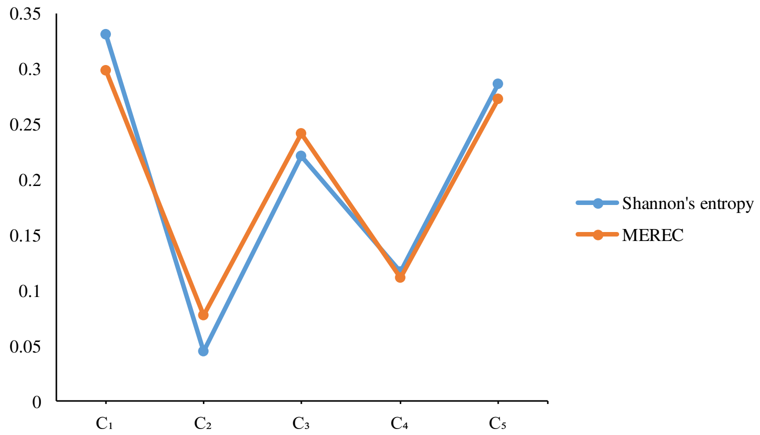

Figure 1. Graphical review of criteria weights obtained by Shannon's entropy and MEREC method.

criteria weights determination. Results are shown in Table XI and Table XII.

Based on (25) – (28), magnitude of optimal alternative and alternatives is calculated for both methods for criteria weights determination. The values are shown in Table XIII.

Using (29) - (32), Multiple-Criteria Ranking by Alternative Trace (MCRAT) method is applied and trace of the matrix $tr(T_1), tr(T_2), \ldots, tr(T_7)$ such as final rank by descending order is represented in Table XIV

TABLE XI. DECOMPOSITION OF ALTERNATIVES USING SHANNON'S ENTROPY METHOD.

A/C		C_1	C_2	C_3	C_4	C_5
		max	*min*	*min*	*min*	*min*
A_1	U^{max}	0.1844	-	-	-	-
	U^{min}	-	0.0333	0.1038	0.0705	0.2045
A_2	U^{max}	0.1960	-	-	-	-
	U^{min}	-	0.0314	0.0967	0.0749	0.1789
A_3	U^{max}	0.1727	-	-	-	-
	U^{min}	-	0.0305	0.2214	0.0704	0.2863
A_4	U^{max}	0.3314	-	-	-	-
	U^{min}	-	0.0346	0.0797	0.1161	0.1101
A_5	U^{max}	0.3221	-	-	-	-
	U^{min}	-	0.0448	0.0996	0.1076	0.1193
A_6	U^{max}	0.1400	-	-	-	-
	U^{min}	-	0.0307	0.1132	0.0733	0.1363
A_7	U^{max}	0.1820	-	-	-	-
	U^{min}	-	0.0340	0.0977	0.0722	0.1301

TABLE XII. DECOMPOSITION OF ALTERNATIVES USING MEREC METHOD.

A/C		C_1	C_2	C_3	C_4	C_5
		max	*min*	*min*	*min*	*min*
A_1	U^{max}	0.1661	-	-	-	-
	U^{min}	-	0.0574	0.1130	0.0671	0.1949
A_2	U^{max}	0.1766	-	-	-	-
	U^{min}	-	0.0541	0.1053	0.0713	0.1705
A_3	U^{max}	0.1556	-	-	-	-
	U^{min}	-	0.0525	0.2410	0.0670	0.2729
A_4	U^{max}	0.2985	-	-	-	-
	U^{min}	-	0.0595	0.0868	0.1105	0.1049
A_5	U^{max}	0.2901	-	-	-	-
	U^{min}	-	0.0771	0.1085	0.1024	0.1137
A_6	U^{max}	0.1261	-	-	-	-
	U^{min}	-	0.0528	0.1233	0.0698	0.1299
A_7	U^{max}	0.1640	-	-	-	-
	U^{min}	-	0.0585	0.1063	0.0688	0.1240

and Table XV for both methods for criteria weights determination.

TABLE XIII. MAGNITUDE OF OPTIMAL ALTERNATIVE AND ALTERNATIVES USING SHANNON'S ENTROPY AND MEREC METHOD.

A	MCRAT with Shannon's entropy		MCRAT with MEREC	
	max	*min*	*max*	*min*
	Q_k U_{ik}	Q_h U_{ik}	Q_k U_{ik}	Q_h U_{ik}
Q	0.3314	0.3827	0.2985	0.3882
cc	0.1844	0.2422	0.1661	0.2420
A_2	0.1960	0.2190	0.1766	0.2195
A_3	0.1727	0.3700	0.1556	0.3739
A_4	0.3314	0.1821	0.2985	0.1852
A_5	0.3221	0.1943	0.2901	0.2028
A_6	0.1400	0.1942	0.1261	0.1993
A_7	0.1820	0.1812	0.1640	0.1867

TABLE XIV. TRACE OF THE MATRIX AND FINAL RANK OF ALTERNATIVES USING SHANNON'S ENTROPY METHOD FOR CRITERIA WEIGHTS DETERMINATION.

A	MCRAT with Shannon's entropy		
	Trace $tr(T_i)$	*Value*	*Rank*
A_1	$tr(T_1)$	0.4266	4
A_2	$tr(T_2)$	0.4151	5
A_3	$tr(T_3)$	0.5427	1
A_4	$tr(T_4)$	0.5135	3
A_5	$tr(T_5)$	0.5163	2
A_6	$tr(T_6)$	0.3343	7
A_7	$tr(T_7)$	0.3633	6

TABLE XV. TRACE OF THE MATRIX AND FINAL RANK OF ALTERNATIVES USING MEREC METHOD FOR CRITERIA WEIGHTS DETERMINATION.

A	MCRAT with MEREC		
	Trace $tr(T_i)$	*Value*	*Rank*
A_1	$tr(T_1)$	0.4080	4
A_2	$tr(T_2)$	0.3961	5
A_3	$tr(T_3)$	0.5294	1
A_4	$tr(T_4)$	0.4837	3
A_5	$tr(T_5)$	0.4929	2
A_6	$tr(T_6)$	0.3255	7
A_7	$tr(T_7)$	0.3506	6

IV. CONCLUSION

Having ability to select the best coal supplier for thermal power plant is recognized as a major activity to provide stable and sustainable electricity production as well as to improve the sustainable development of each mining company. This paper proposed a newly multi – criteria decision – making model based on MCRAT method with two approaches for objective criteria weights determination (Shannon's entropy and MEREC method) for optimal coal supplier selection for thermal power plant. The high level of correlation between these two methods for criteria weights determination leads to equal rank of alternatives by using MCRAT method. Having in mind the values of rank of alternatives in both approaches, our developed model is absolutely acceptable and capable to solve such complex problem.

The model is not closed and can be upgraded by increasing the uncertainty of input data using fuzzy or interval numbers. Also, there is possibility to create dynamic model by integrating the stochastic differential equations to describe the behavior of some criterion.

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