



AHP–TOPSIS hybrid decision-making analysis: Simav integrated system case study

Asli Ergenekon Arslan¹ · Oguz Arslan² · Suheyla Yerel Kandemir³

Received: 28 July 2020 / Accepted: 15 September 2020 / Published online: 10 October 2020
© Akadémiai Kiadó, Budapest, Hungary 2020

Abstract

In this study, Simav Integrated Geothermal Energy System (Simav-IGES) was evaluated by using Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) which is one of the multi-criteria decision-making techniques. In the decision-making process, the importance scale of the analytic hierarchy process (AHP) was used to determine the masses of TOPSIS to obtain more sensitive results. In this way, a new model was developed combining AHP and TOPSIS. The used data were obtained from the analytical calculations of Simav-IGES. IGES was formed of the electricity generation, district heating of residences, district heating of greenhouses, and spas. For this purpose, the electricity generation amount (ORC), the number of heated residences (RH), and the heated area of greenhouses were determined through energy, exergy, and economical methods. The present status of spas was taken into account for the balneology use. As a conclusion, it is determined that the best design is Design 16 for the all basis included solution in Simav-IGES. Design 16 is the one which includes the highest residential heating number with 16,311 and the lowest power generation with 41,153 kWh. In this case, the situation of greenhouse heating has a medium value of 631,449 m². So, it is the optimum application to install the integrated system taking into lower outlet temperatures (313.15 K) of power plant (ORC).

Keywords AHP · Energy · Exergy · Geothermal energy · Integrated system · TOPSIS

Introduction

Integration and thermodynamic analysis of the single systems for multi-generation purposes is very important to achieve the best designs from the environmental, economical, and efficiency (3E) sides [1–10]. Optimization of these systems is also important. In this aim, artificial intelligence is commonly used to obtain the extreme points of

the systems which includes the highest values of the handled designs [11–13]. However, this thermodynamic and artificial analysis cannot decide the optimum use of the resources of these designs. In this regard, the multi-criteria decision-making (MCDM) techniques are the best choice. MCDM techniques are widely used in several problems with the criteria more than one since it helps to make a decision more efficient. These problems include several areas such as data centers, universities, manufacturing industry, recruitment of the candidates, power plants, water management for the optimization or efficiency evaluations of the systems [14–18]. MCDM techniques have more attention to the energy systems in the last decades. There are many studies evaluating the efficiency terms of sources. These studies generally include thermal power plants, price, and possible problems in the energy sector, renewable energy sources, environmental factors, and so on [19–32].

There are many decision-making techniques used in the literature. Generally, these techniques have a structure that makes an ordering taking the input criteria into account. The analysis techniques such as Data Enveloping Analysis (DEA), Efficiency Analysis Technique with Output

✉ Oguz Arslan
oguz.arslan@bilecik.edu.tr

Asli Ergenekon Arslan
asli.arslan@bilecik.edu.tr

Suheyla Yerel Kandemir
suheyla.yerel@bilecik.edu.tr

¹ Program of Quality Control in Production, Machine and Metal Technologies Department, Vocational School, Bilecik Seyh Edebali University, 11230 Bilecik, Turkey

² Mechanical Engineering Department, Engineering Faculty, Bilecik Seyh Edebali University, 11230 Bilecik, Turkey

³ Industrial Engineering, Department Engineering Faculty, Bilecik Seyh Edebali University, 11230 Bilecik, Turkey

Satisficing (EATWOS), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) are the most commonly used ones for the numeric data in the literature [33–40]. The most important problem in these techniques is the weighting problem of decision points. The most common application in this way is the arithmetical sum of the input and out values. It is not sufficient from the engineering side of view although it gives approximate results. This approach may be useful for a rapid decision of engineering processes. However, a more sensitive approach is a need for the ultimate evaluations of engineering systems. At this point, an expert sight would be more attractive. So, the analytic hierarchy process (AHP) is one of the available solutions on this aim since it has a scale that can be evaluated by the experts of a research field [41, 42]. In this regard, the most attractive way, to take advantage of the experts' view for a sensitive decision making, is to combine AHP with MCDM techniques. In the literature, there is some sample of studies for these combinations. Karahalios [43] evaluated the ship operators from the point of cost–benefit. In this study, the hybrid of AHP and TOPSIS was handled for decision making. Sennaroglu and Celebi [44] integrated AHP with different MCDM techniques for the location selection of military airports. In this aim, they evaluated the criteria masses by AHP. Muhsen et al. [45], in their study, used the AHP–TOPSIS combination for the calculation of customer load management. In the study, they included that the energy-saving provided by the proposed method is superior. Sun [46] combined gray analysis and entropy model to evaluate the regional rainwater resource. In the study, it was found that the proposed method is reasonable to determine the mass of the criteria.

Geothermal energy systems are commonly based on heating, balneology, and power applications. The heating section is formed of residential and greenhouse heating where the power section is formed of the organic Rankine cycle (ORC). Since there are limited energy sources based on the geothermal water, the decision makers should carefully organize the systems. Therefore, the integrated usage of these systems is the best way to evaluate the geothermal resources. In this regard, the experts need to take all the cases and designs into account for an effective solution and need to expose solutions for the main aim of the purposes of heating and power generation. In this case, a decision-making problem occurs. Therefore, it would certainly be more advantageous to use a more efficient method for the energy design problems in which multiple criteria with numerical parameters are compared and the most effective solution is decided.

In this study, Simav Integrated Geothermal Energy System is evaluated by using TOPSIS. However, TOPSIS is not enough to make a sensitive order of the system designs since it depends on the masses of criteria. In this aim, AHP can be used as a key tool since it has an expertise scale which

can effectively be used to increase the sensitivity of TOPSIS. So, a new model based on the hybridization of AHP and TOPSIS can be an attractive solution for the integration of systems through an expert in this area. In this study, the integrated usage of energy systems including electricity generation, district heating, greenhouse heating, and balneology use of geothermal resources was taken into account. In this purpose, different system configurations were formed. Finally, the effective solution was decided employing the hybrid AHP–TOPSIS analysis.

Materials and methods

Simav geothermal region was handled to evaluate the geothermal water in the integrated system. Simav geothermal resources are currently used for heating for approximately 10,000 residences. The heat center is already present for the residence heating. The heated network water is pumped to the substation located at each residence [47]. Besides, the geothermal resources are already in use for the greenhouse heating purpose. However, the geothermal fluid is directly used in this system. Also, spas are actively used for balneological purposes. However, the energy potential is very higher just for the residence heating. The average fluid temperature of the region, which currently consists of 10 wells, is 406.65 K and the total fluid flow rate is 462 kg s⁻¹. So, this energy potential can be evaluated more effectively in an integrated system [48]. The integrated system, as given in Fig. 1, is orderly formed of 4 subsystems namely power generation (ORC), residential heating (RH), greenhouse heating (GH), and balneology use (BU) of the spa. These configurations were formed according to the temperature scale of the systems. In ORC, R141b is chosen as the working fluid with the best power generation performance [48, 49]. Four substations, installed in the geothermal region, are taken into account for the delivery of heat energy. Finally, the geothermal fluid is re-injected to ensure the continuity of the sources for a sustainable future.

Taking the integrated system given in Fig. 1 into consideration, different models were formed by energy and exergy

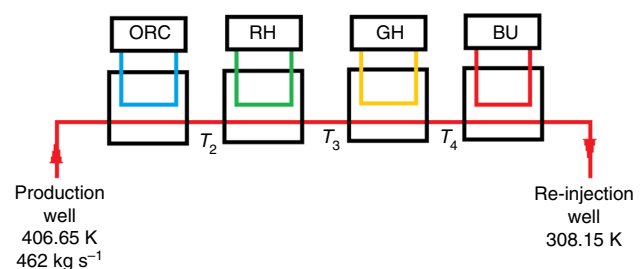


Fig. 1 The flow diagram of the integrated geothermal energy system

analysis. In these models, configurations were parametrically performed and results were obtained as generated electricity (ORC), the number of heated residences (RH), area of heated greenhouse (GH), and balneology use (BU) in its current status. For the decision-making point, the benefit of the system was handled as the objective function. On this aim, this function was calculated through the net present value (NPV) analysis. This analysis technique is very useful since it includes the time dimension of the money. So, the results of the analysis are obtained for the system lifetime of 20 years. The detailed information about the parametric calculation can be found in Ref. [46–49]. In this regard, 21 different models were observed for decision-making analysis. The analytical results are given in Table 1.

Hybrid analysis

AHP has more sensitive ordering since it allows scaling the importance by an expert in the view analytic hierarchical process. Although AHP is a method that determines the order of convergence to the best in itself, TOPSIS makes a better decision in ordering scale depending on its mathematical procedure. So, the hybridization of these two methods would produce more powerful and effective results on the decision point. In this aim, the convergence values of AHP can be used as the masses of TOPSIS. The stepwise of the analysis is given in Fig. 2. According to this flowchart, the integrated system is analyzed analytically as the first step.

So, the data for hybrid analysis are obtained. According to Fig. 2, the decision units are determined first. In this regard, 3 different decision units were determined for Simav geothermal resources. The first one is predominantly based on the higher power generation, the second one is predominantly based on higher greenhouse heating, and the last one is predominantly based on higher residence heating. All these configurations should be evaluated by an expert according to the importance scale of the AHP analysis chart (see Table 2) since it directly affects the final results. Then, the AHP is run to determine the order of priority. The results of the AHP step generate the masses of TOPSIS. Including these masses into TOPSIS analysis, AHP and TOPSIS are hybridized. Finally, the common results are obtained and are eliminated for the best choice by the expert.

AHP part of hybrid analysis

As the second step, the expert view is very important since the integrated system occurs from 4 subsystems. So, at this stage, it is decided which step is more important for the integrated system by the expert view. So, the hybrid analysis can be run according to these views. In this aim, three different cases come insight. The first case is the case that the power generation (ORC) is the most important issue. The second one is the case including greenhouse heating (GH) as the most important issue. The third one is the case for residential heating (RH) as the most important issue. According to these

Table 1 Analytical results of models

Design no.	T_2/K	T_3/K	T_4/K	RH	GH/m ²	ORC/kWh	$\eta/\%$	$\epsilon/\%$	Benefit/million \$
1	353.15	333.15	313.15	10,844	420,765	48,190	15.09	64.47	258.81
2			323.15	10,844	210,433	48,190	12.77	63.07	238.31
3		343.15	313.15	5427	631,449	48,190	15.49	65.75	250.50
4			323.15	5427	421,117	48,190	13.16	63.99	232.79
5			333.15	5427	254,033	48,190	10.86	62.28	219.09
6	363.15	333.15	313.15	16,280	420,765	45,027	15.14	60.60	283.27
7			323.15	16,280	255,596	45,027	12.75	59.21	267.19
8		343.15	313.15	10,862	631,449	45,027	17.58	63.10	269.37
9			323.15	10,862	421,117	45,027	15.18	61.34	251.66
10			333.15	10,862	254,033	45,027	12.81	59.63	237.95
11		353.15	313.15	5436	842,486	45,027	17.98	63.47	259.55
12			323.15	5436	632,154	45,027	15.58	61.79	241.62
13			333.15	5436	421,721	45,027	13.21	61.48	223.23
14	373.15	333.15	313.15	21,729	420,765	41,153	15.07	55.60	302.41
15			323.15	21,729	210,433	41,153	12.60	54.20	281.91
16		343.15	313.15	16,311	631,449	41,153	17.61	59.42	288.89
17			323.15	16,311	421,117	41,153	15.14	57.67	271.18
18			333.15	16,311	254,033	41,153	12.70	55.96	257.48
19		353.15	313.15	10,884	842,486	41,153	20.12	61.18	275.12
20			323.15	10,884	632,154	41,153	17.65	59.51	257.19
21			333.15	10,884	421,721	41,153	15.21	59.19	238.80

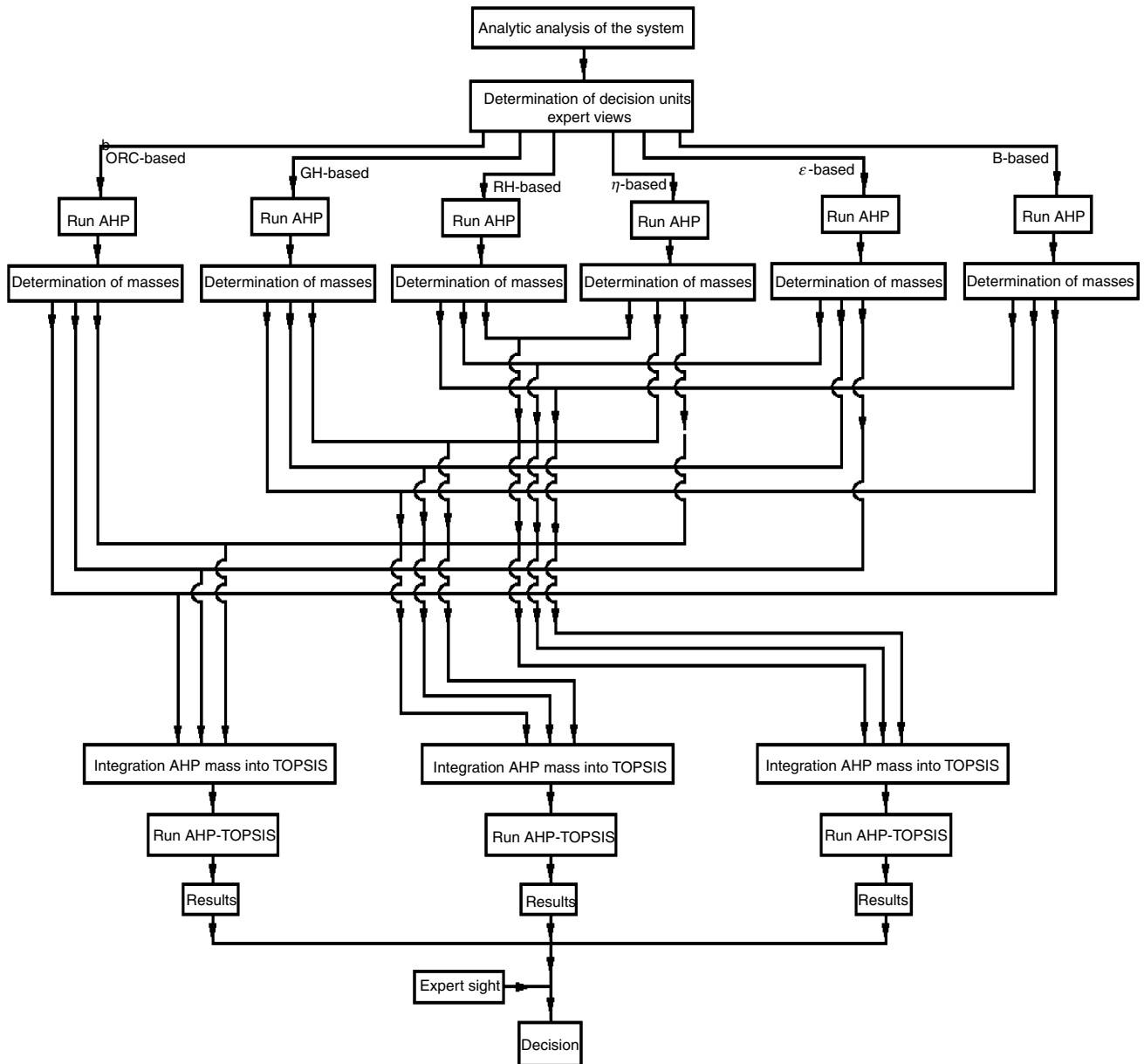


Fig. 2 Flowchart of AHP–TOPSIS analysis

Table 2 Importance scale [41]

Scale	Value definitions
1	The equal importance of both factors
3	The first factor is more important than the second factor
5	The first factor is much more important than the second factor
7	The fact that the first factor has very strong importance compared to the second factor
9	The fact that the first factor has absolute superiority than the second factor
2, 4, 6, 8	Intermediate values

views, AHP is run separately for each case as the third step of the hybrid analysis.

AHP was conducted by Myers and Alpert in 1968 for the first time [50]. Then, in 1977, AHP was developed as a model and started to be used for the solution of the problems of making-decision. AHP uses a comparing scale, defined before, on the decision hierarchy. This scale, given in Table 2, is a useful tool for the expert views to compare the decision points in each other.

In order to define the decision-making problem, the comparison matrix formed by n input parameters is defined as follows [42];

$$A = \begin{bmatrix} 1 & \dots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{1n} & \dots & 1 \end{bmatrix}. \tag{1}$$

a_{ij} , the importance of the i criteria according to the criteria of j , the importance of the j criteria according to the criteria of i , is given by $a_{ji} = \frac{1}{a_{ij}}$. B matrix is generated to determine significance levels within all factors and given by Eq. (2);

$$B = \begin{bmatrix} 1 & \dots & B_{1n} \\ \vdots & \ddots & \vdots \\ B_{1n} & \dots & 1 \end{bmatrix}, \tag{2}$$

where b_{ij} is given by $b_{ij} = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}}$. After the creation of the significance matrix, the priority vector is generated to determine the masses of the factors and it is given as follows;

$$W = \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix}, \tag{3}$$

where w_n is calculated by the following equation;

$$w_n = \frac{\sum_{j=1}^n b_{ij}}{n}. \tag{4}$$

The next process includes the determination of the consistency of the determined masses (CR). In this aim, the following steps are applied;

$$C = \begin{bmatrix} 1 & \dots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{1n} & \dots & 1 \end{bmatrix} \times \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} c_1 \\ \vdots \\ c_n \end{bmatrix} \tag{5}$$

$$d_i = \frac{c_i}{w_i}. \tag{6}$$

Accordingly, CI, the consistency indicator, is given as follows,

$$CI = \frac{\gamma - n}{n - 1}, \tag{7}$$

where γ is calculated by the following equation;

$$\gamma = \frac{\sum_{i=1}^n d_i}{n}. \tag{8}$$

Finally, calculation of CR using with random indicators (RI), which are taken as 0.58 for this study, is obtained as;

$$CR = \frac{CI}{RI}. \tag{9}$$

CR value should be less than 0.10 for a consistent assignments of the decision making.

AHP–TOPSIS hybridization

In TOPSIS analysis, the starting point is the decision matrix which includes evaluation factors. Decision matrix (D_{ij}) is given as;

$$D_{ij} = \begin{bmatrix} d_{11} & \dots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{m1} & \dots & d_{mn} \end{bmatrix}, \tag{10}$$

where m is the number of decision points and n is the number of evaluation factors. As the second step, standard decision matrix is formed and given as;

$$R_{ij} = \begin{bmatrix} r_{11} & \dots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \dots & r_{mn} \end{bmatrix}. \tag{11}$$

Here the elements of standard decision matrix are calculated as;

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^m a_{kj}^2}}. \tag{12}$$

For the last step, weighted standard decision matrix (V_{ij}) is formed and given as;

$$V_{ij} = \begin{bmatrix} w_1 r_{11} & \dots & w_n r_{1n} \\ \vdots & \ddots & \vdots \\ w_1 r_{m1} & \dots & w_n r_{mn} \end{bmatrix}. \tag{13}$$

Here w_i describes the masses of decision points and is taken from AHP results. This process combines the AHP and TOPSIS for a strong decision. Since TOPSIS accepts that each evaluation factor is in a way of monotone increase or decrease, ideal solution set (E^+) is described by the maximum values of the evaluation factors and is given as;

$$E^+ = \left\{ (\max_i v_{ij} | j \in J), (\min_i v_{ij} | j \in J') \right\} \tag{14}$$

$$= \{v_1^+, v_2^+, \dots, v_n^+\}.$$

Negative ideal solution set (E^-) is described by the maximum values of the evaluation factors and is given as;

$$E^- = \left\{ (\min_i v_{ij} | j \in J), (\max_i v_{ij} | j \in J') \right\} \tag{15}$$

$$= \{v_1^-, v_2^-, \dots, v_n^-\}.$$

In these equations, J indicates the maximization value where J' indicates minimization one. As the next step, deviation values of evaluation factors from the ideal or negative ideal solution set are calculated for each decision point. By the Euclidian approach, these deviations are given as;

$$S_i^* = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^*)^2} \tag{16}$$

$$S_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2}. \tag{17}$$

For the final step, relative convergences of each decision point to ideal or negative ideal solution are calculated and are given by;

Table 3 CR values of input and output parameters

CR			
Inputs		Outputs	
RH	0.0061	ϵ	0.0079
GH	0.0023	η	0.0252
ORC	0.0467	B	0.0567

Table 4 The mass values of inputs and outputs

AHP-TOPSIS model	w_i					
	Inputs			Outputs		
	RH	DHG	EG	ϵ	η	B
RH-based η	0.6687	0.0882	0.2431	0.6689	0.2674	0.0637
RH-based ϵ	0.6687	0.0882	0.2431	0.1638	0.5390	0.2973
RH-based B	0.6687	0.0882	0.2431	0.0833	0.1932	0.7235
GH-based η	0.1026	0.6814	0.2160	0.6689	0.2674	0.0637
GH-based ϵ	0.1026	0.6814	0.2160	0.1638	0.5390	0.2973
GH-based B	0.1026	0.6814	0.2160	0.0833	0.1932	0.7235
ORC-based η	0.1824	0.1454	0.6722	0.6689	0.2674	0.0637
ORC-based ϵ	0.1824	0.1454	0.6722	0.1638	0.5390	0.2973
ORC-based B	0.1824	0.1454	0.6722	0.0833	0.1932	0.7235

$$F_i^* = \frac{S_i^-}{S_i^- + S_i^*}. \tag{18}$$

Here F_i^* value changes between 0 and 1. When the value F_i^* converges to 1, it determines the ideal solution, and when the value F_i^* converges to 0, and then it determines the negative ideal solution.

Results and discussion

AHP results

According to AHP analysis, CR values were calculated as given in Table 3. For all the handled expert views, CR values were determined between 0.0023 and 0.0467 for inputs and between 0.0079 and 0.0567 for outputs. So, the results show that the AHP consistency of expert view is very reliable.

Depending on the input and output parameters of AHP, 9 different AHP-TOPSIS models were formed. The mass values of these models obtained by AHP are given in Table 4.

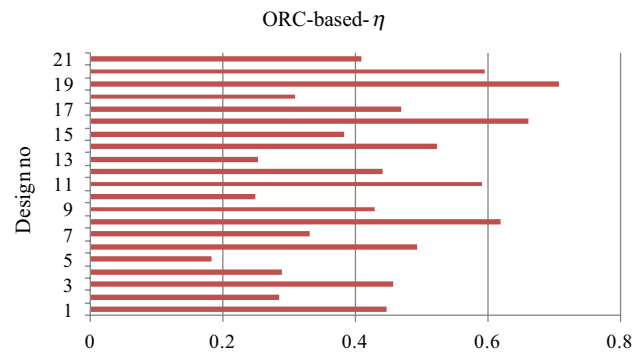


Fig. 3 Convergence values of ORC-based designs for the output of η

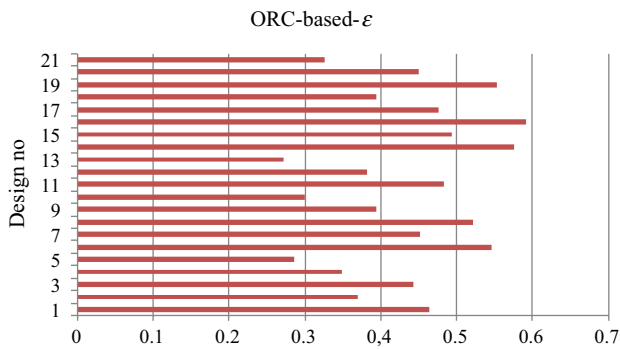


Fig. 4 Convergence values of ORC-based designs for the output of ϵ

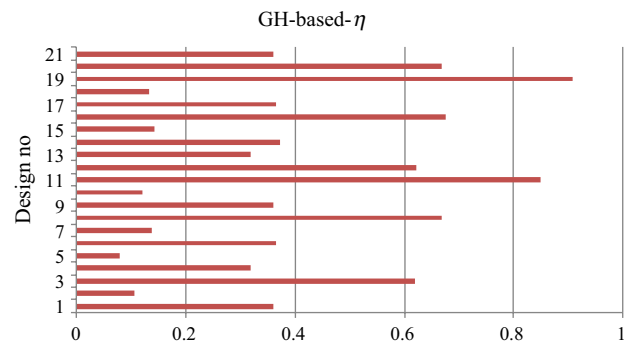


Fig. 6 Convergence values of GH-based designs for the output of η

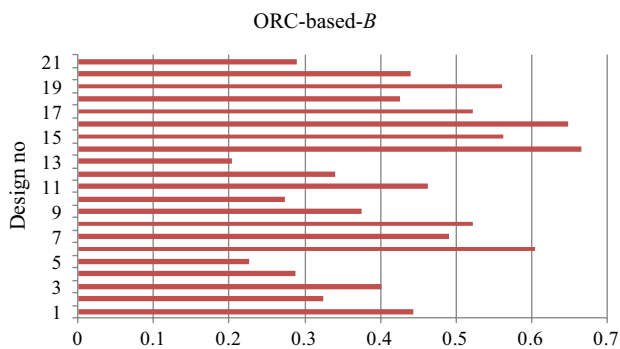


Fig. 5 Convergence values of ORC-based designs for the output of B

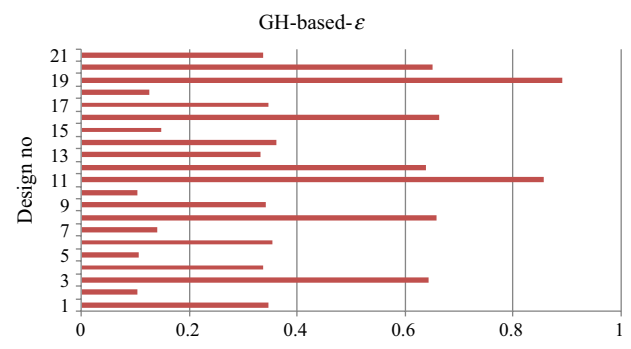


Fig. 7 Convergence values of GH-based designs for the output of ϵ

AHP-TOPSIS results of ORC-based analysis

In the base of expert view, if the power generation is accepted as the main mission, the results of the hybrid analysis for the output of first law efficiency are as given in Fig. 3.

According to Fig. 3, the best design is determined as Design 19 with a positive convergence value of 0.707. The second and third best configurations are determined as Design 16 with 0.660 and Design 8 with 0.620, respectively. The worst design is determined as Design 5 with 0.184. The results of the hybrid analysis for the output of second law efficiency are as given in Fig. 4.

According to Fig. 4, the best design is determined as Design 16 with the highest convergence of 0.592. The second and third best configurations are determined as Design 14 with 0.577 and Design 19 with 0.553, respectively. The worst design is determined as Design 13 with 0.272. The results of the hybrid analysis for the output of benefits are as given in Fig. 5.

As seen in Fig. 5, the best design is determined as Design 14 with 0.667. The second and third best configurations are determined as Design 16 with 0.649 and Design 6 with 0.605, respectively. The worst design is determined as Design 13 with 0.272.

According to these results, if all the output factors are taken into consideration, the best configuration is determined as Design 16 since it ranks among the best three design and convergence values that are close to each other. So, the results show that the system prominently speculated on greenhouse heating would be the more attractive choice although the power generation is handled for the main of the integration.

AHP-TOPSIS results of GH-based analysis

In the base of expert view, if the greenhouse heating is accepted as the main mission, the results of the hybrid analysis for the output of first law efficiency are as given in Fig. 6.

According to Fig. 6, the best design is determined as Design 19 with 0.909. The second and third best configurations are determined as Design 11 with 0.850 and Design 16 with 0.675, respectively. The worst design is determined as Design 5 with 0.078. The results of the hybrid analysis for the output of second law efficiency are as given in Fig. 7.

According to Fig. 7, the best design is determined as Design 19 with 0.891. The second and third best configurations are determined as Design 11 with 0.858 and Design 16 with 0.664, respectively. The worst design is determined as

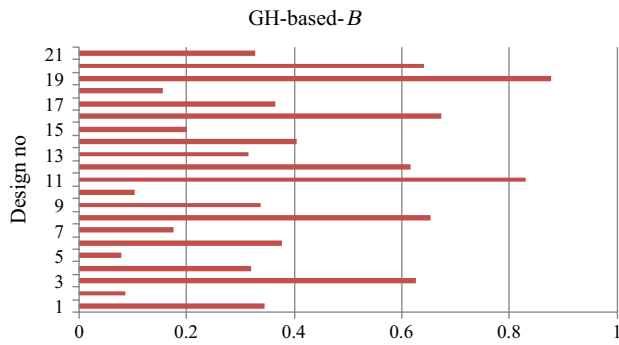


Fig. 8 Convergence values of GH-based designs for the output of B

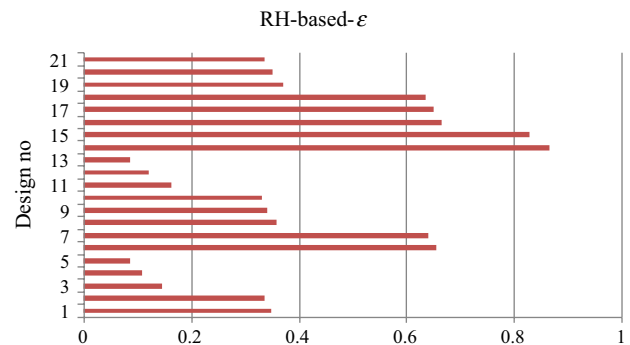


Fig. 10 Convergence values of RH-based designs for the output of ϵ

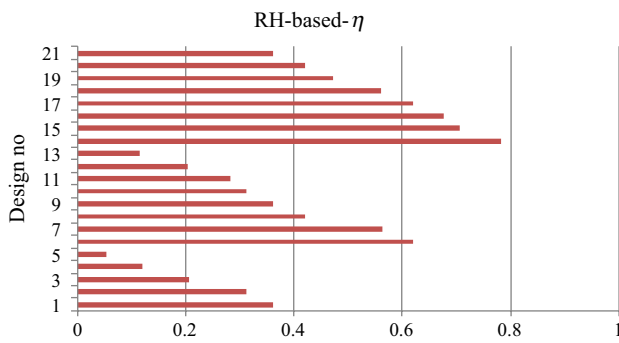


Fig. 9 Convergence values of RH-based designs for the output of η

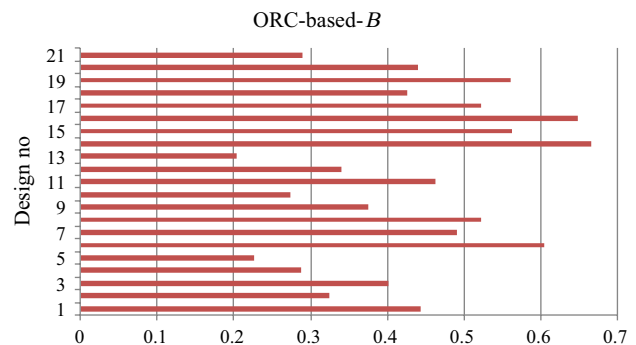


Fig. 11 Convergence values of RH-based designs for the output of B

Design 2 with 0.103. The results of the hybrid analysis for the output of benefits are as given in Fig. 8.

As seen in Fig. 8, the best design is determined as Design 19 with 0.879. The second and third best configurations are determined as Design 11 with 0.830 and Design 16 with 0.674, respectively. The worst design is determined as Design 5 with 0.079. According to these results, if all the output factors are taken into consideration, the best configuration is determined as Design 19. In the view of all the output, the best configuration is determined as Design 19 since it has the highest convergence. Design 19 also indicates that greenhouse heating is the most critical issue for the integrated system.

AHP-TOPSIS results of RH-based analysis

In the base of expert view, if the residence heating is accepted as the main mission, the results of the hybrid analysis for the output of first law efficiency are as given in Fig. 9.

According to Fig. 9, the best design is determined as Design 14 with 0.783. The second and third best configurations are determined as Design 15 with 0.707 and Design 16 with 0.676, respectively. The worst design is determined as

Design 5 with 0.053. The results of the hybrid analysis for the output of second law efficiency are as given in Fig. 10.

According to Fig. 10, the best design is determined as Design 14 with 0.865. The second and third best configurations are determined as Design 15 with 0.828 and Design 16 with 0.665, respectively. The worst design is determined as Design 5 with 0.085. The results of the hybrid analysis for the output of benefits are as given in Fig. 11.

As seen in Fig. 11, the best design is determined as Design 14 with 0.904. The best design is determined as Design 14. The second and third best configurations are determined as Design 15 with 0.860 and Design 16 with 0.675, respectively. The worst design is determined as Design 5 with 0.050. In the view of all the output, the best configuration is determined as Design 14 since it has the highest convergence. Design 14 indicates that the residence heating has more importance in comparison with power generation. For each output basis, the results including all configurations are given in Figs. 12–14.

If all the basis and output parameters have been taken into consideration, Design 16 seems as the best choice with a value of convergence to an ideal solution between 0.59 and 0.68. For this design, the benefit, energy

Fig. 12 Convergence values of η -based configurations

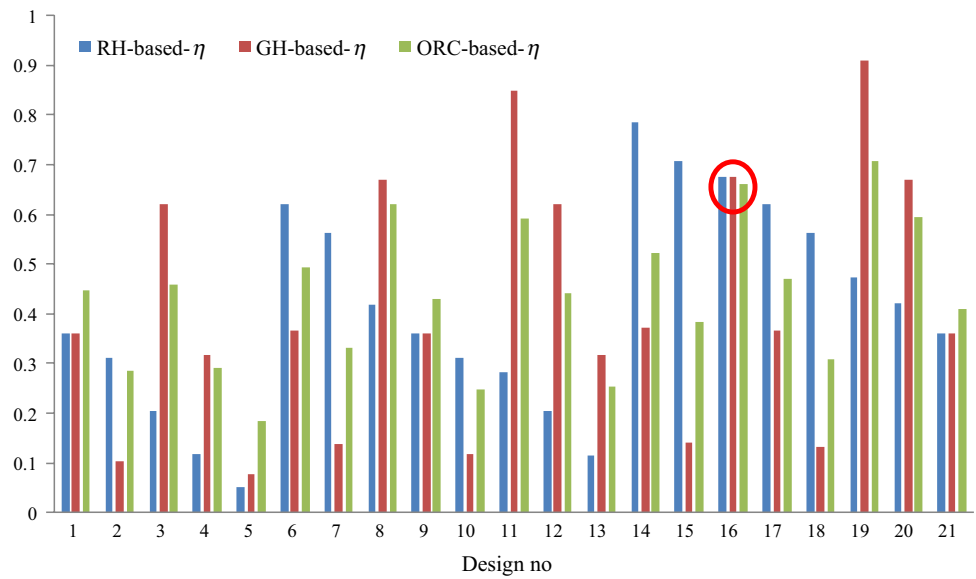
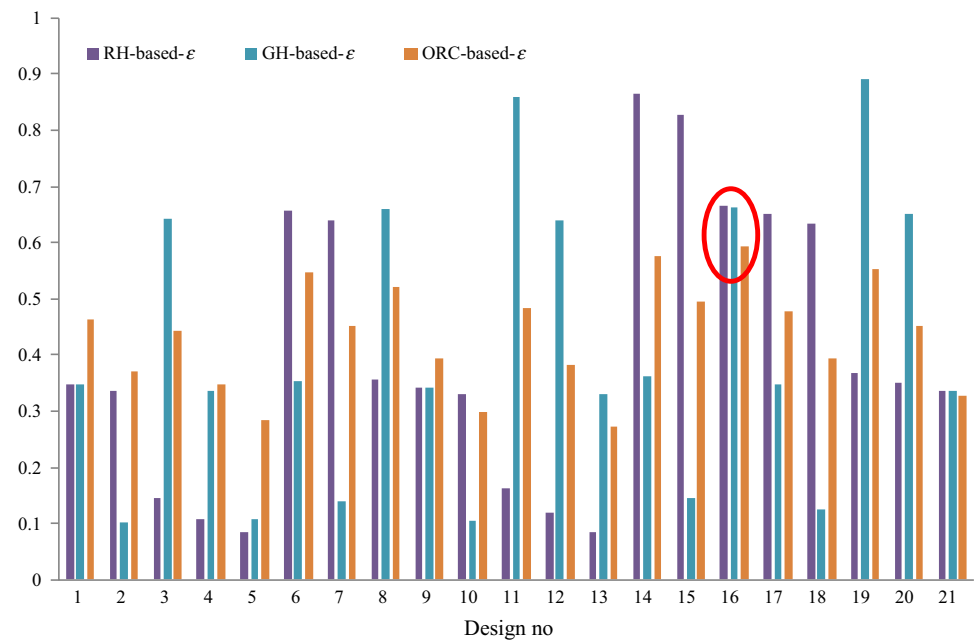


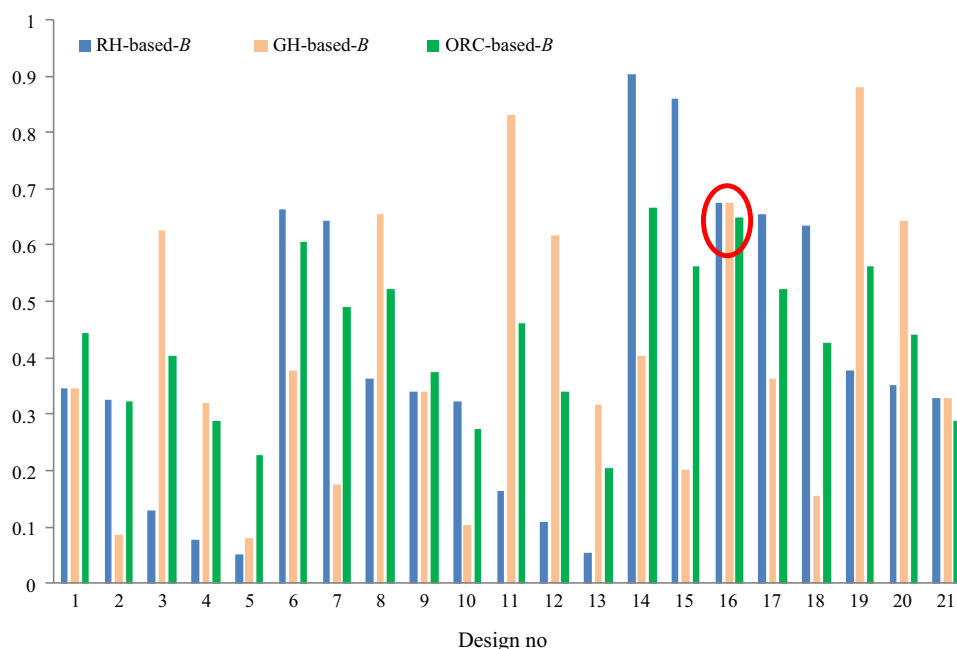
Fig. 13 Convergence values of ε -based configurations



efficiency, and exergy efficiency are obtained as 17.61%, 59.42%, and 288.89 million US\$, respectively. If the dual usage is taken into account, when ORC-based and GH-based situations are the point, Design 16 and 19 seem as the best choices with a value of convergence to the ideal solution between 0.55 and 0.91. When ORC-based and RH-based situations are the point, Design 14 and 19

seem as the best choices with a value of convergence to the ideal solution between 0.52 and 0.91. For Design 19, the benefit, energy efficiency, and exergy efficiency are obtained as 20.12%, 61.68%, and 275.12 million US\$, respectively. For Design 14, the benefit, energy efficiency, and exergy efficiency are obtained as 15.07%, 55.60%, and 302.41 million US\$, respectively.

Fig. 14 Convergence values of ϵ -based configurations



Conclusions

Energy system design is an urgent issue for sustainable usage of energy. In this regard, the decision for the best design is one of the most important issues, since the integrated systems include more confused energy relations. In this aim, multi-criteria decision-making techniques are very useful. Since these techniques need weighted values for decision points, the selection of these values directly affects the solution; therefore, they should be calculated sensitively. The expert view is very important at this point, so, AHP is one of the most useful tools in this relation. Combining the AHP solutions in the TOPSIS analysis would be a more attractive way to decide energy problems. Therefore, an integrated geothermal energy system was analyzed employing the hybrid analysis named AHP–TOPSIS. In this regard, the best design was determined as Design 16 among the analytically formed designs based on the aim of the usage area of geothermal energy. Design 16 is the one which includes the highest residential heating with a number of 16,311 and lowest power generation with 41,153 kWh. In this case, the situation of greenhouse heating has a medium value of 631,449 m². So, it is the optimum application to install the integrated system taking into lower outlet temperatures (313.15 K) of power plant (ORC). From this side, it does not mean that the designs with the highest energy efficiency or exergy efficiency, or the highest benefit are the most efficient design. By so, AHP–TOPSIS results also show that the system has still the possibility to be improved. Moreover, to make a decision on the integrated energy system, the dynamics,

needs, and future requirements of the area should be taken into account.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethics approval The authors declare that this study does not include any inconvenient or illegal data.

References

- Ahmadi MH, Mehrpooya M, Pourfayaz F. Exergoeconomic analysis and multi objective optimization of performance of a Carbon dioxide power cycle driven by geothermal energy with liquefied natural gas as its heat sink. *Energy Conv Manag.* 2006;119:422–34.
- Abdollahpour A, Ghasempour R, Kasaiean A, Ahmadi MH. Thermodynamic and exergy analysis and optimization of a transcritical CO₂ power cycle driven by geothermal energy with liquefied natural gas as its heat sink. *Appl Therm Eng.* 2016;109:640–52.
- Naseeri A, Bidi M, Ahmadi MH. Thermodynamic and exergy analysis of a hydrogen and permeate water production process by a solar-driven transcritical CO₂ power cycle with liquefied natural gas heat sink. *Renew Energy.* 2017;113:1215–28.
- Ashouri M, Ahmadi MH, Pourkiaei SM, Astarai FR, Ghasempour R, Ming T, Hemati JH. Exergy and exergo-economic analysis and optimization of a solar double pressure organic Rankine cycle. *Therm Sci Eng Prog.* 2018;6:72–86.
- Arslan O. Technoeconomic analysis of electricity generation from wind energy in Kutahya, Turkey. *Energy.* 2010;35(1):120–31.

6. Mohammadi A, Ahmadi MH, Bidi M, Ghazvini M, Ming T. Exergy and economic analyses of replacing feedwater heaters in a Rankine cycle with parabolic trough collectors. *Energy Rep.* 2018;4:243–51.
7. Ahmadi MH, Sadaghiani MS, Pourfayaz F, Ghazvini M, Hahian O, Mehrpooya M, Wongwises S. Energy and exergy analyses of a solid oxide fuel cell-gas turbine-organic Rankine cycle power plant with liquefied natural gas as heat sink. *Entropy.* 2018;20(7):484.
8. Arslan O. Exergoeconomic evaluation of electricity generation by the medium temperature geothermal resources, using a Kalina cycle: Simav case study. *Int J Therm Sci.* 2010;49(9):1866–73.
9. Mirzei M, Ahmadi MH, Mobin M, Nazari MA, Alayi R. Energy, exergy and economics analysis of an ORC working with several fluids and utilizes smelting furnace gases as heat source. *Therm Sci Eng Prog.* 2018;5:230–7.
10. Acar MS, Arslan O. Energy and exergy analysis of solar energy-integrated, geothermal energy-powered organic Rankine cycle. *J Therm Anal Calorim.* 2019;137:659–66.
11. Arslan O. Power generation from medium temperature geothermal resources: ANN-based optimization of Kalina cycle system-34. *Energy.* 2011;36(5):2528–34.
12. Arslan O, Yetik O. ANN modeling of an ORC-binary geothermal power plant: simav case study. *Energy Sources Part A: Recov Util and Environ Eff.* 2014;36(4):418–28.
13. Arslan O. ANN-based determination of optimum working conditions of residential combustors with respect to optimum insulation. *Energy Sources Part A: Recov Util and Environ Eff.* 2014;36(23):2603–12.
14. Cota LP, Vitor N, Coelho VN, Guimaraes FG, Souza MJF. Bi-criteria formulation for green scheduling with unrelated parallel machines with sequence-dependent setup times. *Int Trans Oper Res.* 2018;2018:1–22. <https://doi.org/10.1111/itor.12566>.
15. Covasa MT, Silva AC, Dias LC. Multicriteria decision analysis for sustainable datacenters location. *Int Trans Oper Res.* 2013;2013(20):269–99.
16. Pohekar SD, Ramachandran M. Application of multi-criteria decision making to sustainable energy planning—a review. *Renew Sust Energy Rev.* 2004;8(4):365–81.
17. Yu D. Multiattribute decision making based on intuitionistic fuzzy interaction average operators: a comparison. *Int Trans Oper Res.* 2015;22:1017–32.
18. Zhang Y, Xu Z. Efficiency evaluation of sustainable water management using the HF-TODIM method. *Int Trans Oper Res.* 2019;26:747–64.
19. Afgan NH, Carvalho MG. Multi-criteria assessment of new and renewable energy power plants. *Energy.* 2002;27:739–55.
20. Arslan AE. Multi-Criteria Decision Making OF Simav Integrated Geothermal Energy System: AHP-EATWOS Hybrid Analysis. *Curr Res in Humanit and Soc Sci.* First Edition, Iype Cetinje Publicat, Montenegro, 2020. pp. 83–107.
21. Arslan O, Arslan AE, Kandemir SY. EATWOS Analysis of s-Type ORC-Binary Geothermal Power Plant. *International Congress on Afro-Eurasian Research V*, 19–22 April 2019, Nicosia, Cyprus.
22. Arslan O, Arslan, AE, Kandemir SY. Optimization of Simav Integrated Geothermal Energy System by EATWOS. *International Congress on Afro - Eurasian Research V*, 19–22 April 2019, Nicosia, Cyprus.
23. Arslan O, Arslan AE, Acar MS. Multi-criteria making-decision modeling of b-type ORC-binary geothermal power plant: EATWOS analysis. *BSEU J Sci.* 2019;6:29–48. <https://doi.org/10.35193/bseufbd.561668>.
24. Arslan O, Arslan AE, Acar MS. o-Tipi ORC-binary Jeotermal Güç Santrali Optimizasyonu: EATWOS Analizi. *BSEU J Sci.* 2019;6:222–36. <https://doi.org/10.35193/bseufbd.601745>.
25. Cavallaro F, Ciraolo L. A multicriteria approach to evaluate wind energy plants on an Italian Island. *Energy Policy.* 2005;33:235–44.
26. Arslan AE, Acar MS, Arslan O. Effectiveness Analysis of ORC-Binary Geothermal Power Plant Using Data Enveloping. *Proceedings of International Congress on Afro - Eurasian Research IV*, pp. 110–118, 27–29 April 2018, Budapest, Hungary.
27. Arslan AE, Acar MS, Arslan O. Data Enveloping Based Effectiveness Analysis of Integrated Geothermal System: Simav Case Study. *Proceedings of International Congress on Afro - Eurasian Research IV*, pp. 119–125, 27–29 April 2018, Budapest, Hungary.
28. Georgopoulou E, Lalas D, Papagiannakis L. A multicriteria decision aid approach for energy planning problems: the case of renewable energy option. *Eur J Oper Res.* 1997;103(9):38–54.
29. Goumas MG, Lygerou VA, Papayannakis LE. Computational methods for planning and evaluating geothermal energy projects. *Energy Policy.* 1999;27:147–54.
30. Mirasgedis S, Diakoulaki D. Multicriteria analysis vs. externalities assessment for the comparative evaluation of electricity generation systems. *Eur J Oper Res.* 1997;102:364–79.
31. Siksnelyte I, Zavadskas EK, Streimikiene D, Sharma D. An overview of multi-criteria decision-making methods in dealing with sustainable energy development issues. *Energies.* 2018;11(10):2754. <https://doi.org/10.3390/en11102754>.
32. Taha RA, Daïm T. Multi-Criteria Applications in Renewable Energy Analysis, a Literature Review. *Res and Technol Manag in the Electr Ind, Green Energy and Tech.* Springer, London, 2013.
33. Boran FE. A multidimensional analysis to evaluate district heating systems. *Energy Sources Part B.* 2013;8:122–9.
34. Huang W, Eling M. An efficiency comparison of the non-life insurance industry in the BRIC countries. *Eur J Oper Res.* 2013;226(3):577–91.
35. Oztaysi B, Onar SC, Kahraman C, Yavuz M. Multi-criteria alternative-fuel technology selection using interval-valued intuitionistic fuzzy sets. *Transp Res Part D.* 2017;53:128–48.
36. Peters ML, Zelewski S. Efficiency Analysis Under Consideration of Satisficing Levels for Output Quantities. In *Proceedings of the 17th Annual Conference of the Production and Operations Management Society (POMS)*, April 28–May 01 2006, Boston, USA.
37. Shen Y, Hermans E, Brijts T, Wets G. Data envelopment analysis for composite indicators: a multiple layer model. *Soc Indic Res.* 2013;114:739–56.
38. Si J, Halburd LM, Nasiri F, Bell S. Assessment of building-integrated green technologies: a review and case study on applications of multi-criteria decision making (MCDM) method. *Sustain Cities Soc.* 2016;27:106–15.
39. Wang B, Xie HL, Ren HY, Li X, Chen L, Wu BC. Application of AHP, TOPSIS, and TFNs to plant selection for phytoremediation of petroleum-contaminated soils in shale gas and oil fields. *J Clean Prod.* 2019;233:13–22.
40. Yadav VK, Kumar N, Ghosh S, Singh K. Indian thermal power plant challenges and remedies via application of modified data envelopment analysis. *Int Trans Oper Res.* 2014;21:955–77.
41. Saaty TL. Decision making with the analytic hierarchy process. *Int J Serv Sci.* 2008;1(1):83–98.
42. Saaty TL. *Multicriteria Decision Making: The Analytic Hierarchy Process.* 2nd ed. Pittsburgh: RWS Publ; 1990.
43. Karahalios H. The application of the AHP-TOPSIS for evaluating ballast water treatment systems by ship operators. *Transp Res Part D.* 2017;52:172–84.
44. Sennaroglu B, Celebi GV. A military airport location selection by AHP integrated PROMETHEE and VIKOR methods. *Transp Res Part D.* 2018;59:160–73.
45. Muhsen DH, Haider HT, Al-Nidawi YM, Khatib T. Domestic load management based on integration of MODE and AHP-TOPSIS decision making methods. *Sustain Cities Soc.* 2019;50:101651.

46. Sun CC. Combining grey relation analysis and entropy model for evaluating the operational performance: an empirical study. *Qual Quant.* 2014;48:1589–600.
47. Arslan O, Ozgur MA, Kose R, Tugcu A. Exergoeconomic evaluation on the optimum heating circuit system of Simav geothermal district heating system. *Energy Build.* 2009;41:1325–33.
48. Arslan O, Kose R. Exergoeconomic optimization of the integrated geothermal system in Simav, Kutahya. *Energy Convers Manag.* 2010;51:663–76.
49. Arslan O, Ozgur MA, Kose R. Electricity generation ability of the Simav geothermal field: a techno-economic approach. *Energy Sources Part A: Recov Util Environ Eff.* 2012;34:1130–44.
50. Myers JH, Alpert MI. Determinant buying attributes: meaning and measurement. *Marketing.* 1968;32(10):13–20.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.