

SELECTING THE OPTIMAL RENEWABLE ENERGY USING MULTI CRITERIA DECISION MAKING

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Abstract. Renewable energies are well-known as one of the most important energy resources not only due to limited other energy resources, but also due to environmental problems associated with air pollutants and greenhouse gas emissions. Renewable energy project selection is a multi actors and sophisticated problem because it is a need to incorporate social, economic, technological, and environmental considerations. Multi criteria decision making (MCDM) methods are powerful tools to evaluate and rank the alternatives among a pool of alternatives and select the best one. COPRAS (Complex Proportional Assessment) is an MCDM technique which determines the best alternative by calculating the ratio to the ideal solution and the negative ideal solution. On the other hand, analytical hierarchy process (AHP) is widely used in order to calculate the importance weights of evaluation criteria. In this paper an integrated COPRAS-AHP methodology is proposed to select the best renewable energy project. In order to validate the output of the proposed model, the model is compared with five MCDM tools. The results of this paper demonstrate the capability and effectiveness of the proposed model in selecting the most appropriate renewable energy option among the existing alternatives.

Keywords: renewable energy, MCDM, AHP, COPRAS.

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1. Introduction

Renewable energy is recognized as a key resource for future life and plays a significant role in supplying energy and reducing air pollutants and greenhouse gas emissions. Main renewable energy resources are (Kaltschmitt *et al.* 2007): (i) solar radiation, (ii) wind energy, (iii) hydropower, (iv) photosynthetically fixed energy, and (v) geothermal energy. In 2009, about 16% of global final energy consumption comes from renewable energies, with 10% coming from traditional biomass, 3.4% from hydropower, and 2.6% from all other renewable energies (REN21 2011). This is due to the negative effect of fossil fuels on the environment, the precarious nature of dependency on fossil fuel imports, and the advent of renewable energy alternatives (Cristóbal *et al.* 2011). These are environment-friendly and capable of replacing conventional sources in a variety of applications at competitive prices (Haralambopoulos, Polatidis 2003; Aras *et al.* 2004).

The selection of different energy investment projects is a multi criteria decision making (MCDM) problem, because various criteria should be analyzed and considered that are often in conflicting with each other. These criteria affect the success of a renewable energy project. For instance, two criteria that could be employed in renewable energy selection might be power and operation and maintenance costs. There are two conflicting criteria because an attempt in order to enhance power possibly causes a growth in operation and maintenance costs. According to the capability and effectively of MCDM and the need to incorporate social, economic, technological, and environmental considerations in energy issues, there is a vast MCDM literature on energy problems.

Beccali *et al.* (2003) applied the ELECTERE (ELimination Et Choix Traduisant la Réalité or Elimination and Choice Translating Reality) method to determine regional level for the diffusion of renewable energy technology. Heo *et al.* (2010) used fuzzy analytical hierarchy process (FAHP) to analyze the assessment factors for renewable energy dissemination program evaluation. Kahraman *et al.* (2010) applied a comparative analysis for multi attribute selection among renewable energy alternatives using fuzzy axiomatic design and FAHP.

Evans *et al.* (2009) employed sustainability indicators to assess renewable energy technologies. They indicators include price of generated electricity, greenhouse gas emissions during the full life cycle of the technology, availability of renewable sources, efficiency of energy conversion, land requirements, water consumption and social impacts. In this study, each indicator was assumed to have equal importance to sustainable development and utilized to rank the renewable energy technologies against their impacts.

Lee *et al.* (2009) utilized the FAHP technique in order to prioritize energy technologies against high oil prices. The results show that building technology is the most preferred technology in the sector of energy technologies against high oil prices, and the coal technology and transportation technology are located in the second and third place, respectively.

Cavallaro (2005) set out the application of PROMETHEE to assess sustainable energy options. Oberschmidt *et al.* (2010) developed the modified PROMETHEE approach for

assessing energy technologies. Sola *et al.* (2011) proposed a multi-criteria model using the PROMETHEE II method, with the aim of ranking alternatives for induction motors replacement. Lee *et al.* (2011) used a fuzzy AHP approach to prioritize the weights of hydrogen energy technologies in the sector of the hydrogen economy. Virtanen (2011) developed the PROMETHEE II method to select the optimal energy system for buildings and districts. In order to achieve the renewable energy policy goals, Shen *et al.* (2011) showed how different policy goals lead to corresponding renewable energy sources. In this paper, the relative importance of each goal was evaluated by using AHP.

Anagnostopoulos *et al.* (2007) developed a logic-based fuzzy multi criteria decision support system using the ideal and the anti-ideal solutions in order to assess the sustainability of renewable energy policies. Braune *et al.* (2009) presented a review of the recent literature to analyze the potential of multi criteria decision analysis for real world applications. The Multi-Attribute Utility Theory (MAUT) is utilized for the evaluation of renewable energy alternatives by I. Kaya and Kahraman (2011).

Doukas *et al.* (2009) developed a linguistic TOPSIS (technique for order preference by similarity ideal solution) model to evaluate the sustainability of renewable energy options. Kabir and Shihan (2003) used the AHP method for selection of renewable energy sources. Nigim *et al.* (2004) proposed two multi-criteria decision-making (MCDM) tools for prioritizing local viable renewable energy sources. The first tool is AHP and the second is sequential interactive model for urban sustainability (SIMUS). In this paper, AHP is based on community participation in the decision-making process through data collection and elicitation of expert opinions, and SIMUS uses mathematical linear programming manipulation, which also and primarily relies on elicitation of expert opinions, but in a less subjective and more objective manner.

Axiomatic design (AD) methodology is proposed for the selection among renewable energy alternatives under fuzzy environment by Kahraman *et al.* (2010). T. Kaya and Kahraman (2011) proposed a modified fuzzy TOPSIS methodology for the selection of the best energy technology alternative. Kahraman and Kaya (2010) proposed a fuzzy multicriteria decision-making methodology for the selection among energy policies. The proposed method is based on the analytic hierarchy process (AHP) under fuzziness.

Yi *et al.* (2011) developed an AHP method based on benefit, opportunity, cost, and risk (BOCR) in order to select sustainable renewable energy source for energy assistance to North Korea. Kaya and Kahraman (2010) proposed an integrated VIKOR-AHP methodology to the selection of the best energy policy and production site. They applied pairwise comparison matrices of AHP for determining the weights of the evaluation criteria. Cristóbal (2011) applied the VIKOR method and the AHP technique for the selection of a renewable energy project corresponding to the renewable energy plan launched by the Spanish Government. The AHP method is employed to weight the importance of the various evaluation criteria, which allows decision-makers to determine these values based on their preferences.

Balezentiene *et al.* (2013) proposed a MCDM framework for prioritization of energy crops based on fuzzy MULTIMOORA method which enables to tackle imprecise in-

formation. Streimikiene and Balezentis (2013) developed a MCDM methodology for climate change mitigation policies ranking in Lithuania based on priorities of sustainable energy development. Streimikiene *et al.* (2012) developed a multi-criteria decision support framework based on MULTIMOORA and TOPSIS for choosing the most sustainable electricity production technologies.

It is clear that the MCDM methods have demonstrated their capability and effectiveness as a problem-solving tool in energy issues.

COPRAS (COmplex PROportional ASsessment) is an MCDM technique that is employed by different researchers in order to solve many various problems. This method has some advantages as follows: 1) COPRAS allows simultaneous consideration of the ratio to the ideal solution and the negative ideal solution, 2) simple and logical computations, and 3) results are obtained in shorter time than other methods such as AHP and ANP.

In order to calculate the importance weights of criteria, analytical hierarchy process (AHP) can be employed since it is based on pairwise comparisons. This technique provides an organized description of the hierarchical interaction or connection among the elements (impacts, criteria or alternatives) (Reza *et al.* 2011).

In this paper, an integrated AHP-COPRAS method is proposed to select the most appropriate renewable energy project among the feasible alternatives. In the proposed method, AHP computes the relative importance of evaluation criteria. Then, the COPRAS method is used to obtain the final ranking order of alternatives.

2. Analytical hierarchy process (AHP)

Analytical hierarchy process (AHP) was first introduced by Saaty (1980). The AHP is a powerful tool that helps decision makers by organizing perceptions and judgments into a multi-level hierarchic structure. This technique decomposes a complex problem into a structure of hierarchy and then aggregates the solutions of all the sub problems into a conclusion (Saaty 1994). AHP uses pair-wise comparisons to obtain the relative importance of a criterion with respect to other criterion (Lashgari *et al.* 2011; Azimi *et al.* 2011; Fouladgar *et al.* 2012 a,b,c; Yazdani-Chamzini, Yakhchali 2012; Lashgari *et al.* 2012). The importance of pairwise comparisons in decision making is caused to the AHP technique be a popular method for determining weights in multi criteria problems.

3. COPRAS (COmplex PROportional ASsessment) method

COPRAS is an MCDM method that was developed by Zavadskas and Kaklauskas (1996). This method assumes that the significance and priority of the investigated versions depend directly on and are proportional to a system of criteria adequately describing the alternatives and to the values and weights of the criteria (Banaitiene *et al.* 2008). This technique allows simultaneous consideration of the ratio to the ideal solution and the negative ideal solution. The ideal solution is a solution that minimizes the cost criteria and maximizes the benefit criteria; whereas, the negative ideal solution maximizes

the cost criteria and minimizes the benefit criteria. The COPRAS technique is employed by different researchers to model decision making problems.

4. Proposed model

The proposed model for ranking renewable energy, composed of AHP and COPRAS techniques, has following three steps:

1. Criteria identification.
2. Criteria weight calculation.
3. Evaluation and selection of renewable energies with COPRAS.

Schematic diagram of the proposed model for selecting the optimal renewable energy is depicted in Fig. 1.

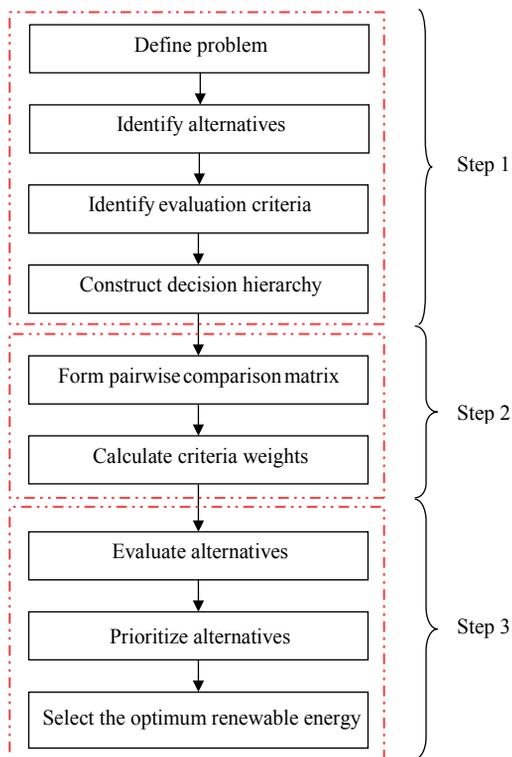


Fig. 1. Schematic diagram of the proposed model

4.1. Criteria identification

In the first step, renewable energy sources and the evaluation criteria which will be used in decision making process are identified and the decision hierarchy is organized. The AHP model is constructed such that the first level comprises the overall goal, the second level contains of criteria, and the last level includes alternatives.

4.2. Criteria weight calculation

In this step, pair-wise comparison matrices are established to obtain the weights of evaluation criteria. Decision makers make their evaluations using the scale presented in Table 1, to assign the values of the elements of pair-wise comparison matrix. The relative weights of the evaluation criteria are computed based on this matrix.

Table 1. Pair-wise comparison scale

Definition	Value
Equal importance	1
Weak importance	3
Essential importance	5
Demonstrated importance	7
Extreme importance	9
Intermediate values	2, 4, 6, 8

4.3. Evaluation of renewable energies with COPRAS

In the last step, evaluation of alternatives is accomplished by using COPRAS approach. Prioritizing renewable energies is determined based on the values of N_i derived by COPRAS. In the last phase of this step, the most appropriate alternative with the top value of 100% is selected.

5. Case analyses

An example in three different cases considered to demonstrate and validate the proposed method. Cristóbal (2011) proposed VIKOR method for selection of a renewable energy investment project. This example problem is related with selection of a suitable renewable energy for the Renewable Energy Plan launched by the Spanish Government in 2005. Proposed model is applied to rank renewable energies in three various cases. These cases are as follows:

Case 1: The weights of criteria are similar to the weights used by Cristóbal (2011);

Case 2: The weights of two criteria (selected as randomly) are inflated by keeping those of the remaining criteria constant;

Case 3: The weights of three criteria (selected as randomly) are inflated by keeping those of the remaining criteria constant.

Case 1

The application is based on the steps provided in previous section and described as following.

Step 1: criteria identification

In this step, criteria to be used in the model include Power (P), Investment Ratio (IR), Implementation Period (IP), Operating Hours (OH), Useful Life (UL), Operation and

Maintenance Costs (O&M) and tons of emissions of CO₂ avoided per year (tCO₂/y). In this problem, P, OH, UL, and tCO₂/y are benefit criteria whereas IR, IP, and O&M are cost criteria.

There are 13 alternative renewable energy projects as presented in Table 2. The performance ratings of alternatives with respect to each criterion are given in Table 3. Thus, the result of decision hierarchy is depicted in Fig. 2.

Table 2. Alternatives for electricity generation (Cristóbal 2011)

Symbol	Alternative
A1	Wind power $P \leq 5\text{MW}$
A2	Wind power $5 \leq P \leq 10\text{MW}$
A3	Wind power $10 \leq P \leq 50\text{MW}$
A4	Hydroelectric $P \leq 10\text{MW}$
A5	Hydroelectric $10 \leq P \leq 25\text{MW}$
A6	Hydroelectric $25 \leq P \leq 50\text{MW}$
A7	Solar Thermo-electric $P \geq 10\text{MW}$
A8	Biomass (energetic cultivations) $P \leq 5\text{MW}$
A9	Biomass (forest and agricultural wastes) $P \leq 5\text{MW}$
A10	Biomass (farming industrial wastes) $P \leq 5\text{MW}$
A11	Biomass (forest industrial wastes) $P \leq 5\text{MW}$
A12	Biomass (co-combustion in conventional central) $P \leq 50\text{MW}$
A13	Bio fuels $P \leq 2\text{MW}$

Table 3. Preference ratings of alternatives (Cristóbal 2011)

	P	IR	IP	OH	UL	O&M	tCO ₂ /y
A1	5000	937	1	2350	20	1.47	1929936
A2	10000	937	1	2350	20	1.47	3216560
A3	25000	937	1	2350	20	1.51	9649680
A4	5000	1500	1.5	3100	25	1.45	472812
A5	20000	700	2	2000	25	0.7	255490
A6	35000	601	2.5	2000	25	0.6	255490
A7	50000	5000	2	2596	25	4.2	482856
A8	5000	1803	1	7500	15	7.106	2524643
A9	5000	1803	1	7500	15	5.425	2524643
A10	5000	1803	1	7500	15	5.425	2524643
A11	5000	1803	1	7500	15	2.813	2524643
A12	56000	856	1	7500	20	4.56	4839548
A13	2000	1503	1.5	7000	20	2.512	5905270

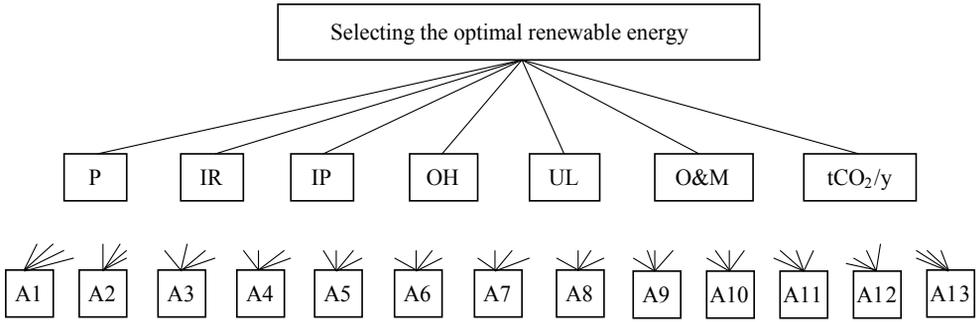


Fig. 2. Decision hierarchy

Decision hierarchy includes three levels; the overall goal of the decision process is in the first level, the second level of the hierarchy comprises the evaluation criteria and renewable energy projects are located in the last level of the hierarchy.

Step 2: criteria weight calculation

In this step, the relative importance of evaluation criteria with respect to the goal is calculated. To achieving the aim, one has to form a pairwise comparison matrix based on scale presented in Table 1. For example, when P and IR are pairwise compared, P is judged as five time important than IR. Table 4 presents the results of pairwise comparison of evaluation criteria.

Table 4. Pairwise comparison matrix

	P	IR	IP	OH	UL	O&M	tCO ₂ /y
P	1	5	9	3	5	7	1
IR	1/5	1	5	1/3	1/3	5	1/3
IP	1/9	1/5	1	1/5	1/7	1/3	1/5
OH	1/3	3	5	1	1	3	1/5
UL	1/5	3	7	1	1	5	1/3
O&M	1/7	1/5	3	1/3	1/5	1	1/5
tCO ₂ /y	1	3	5	5	3	5	1

In order to obtain the vector $W = (W_1, W_2, \dots, W_N)$ which indicates the importance weights of criteria, each entry in column i of pairwise comparison matrix is divided by the sum of the entries in column i to form the normalized matrix in which the sum of the entries in each column is 1. Then the average of the entries in row i of the normalized matrix is calculated to obtain the vector W . The CR is found to be acceptable, that is, less than 0.1. Priority weights form $W = (0.319, 0.09, 0.026, 0.116, 0.134, 0.042, 0.273)$ vector.

It is observed that power (0.319) is the most important criterion in renewable energy selection. It is followed by tons of emissions of CO₂ avoided per year (0.273), useful life (0.134) operating hours (0.116), operation and maintenance costs (0.042), implementation period (0.026), and investment ratio (0.09).

Step 3: Evaluation of renewable energies with COPRAS

To apply the COPRAS method, the decision matrix presented in Table 3. Table 5 shows the weighted normalized decision matrix.

The values of P_j and R_i are presented in Table 5. Next, the relative weight and the utility degree of each alternative are computed. The final rank of alternatives is listed in the last column of Table 5. Fig. 3 depicts the ranking of renewable energies according to the N_i values. According to the utility degree, the best renewable energy is A12, i.e. $N_{12} = 100\%$. The utility degree has the highest value, meaning that the needs of the decision maker and the project are satisfied the best (Banaitiene *et al.* 2008).

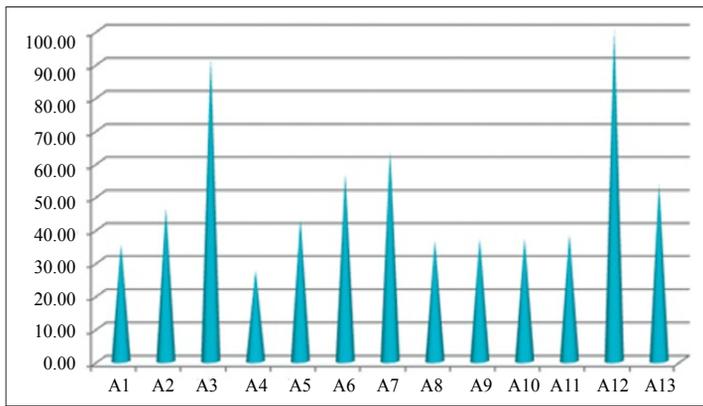


Fig. 3. The utility degrees of alternatives obtained by AHP-COPRAS (Case 1)

Often all the MCDM methods criticized for the fact that in some cases using different methods, different results are obtained. These differences across algorithms occur are caused by (Zavadskas, Turskis 2011):

- Using weights differently;
- Different selection of the best solution;
- Attempt to scale objectives;
- Introducing additional parameters that affect solution.

Hence the evaluation process should be carried out by different methods. Based on the relative weights of the evaluation criteria obtained by AHP, the five MCDM tools, including SAW (simple additive weighting) (MacCrimmon 1968), TOPSIS (technique for order preference by similarity to ideal solution) (Hwang, Yoon 1981), VIKOR (Vlsekriterijumska Optimizacija I Kompromisno Resenje) (Opricovic 1998), ARAS (additive ratio assessment) (Zavadskas, Turskis 2010) and MOORA (Multi-Objective Optimization on the basis of Ratio Analysis) (Brauers, Zavadskas 2006) were adopted for evaluating and ranking the feasible renewable energies in order to validate the capability and effectiveness of the proposed model.

The performance ranking order of the thirteen renewable energies using SAW, TOPSIS, VIKOR, ARAS, and MOORA is as follows:

Table 5. Analysis results

	P	IR		IP		OH		UL		O&M		tCO ₂ /y		P _i	R _i	Q _i	N _i	Rank
		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max						
A1	0.0070	0.0042	0.0015	0.0044	0.0103	0.0016	0.0016	0.0142	0.0359	0.0073	0.0530	0.0530	35.20	12				
A2	0.0140	0.0042	0.0015	0.0044	0.0103	0.0016	0.0236	0.0524	0.0073	0.0694	0.0694	46.14	6					
A3	0.0350	0.0042	0.0015	0.0044	0.0103	0.0016	0.0709	0.1207	0.0073	0.1376	0.1376	91.43	2					
A4	0.0070	0.0067	0.0023	0.0059	0.0129	0.0016	0.0035	0.0292	0.0105	0.0410	0.0410	27.25	13					
A5	0.0280	0.0031	0.0030	0.0038	0.0129	0.0008	0.0019	0.0465	0.0069	0.0645	0.0645	42.86	7					
A6	0.0490	0.0027	0.0038	0.0038	0.0129	0.0006	0.0019	0.0675	0.0071	0.0850	0.0850	56.46	4					
A7	0.0700	0.0222	0.0030	0.0049	0.0129	0.0045	0.0035	0.0913	0.0298	0.0955	0.0955	63.42	3					
A8	0.0070	0.0080	0.0015	0.0142	0.0077	0.0076	0.0186	0.0475	0.0172	0.0547	0.0547	36.32	11					
A9	0.0070	0.0080	0.0015	0.0142	0.0077	0.0058	0.0186	0.0475	0.0154	0.0555	0.0555	36.88	9					
A10	0.0070	0.0080	0.0015	0.0142	0.0077	0.0058	0.0186	0.0475	0.0154	0.0555	0.0555	36.88	9					
A11	0.0070	0.0080	0.0015	0.0142	0.0077	0.0030	0.0186	0.0475	0.0125	0.0573	0.0573	38.08	8					
A12	0.0783	0.0038	0.0015	0.0142	0.0103	0.0049	0.0356	0.1384	0.0102	0.1505	0.1505	100.00	1					
A13	0.0028	0.0067	0.0023	0.0132	0.0103	0.0027	0.0434	0.0698	0.0116	0.0804	0.0804	53.40	5					

SAW: A12 > A3 > A6 > A7 > A13 > A5 > A2 > A11 > A9 = A10 > A8 > A1 > A4,
 TOPSIS: A12 > A3 > A7 > A6 > A13 > A2 > A5 > A11 > A9 = A10 > A8 > A1 > A4,
 VIKOR: A12 > A3 > A7 > A6 > A5 A2 > A13 > A11 > A4 > A9 = A10 > A8 > A1,
 ARAS: A12 > A3 > A7 > A13 > A5 > A2 > A11 > A9 = A10 > A8 > A1 > A4,
 MOORA: A12 > A3 > A13 > A6 > A7 > A2 > A5 > A11 > A9 = A10 > A8 > A1 > A4.

The ranking orders of different methods are listed in Table 6.

Table 6. Rankings obtained by using various methods

Alternative	Method												Final rank
	TOPSIS		VIKOR		SAW		MOORA		ARAS		Proposed model (AHP-COPRAS)		
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	
A1	0.074	12	0.951	13	0.328	12	0.084	12	0.051	12	35.20	12	12.2
A2	0.147	6	0.798	6	0.393	7	0.127	6	0.067	6	46.14	6	6.8
A3	0.772	2	0.262	2	0.660	2	0.307	2	0.135	2	91.43	2	2.0
A4	0.043	13	0.929	9	0.295	13	0.059	13	0.040	13	27.25	13	12.3
A5	0.134	7	0.775	5	0.413	6	0.112	7	0.067	7	42.86	7	7.2
A6	0.302	4	0.688	4	0.514	3	0.164	4	0.091	4	56.46	4	4.0
A7	0.439	3	0.666	3	0.503	4	0.158	5	0.095	3	63.42	3	3.5
A8	0.086	11	0.946	12	0.356	11	0.088	11	0.055	11	36.32	11	10.3
A9	0.087	9	0.935	10	0.357	9	0.094	9	0.055	9	36.88	9	8.8
A10	0.087	9	0.935	10	0.357	9	0.094	9	0.055	9	36.88	9	8.8
A11	0.090	8	0.917	8	0.361	8	0.102	8	0.056	8	38.08	8	8.2
A12	0.841	1	0.000	1	0.774	1	0.344	1	0.151	1	100.00	1	1.0
A13	0.272	5	0.823	7	0.457	5	0.167	3	0.079	5	53.40	5	4.8

From Table 6, all these methods suggest A12 (i.e. Biomass (co-combustion in conventional central) $P \leq 50\text{MW}$) as the first choice and A3 (i.e. Wind power $10 \leq P \leq 50\text{MW}$) as the second choice. Thus, the present method is validated.

The rankings of six methods are then compared with the final ranking (the arithmetic average of each row) results using the Spearman’s rank correlation coefficients in order to demonstrate the capability and effectiveness of each method. The Spearman’s rank correlation coefficients between the final ranking and the proposed model, VIKOR, SAW, MOORA, ARAS and TOPSIS methods are 0.994, 0.885, 0.986, 0.96, 0.994 and 0.994 respectively. The results show that the proposed model (AHP-COPRAS), TOPSIS and ARAS outperform other methods. It is followed by SAW, MOORA and VIKOR methods. The high Spearman’s rank correlation coefficient between the proposed model and the final ranking demonstrates the potential application of the proposed model.

Case 2

The new application is based on the steps provided in previous section and described as following.

Step 1 for case 2 is identical to step 1 for case 1.

Step 2 for case 2 is similar to step 2 for case 1, but with this difference that only the weights calculated by the AHP technique are changed in order to establish a new condition to validate the proposed model more comprehensive. The new weights are obtained by increasing fifty percent in the weights of two criteria O&M and tCO_2/y , then normalizing the final weights. The results of the importance weights of evaluation criteria are computed as $W = (0.276, 0.078, 0.023, 0.1, 0.116, 0.055, 0.352)$.

Based on above assumptions, tons of emissions of CO_2 avoided per year (0.352) is the most critical criterion in this case. It is followed by power (0.276), useful life (0.116) operating hours (0.1), investment ratio (0.078), operation and maintenance costs (0.055), and implementation period (0.023).

Step 3: Evaluation of renewable energies with COPRAS

According to the weights of evaluation criteria derived from AHP in previous step, the COPRAS technique is applied to rank the feasible alternatives in order to select the best renewable energy among a pool of possible alternatives. The decision matrix presented in Table 3 is normalized, and the results are depicted in Table 7. Since the weights of evaluation criteria are different, the weighted normalized decision matrix results are shown in Table 8.

Table 7. Normalized decision matrix

	P	IR	IP	OH	UL	O&M	tCO_2/y
A1	0.022	0.046	0.057	0.038	0.077	0.037	0.052
A2	0.044	0.046	0.057	0.038	0.077	0.037	0.087
A3	0.110	0.046	0.057	0.038	0.077	0.038	0.260
A4	0.022	0.074	0.086	0.051	0.096	0.037	0.013
A5	0.088	0.035	0.114	0.033	0.096	0.018	0.007
A6	0.154	0.030	0.143	0.033	0.096	0.015	0.007
A7	0.219	0.248	0.114	0.042	0.096	0.107	0.013
A8	0.022	0.089	0.057	0.122	0.058	0.181	0.068
A9	0.022	0.089	0.057	0.122	0.058	0.138	0.068
A10	0.022	0.089	0.057	0.122	0.058	0.138	0.068
A11	0.022	0.089	0.057	0.122	0.058	0.072	0.068
A12	0.246	0.042	0.057	0.122	0.077	0.116	0.130
A13	0.009	0.074	0.086	0.114	0.077	0.064	0.159

The values of P_j and R_i are listed in Table 8. Then, the utility degree of each alternative is computed as depicted in Table 8 and Fig. 4. The final rank of alternatives is presented in the last column of Table 8. According to the utility degree, the most appropriate renewable energy is A3, i.e. $N3 = 100\%$. It is followed by A12 (96.08%), A13 (59%), A7 (55.85%), A2 (47.68%), A5 (39.34%), A11 (38.68%), A9 = A10 (37.22%), A8 (36.6%), A1 (35.6%) and A4 (25.55%).

Table 8. The utility degree and ranking results of thirteen alternatives

	P	IR	IP	OH	UL	O&M	tCO ₂ /y	P_i	R_i	Q_i	N_i	Rank
	Max	Min	Min	Max	Max	Min	Max					
A1	0.0060	0.0036	0.0013	0.0038	0.0089	0.0020	0.0184	0.037	0.007	0.054	35.60	12
A2	0.0121	0.0036	0.0013	0.0038	0.0089	0.0020	0.0306	0.055	0.007	0.072	47.68	6
A3	0.0302	0.0036	0.0013	0.0038	0.0089	0.0021	0.0919	0.135	0.007	0.152	100.00	1
A4	0.0060	0.0058	0.0020	0.0051	0.0111	0.0020	0.0045	0.027	0.010	0.039	25.55	13
A5	0.0242	0.0027	0.0026	0.0033	0.0111	0.0010	0.0024	0.041	0.006	0.060	39.34	7
A6	0.0423	0.0023	0.0033	0.0033	0.0111	0.0008	0.0024	0.059	0.006	0.077	51.05	5
A7	0.0604	0.0192	0.0026	0.0042	0.0111	0.0058	0.0046	0.080	0.028	0.085	55.85	4
A8	0.0060	0.0069	0.0013	0.0122	0.0067	0.0099	0.0241	0.049	0.018	0.055	36.60	11
A9	0.0060	0.0069	0.0013	0.0122	0.0067	0.0076	0.0241	0.049	0.016	0.056	37.22	9
A10	0.0060	0.0069	0.0013	0.0122	0.0067	0.0076	0.0241	0.049	0.016	0.056	37.22	9
A11	0.0060	0.0069	0.0013	0.0122	0.0067	0.0039	0.0241	0.049	0.012	0.059	38.68	8
A12	0.0677	0.0033	0.0013	0.0122	0.0089	0.0063	0.0461	0.135	0.011	0.146	96.08	2
A13	0.0024	0.0058	0.0020	0.0114	0.0089	0.0035	0.0563	0.079	0.011	0.089	59.00	3

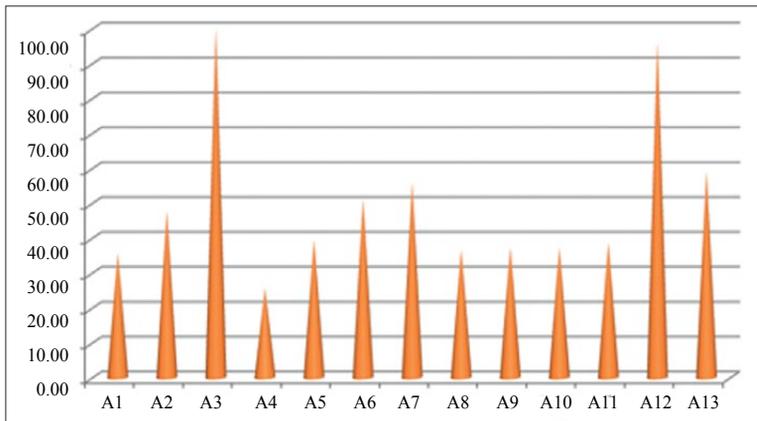


Fig. 4. The utility degrees of alternatives obtained by AHP-COPRAS (Case 2)

Finally, according to the relative importance of the evaluation criteria obtained in step 2, five MCDM tools, including SAW, TOPSIS, VIKOR, ARAS and MOORA, are applied for ranking the feasible alternatives. Based on these five methods, the alternatives are ranked in the descending order indicating the most preferred and least preferred renewable energy as shown below:

SAW: A12 \succ A3 \succ A13 \succ A6 \succ A7 \succ A2 \succ A5 \succ A11 \succ A9 = A10 \succ A8 \succ A1 \succ A4,

TOPSIS: A3 \succ A12 \succ A13 \succ A7 \succ A6 \succ A2 \succ A11 \succ A9 = A10 \succ A8 \succ A5 \succ A1 \succ A4,

VIKOR: A3 \succ A12 \succ A13 \succ A7 \succ A6 \succ A2 \succ A11 \succ A9 = A10 \succ A8 \succ A1 \succ A5 \succ A4,

ARAS: A3 \succ A12 \succ A13 \succ A7 \succ A6 \succ A2 \succ A5 \succ A11 \succ A9 = A10 \succ A8 \succ A1 \succ A4,

MOORA: A3 \succ A12 \succ A13 \succ A6 \succ A7 \succ A2 \succ A11 \succ A5 \succ A9 = A10 \succ A8 \succ A1 \succ A4.

The ranking orders of six techniques are presented in Table 9.

Table 9. Rankings yielded by six methods

Alternative	Method												Final rank
	TOPSIS		VIKOR		SAW		MOORA		ARAS		Proposed model (AHP-COPRAS)		
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	
A1	0.068	12	0.834	11	0.314	12	0.087	12	0.052	12	35.60	12	11.8
A2	0.161	6	0.626	6	0.386	6	0.135	6	0.070	6	47.68	6	6.3
A3	0.870	1	0.053	1	0.695	2	0.345	1	0.149	1	100.00	1	1.3
A4	0.031	13	0.975	13	0.268	13	0.053	13	0.038	13	25.55	13	13.0
A5	0.083	11	0.926	12	0.375	7	0.098	8	0.062	7	39.34	7	9.3
A6	0.179	5	0.846	5	0.466	4	0.143	4	0.084	5	51.05	5	4.8
A7	0.273	4	0.829	4	0.443	5	0.135	5	0.085	4	55.85	4	4.3
A8	0.088	10	0.781	10	0.340	11	0.088	11	0.056	11	36.60	11	9.7
A9	0.089	8	0.765	8	0.341	9	0.095	9	0.056	9	37.22	9	8.3
A10	0.089	8	0.765	8	0.341	9	0.095	9	0.056	9	37.22	9	8.3
A11	0.093	7	0.741	7	0.347	8	0.106	7	0.058	8	38.68	8	7.8
A12	0.741	2	0.058	2	0.730	1	0.332	2	0.147	2	96.08	2	1.7
A13	0.391	3	0.578	3	0.471	3	0.191	3	0.088	3	59.00	3	3.2

As shown in Table 9, all of the methods (with exception of the SAW method) suggest A3 (i.e. Wind power $10 \leq P \leq 50\text{MW}$) as the first choice. Whereas, the SAW method proposes A12 (i.e. Biomass (co-combustion in conventional central) $P \leq 50\text{MW}$) as the best choice.

The Spearman’s rank correlation coefficients between the final ranking and the proposed model, VIKOR, SAW, MOORA, ARAS and TOPSIS methods are 0.978, 0.923, 0.969, 0.975, 0.978 and 0.958 respectively. According to the results obtained by different methods, the proposed model and the ARAS technique outperform other methods. It is followed by MOORA, SAW, TOPSIS and VIKOR methods. Based on the Spearman’s rank correlation coefficient, the performance of the VIKOR method is poorer than other methods in selecting the optimum alternative. Despite the fact that SAW is located in higher rank than TOPSIS and VIKOR, but based on the consensus of the five methods, this method is the poorest method in order to choose the optimum renewable energy. In this case, similar to case 1, there is a high Spearman’s rank correlation coefficient between the proposed model and the final ranking. Therefore, the rank of alternatives by using the present method is validated.

Case 3

The new case is implemented according to the steps described in previous section as following.

Step 1 for case 3 is identical to step 1 for cases 1 and 2.

Step 2 for case 3 is similar to step 2 for case 1 and 2, but with this difference that only the weights calculated by the AHP technique are varied in order to establish a new condition to validate the proposed model more precise and accurate. For this reason, the weights of three criteria P, O&M and tCO₂/y are changed by increasing from 0.319 to 0.415 (increasing 30%), 0.042 to 0.063 (increasing 50%) and 0.273 to 0.409 (increasing 50%) respectively; next the final weights are normalized. Finally, the relative weights of evaluation criteria are obtained as $W = (0.331, 0.072, 0.021, 0.092, 0.107, 0.05, 0.327)$.

Based on what mentioned above, power criterion (0.331) is more important than other criteria in case 3. It is followed by tons of emissions of CO₂ avoided per year (0.327), useful life (0.107) operating hours (0.092), investment ratio (0.072), operation and maintenance costs (0.05), and implementation period (0.021).

Step 3: Evaluation of renewable energies with COPRAS

Similarly, COPRAS was applied to rank the renewable energies based on the relative weights of the evaluation criteria by AHP in previous step. After constructing the normalized decision matrix, the weighted normalized decision matrix results are presented in Table 10.

Table 10. Ranking results of alternatives

	P	IR	IP	OH	UL	O&M	tCO ₂ /y	P_i	R_i	Q_i	N_i	Rank
	Max	Min	Min	Max	Max	Min	Max					
A1	0.0073	0.0033	0.0012	0.0035	0.0082	0.0019	0.0170	0.0360	0.0064	0.052	33.61	12
A2	0.0145	0.0033	0.0012	0.0035	0.0082	0.0019	0.0283	0.0546	0.0064	0.070	45.73	6
A3	0.0363	0.0033	0.0012	0.0035	0.0082	0.0019	0.0849	0.1330	0.0065	0.148	96.80	2
A4	0.0073	0.0053	0.0018	0.0047	0.0103	0.0019	0.0042	0.0264	0.0090	0.037	24.43	13
A5	0.0290	0.0025	0.0024	0.0030	0.0103	0.0009	0.0022	0.0446	0.0058	0.062	40.30	7
A6	0.0508	0.0021	0.0030	0.0030	0.0103	0.0008	0.0022	0.0664	0.0059	0.083	54.28	5
A7	0.0726	0.0178	0.0024	0.0039	0.0103	0.0054	0.0042	0.0910	0.0256	0.095	61.94	3
A8	0.0073	0.0064	0.0012	0.0113	0.0062	0.0091	0.0222	0.0470	0.0167	0.053	34.52	11
A9	0.0073	0.0064	0.0012	0.0113	0.0062	0.0070	0.0222	0.0470	0.0146	0.054	35.09	9
A10	0.0073	0.0064	0.0012	0.0113	0.0062	0.0070	0.0222	0.0470	0.0146	0.054	35.09	9
A11	0.0073	0.0064	0.0012	0.0113	0.0062	0.0036	0.0222	0.0470	0.0112	0.056	36.42	8
A12	0.0813	0.0030	0.0012	0.0113	0.0082	0.0059	0.0426	0.1434	0.0101	0.153	100.00	1
A13	0.0029	0.0053	0.0018	0.0106	0.0082	0.0032	0.0520	0.0737	0.0104	0.083	54.32	4

The values of P_j and R_i are presented in Table 10. Next, the utility degree of each alternative is shown in Table 10 and Fig. 5. The ranking results of thirteen alternatives are listed in the last column of Table 10. Based on the values of the utility degree, the optimal renewable energy is A12, i.e. $N_3 = 100\%$. It is followed by A3 (96.8%), A7 (61.94%), A13 (54.32%), A6 (54.28%), A2 (45.73%), A5 (40.3%), A11 (36.42%), A9 = A10 (35.09%), A8 (34.52%), A1 (33.61%) and A4 (24.43%).

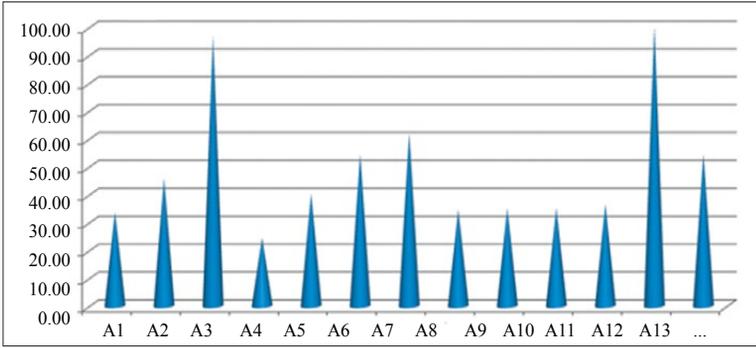


Fig. 5. The utility degrees of alternatives obtained by AHP-COPRAS (Case 3)

In the end, five MCDM methods (SAW, TOPSIS, VIKOR, ARAS and MOORA) are employed to prioritize the alternatives based on the weights of the criteria calculated in step 2. By applying these five methods, the rank orders of the alternatives are computed. The results of different methods are presented in the following:

- SAW: A12 > A3 > A6 > A7 > A13 > A5 > A2 > A11 > A9 = A10 > A8 > A1 > A4,
- TOPSIS: A3 > A12 > A7 > A13 > A6 > A2 > A5 > A11 > A9 = A10 > A8 > A1 > A4,
- VIKOR: A12 > A3 > A2 > A7 > A6 > A13 > A5 > A11 > A9 = A10 > A1 > A8 > A4,
- ARAS: A12 > A3 > A7 > A6 > A13 > A2 > A5 > A11 > A9 = A10 > A8 > A1 > A4,
- MOORA: A12 > A3 > A13 > A7 > A6 > A2 > A5 > A11 > A9 = A10 > A8 > A1 > A4.

Table 11 shows the ranking orders of six methods.

Table 11. Rankings resulted by different methods

Alternative	Method										Final rank		
	TOPSIS		VIKOR		SAW		MOORA		ARAS			Proposed model (AHP-COPRAS)	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank		Value	Rank
A1	0.056	12	0.939	11	0.297	12	0.085	12	0.049	12	33.61	12	11.8
A2	0.135	6	0.768	3	0.370	7	0.133	6	0.068	6	45.73	6	6.2
A3	0.811	1	0.160	2	0.676	2	0.340	2	0.146	2	96.80	2	1.8
A4	0.026	13	0.960	13	0.254	13	0.053	13	0.037	13	24.43	13	13.0
A5	0.097	7	0.902	7	0.374	6	0.107	7	0.064	7	40.30	7	7.5
A6	0.240	5	0.811	5	0.478	3	0.162	5	0.089	4	54.28	5	4.7
A7	0.385	3	0.769	4	0.477	4	0.167	4	0.095	3	61.94	3	3.5
A8	0.070	11	0.944	12	0.321	11	0.085	11	0.053	11	34.52	11	10.3
A9	0.071	9	0.930	9	0.322	9	0.092	9	0.054	9	35.09	9	8.7
A10	0.071	9	0.930	9	0.322	9	0.092	9	0.054	9	35.09	9	8.7
A11	0.074	8	0.909	8	0.327	8	0.102	8	0.055	8	36.42	8	8.3
A12	0.803	2	0.000	1	0.751	1	0.354	1	0.154	1	100.00	1	1.2

As seen in Table 11, all of the methods (with exception of the TOPSIS method) propose A12 (i.e. Biomass (co-combustion in conventional central) $P \leq 50\text{MW}$) as the best choice and A3 as the second choice. Whereas, TOPSIS suggests A3 (i.e. Wind power $10 \leq P \leq 50\text{MW}$) as the first choice. Therefore, the rank of alternatives by using the present method is validated.

Based on the results obtained by different methods, the Spearman's rank correlation coefficients between the final ranking and the proposed model, VIKOR, SAW, MOORA, ARAS and TOPSIS methods are 0.994, 0.936, 0.97, 0.983, 0.994 and 0.987 respectively. According to the Spearman's rank correlation coefficients, the proposed model and the ARAS technique outperform other methods. It is followed by the TOPSIS, MOORA, SAW and VIKOR methods. In this case, according to the consensus of the five methods, the output of the TOPSIS method is the poorest result in order to select the best alternative although its Spearman's rank correlation coefficient is higher than three methods MOORA, SAW and VIKOR. The high Spearman's rank correlation coefficient between the proposed model and the final ranking demonstrates that the proposed model outperform other methods.

6. Discussions

This research conducted a renewable energy selection problem using the MCDM methods. AHP and COPRAS techniques were applied in decision making process for obtaining the relative weights of evaluation criteria, ranking the feasible alternatives and selecting the optimum renewable energy among a pool of alternatives, respectively. Furthermore, five MCDM analytical methods (i.e. SAW, MOORA, TOPSIS, ARAS and VIKOR) were employed in decision making problem for the validation of the proposed model. Based on the results of the computations, some essential findings were discussed as follows.

In this study, AHP is used to calculate the relative importance of the evaluation criteria of the renewable energies based on pairwise comparison matrix. As presented in Table 5, the result of the AHP method reveals that the "power" criterion is the most important evaluation criterion. This is because the performance of renewable energy project is strongly connected with generating power. Furthermore, based on environmental regulations in order to reduce greenhouse gas emissions, the criterion of "tons of emissions of CO_2 avoided per year" is ranked as the second most critical criterion.

Besides, the COPRAS method is employed to rank the renewable energies in order to select the optimum alternative. Often the ranking results of the different MCDM methods are not identical. Therefore assessment should be accomplished by different methods to validate the result obtained by the proposed model. Therefore this study adopted five MCDM methods VIKOR, TOPSIS, ARAS, MOORA and SAW to evaluate the alternatives of this problem. For achieving the aim, an example is illustrated to show the capability of the proposed model. In order to generate several different conditions for ranking the alternatives, the weights of evaluation criteria are changed to make three various cases.

Hence, based on the relative weights of the evaluation criteria obtained by AHP, the performance ranking order of the thirteen renewable energies for three cases using COPRAS is presented in Table 12. Similarly, the ranking order is fulfilled by TOPSIS, VIKOR, ARAS, MOORA and SAW and the results derived from these methods in three various cases are listed in Table 12.

Table 12. Ranking of the alternatives in three different cases

Alternative	Method																		Final rank					
	TOPSIS			VIKOR			SAW			MOORA			ARAS			Proposed model (AHP COPRAS)								
	C1*	C2*	C3*	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3			
A1	12	12	12	13	11	11	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12.2	11.8	11.8
A2	6	6	6	6	6	3	7	6	7	6	6	6	6	6	6	6	6	6	6	6	6	6.8	6.3	6.2
A3	2	1	1	2	1	2	2	2	2	2	1	2	2	1	2	2	1	2	2	1	2	2.0	1.3	1.8
A4	13	13	13	9	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	12.3	13.0	13.0
A5	7	11	7	5	12	7	6	7	6	7	8	7	7	7	7	7	7	7	7	7	7	7.2	9.3	7.5
A6	4	5	5	4	5	5	3	4	3	4	4	5	4	5	4	4	5	5	4	5	5	4.0	4.8	4.7
A7	3	4	3	3	4	4	4	5	4	5	5	4	3	4	3	3	4	3	3	4	3	3.5	4.3	3.5
A8	11	10	11	12	10	12	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	10.3	9.7	10.3
A9	9	8	9	10	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	8.8	8.3	8.7
A10	9	8	9	10	8	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	8.8	8.3	8.7
A11	8	7	8	8	7	8	8	8	8	8	7	8	8	8	8	8	8	8	8	8	8	8.2	7.8	8.3
A12	1	2	2	1	2	1	1	1	1	1	2	1	1	2	1	1	2	1	1	2	1	1.0	1.7	1.2
A13	5	3	4	7	3	6	5	3	5	3	3	3	5	3	5	5	3	4	4	4	4	4.8	3.2	4.3

*C1: Case 1, C2: Case 2 and C3: Case 3.

Based on the ranking order of each method and the Spearman’s rank correlation coefficients between the final ranking and each method, it can be found that the proposed model has a high potential in selecting the best renewable energy. The output of the model for three cases is better than four methods VIKOR, ARAS, SAW and MOORA.

According to the results derived from the proposed model for case 1, the performance of the proposed model, TOPSIS and ARAS are the best; so that, the ranking orders of all alternatives are identical. For case 2, based on the results derived from both ARAS and the proposed model, the ranking orders of all alternatives are the same. For case 2, the results obtained by SAW are poorest output based on the consensus of the five methods. For case 3, the results obtained by TOPSIS are the poorest result because all other methods suggest A12 as the first choice; whereas, TOPSIS proposes A3 as the best alternative.

However, it can be understood that the results of the proposed model (COPRAS-based model) is more stable than TOPSIS and SAW techniques. The output of the proposed model and ARAS are the best in comparison with all other methods in this problem.

7. Conclusions

The rapid growth of demand for energy by the ever increasing population and the need for reducing air pollutants and greenhouse gas emissions generated by fossil fuel caused to the renewable energy resources be developed. Renewable energies are different and each of them have relative advantage and drawbacks; so that, it is found by researchers that it is difficult to evaluate the different alternatives and select the best alternative among all the feasible alternatives because there are tangible and intangible criteria that affect decision making.

The current study proposes an MCDM evaluation model for selecting the most appropriate renewable energy. This method is formed based on the AHP and COPRAS techniques, which AHP is applied for calculating the weights of evaluation criteria and COPRAS is used to rank the existing alternatives. The proposed model can help decision makers in reducing the decision failures. In this paper, an example in three different cases is illustrated to demonstrate the potential application of the proposed model. In order to validate the output of the model, it is compared with five MCDM analytical tools, including VIKOR, SAW, TOPSIS, ARAS and MOORA. It indicates that the final values of the proposed model outperform VIKOR, SAW, TOPSIS and MOORA methods. The final values of the thirteen alternatives obtained by ARAS and the proposed model are close to each other. Therefore, the proposed model is found to be an appropriate method of assessment to rank the renewable energies. Likewise, the proposed model offers a general procedure that can be applicable to diverse selection problems that incorporate complexity and a number of evaluation criteria. The results derived from the proposed model are logical and stable to fulfil when compared with the other MCDM methods.

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