SELECTING THE OPTIMAL RENEWABLE ENERGY USING MULTI CRITERIA DECISION MAKING

Abdolreza Yazdani-Chamzini1, Mohammad Majid Fouladgar2, Edmundas Kazimieras Zavadskas3, S. Hamzeh Haji Moini4

1, 2Young Researchers Club, South Tehran Branch, Islamic Azad University, Tehran, Iran
3Faculty of Civil Engineering, Vilnius Gediminas Technical University, Sauletekio al. 11, LT-10223 Vilnius, Lithuania
4Fateh Research Group, Department of Strategic Management, Milad Building, Mini city, Aghdasieh, Tehran, Iran

E-mails: 1manager@fatehidea.com; 2a.yazdani@fatehidea.com; 3Edmundas.Zavadskas@vgtu.lt (corresponding author); 4smhpm85@yahoo.com

Received 31 October 2012; accepted 10 January 2013

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.

Reference to this paper should be made as follows: Yazdani-Chamzini, A.; Fouladgar, M. M.; Zavadskas, E. K.; Moini, S. H. H. 2013. Selecting the optimal renewable energy using multi criteria decision making, Journal of Business Economics and Management 14(5): 957–978.

JEL Classification: O13, C02, C44, C54.
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.

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.

| 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 CO\(_2\) avoided per year (tCO\(_2\)/y). In this problem, P, OH, UL, and tCO\(_2\)/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 ≤ 5MW                                                          |
| A2     | Wind power 5 ≤ P ≤ 10MW                                                     |
| A3     | Wind power 10 ≤ P ≤ 50MW                                                    |
| A4     | Hydroelectric P ≤ 10MW                                                      |
| A5     | Hydroelectric 10 ≤ P ≤ 25MW                                                 |
| A6     | Hydroelectric 25 ≤ P ≤ 50MW                                                 |
| A7     | Solar Thermo-electric P ≥ 10MW                                               |
| A8     | Biomass (energetic cultivations) P ≤ 5MW                                    |
| A9     | Biomass (forest and agricultural wastes) P ≤ 5MW                            |
| A10    | Biomass (farming industrial wastes) P ≤ 5MW                                 |
| A11    | Biomass (forest industrial wastes) P ≤ 5MW                                  |
| A12    | Biomass (co-combustion in conventional central) P ≤ 50MW                    |
| A13    | Bio fuels P ≤ 2MW                                                           |

### 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     |
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  | tCO₂/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    |
| tCO₂/y | 1 | 3    | 5    | 5    | 3    | 5    | 1      |

In order to obtain the vector \( W = (W_1, W_2, ..., W_N) \) 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. N12 = 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).

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  | tCO₂/y | $P_i$ | $R_i$ | $Q_i$ | $N_i$ | Rank |
|-----|------|------|------|------|------|------|--------|-------|-------|-------|-------|------|
| A1  | 0.0070 | 0.0042 | 0.0015 | 0.0044 | 0.0103 | 0.0016 | 0.0142 | 0.0359 | 0.0073 | 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 | 46.14 | 6    |
| A3  | 0.0350 | 0.0042 | 0.0015 | 0.0044 | 0.0103 | 0.0016 | 0.0709 | 0.1207 | 0.0073 | 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 | 27.25 | 13   |
| A5  | 0.0280 | 0.0031 | 0.0030 | 0.0038 | 0.0129 | 0.0008 | 0.0019 | 0.0465 | 0.0069 | 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 | 56.46 | 4    |
| A7  | 0.0700 | 0.0222 | 0.0030 | 0.0049 | 0.0129 | 0.0045 | 0.0035 | 0.0913 | 0.0298 | 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 | 36.32 | 11   |
| A9  | 0.0070 | 0.0080 | 0.0015 | 0.0142 | 0.0077 | 0.0058 | 0.0186 | 0.0475 | 0.0154 | 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 | 36.88 | 9    |
| A11 | 0.0070 | 0.0080 | 0.0015 | 0.0142 | 0.0077 | 0.0030 | 0.0186 | 0.0475 | 0.0125 | 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 | 100.00 | 1 |
| A13 | 0.0028 | 0.0067 | 0.0023 | 0.0132 | 0.0103 | 0.0027 | 0.0434 | 0.0698 | 0.0116 | 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 > A5 > A2 > 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 | TOPSIS | VIKOR | SAW | MOORA | ARAS | Proposed model (AHP-COPRAS) | Final rank |
|-------------|--------|-------|-----|-------|------|-----------------------------|------------|
|             | Value  | Rank  | Value| Rank  | Value | Value                        |            |
| A1          | 0.074  | 12    | 0.951| 13    | 0.328 | 12                          | 35.20      | 12.2 |
| A2          | 0.147  | 6     | 0.798| 6     | 0.393 | 7                           | 46.14      | 6.8  |
| A3          | 0.772  | 2     | 0.262| 2     | 0.660 | 2                           | 91.43      | 2.0  |
| A4          | 0.043  | 13    | 0.929| 9     | 0.295 | 13                          | 27.25      | 12.3 |
| A5          | 0.134  | 7     | 0.775| 5     | 0.413 | 6                           | 42.86      | 7.2  |
| A6          | 0.302  | 4     | 0.688| 4     | 0.514 | 3                           | 56.46      | 4.0  |
| A7          | 0.439  | 3     | 0.666| 3     | 0.503 | 4                           | 63.42      | 3.5  |
| A8          | 0.086  | 11    | 0.946| 12    | 0.356 | 11                          | 36.32      | 11.03 |
| A9          | 0.087  | 9     | 0.935| 10    | 0.357 | 9                           | 36.88      | 8.8  |
| A10         | 0.087  | 9     | 0.935| 10    | 0.357 | 9                           | 36.88      | 8.8  |
| A11         | 0.090  | 8     | 0.917| 8     | 0.361 | 8                           | 38.08      | 8.2  |
| A12         | 0.841  | 1     | 0.000| 1     | 0.774 | 1                           | 100.00     | 1.0  |
| A13         | 0.272  | 5     | 0.823| 7     | 0.457 | 5                           | 53.40      | 4.8  |

From Table 6, all these methods suggest A12 (i.e. Biomass (co-combustion in conventional central) P ≤ 50MW) as the first choice and A3 (i.e. Wind power 10 ≤ P ≤ 50MW) 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.

|     | 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 $P_i$ 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  | tCO₂/y | P_i | R_i | Q_i | N_i | Rank |
|-------|------|------|------|------|------|------|--------|-----|-----|-----|-----|------|
|       | Max  | Min  | Max  | Max  | Min  | Max  | Max    |     |     |     |     |      |
| A1    | 0.0060 | 0.0036 | 0.0013 | 0.0089 | 0.0020 | 0.0184 | 0.037 | 0.007 | 0.054 | 35.60 | 12   |
| A2    | 0.0121 | 0.0036 | 0.0013 | 0.0089 | 0.0020 | 0.0306 | 0.055 | 0.007 | 0.072 | 47.68 | 6    |
| A3    | 0.0302 | 0.0036 | 0.0013 | 0.0089 | 0.0021 | 0.0919 | 0.135 | 0.007 | 0.152 | 100.00 | 1   |
| A4    | 0.0242 | 0.0027 | 0.0026 | 0.0033 | 0.0111 | 0.0041 | 0.006 | 0.060 | 39.34 | 7    |
| A5    | 0.0423 | 0.0023 | 0.0033 | 0.0011 | 0.0008 | 0.0024 | 0.059 | 0.006 | 0.077 | 51.05 | 5    |
| A6    | 0.0604 | 0.0192 | 0.0042 | 0.0111 | 0.0058 | 0.0046 | 0.080 | 0.028 | 0.085 | 55.85 | 4    |
| A7    | 0.0606 | 0.0069 | 0.0013 | 0.0022 | 0.0067 | 0.0099 | 0.0241 | 0.049 | 0.018 | 0.055 | 36.60 | 11   |
| A8    | 0.0606 | 0.0069 | 0.0013 | 0.0122 | 0.0067 | 0.0076 | 0.0241 | 0.049 | 0.016 | 0.056 | 37.22 | 9    |
| A9    | 0.0606 | 0.0069 | 0.0013 | 0.0122 | 0.0067 | 0.0393 | 0.0241 | 0.049 | 0.012 | 0.059 | 38.68 | 8    |
| A10   | 0.0677 | 0.0033 | 0.0013 | 0.0122 | 0.0089 | 0.0063 | 0.0461 | 0.135 | 0.011 | 0.146 | 96.08 | 2    |
| A11   | 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 ≻ A3 ≻ A13 ≻ A6 ≻ A7 ≻ A2 ≻ A5 ≻ A11 ≻ A9 = A10 ≻ A8 ≻ A1 ≻ A4,
TOPSIS: A3 ≻ A12 ≻ A13 ≻ A7 ≻ A6 ≻ A2 ≻ A11 ≻ A9 = A10 ≻ A8 ≻ A5 ≻ A1 ≻ A4,
VIKOR: A3 ≻ A12 ≻ A13 ≻ A7 ≻ A6 ≻ A2 ≻ A11 ≻ A9 = A10 ≻ A8 ≻ A1 ≻ A5 ≻ A4,
ARAS: A3 ≻ A12 ≻ A13 ≻ A7 ≻ A6 ≻ A2 ≻ A5 ≻ A11 ≻ A9 = A10 ≻ A8 ≻ A1 ≻ A4,
MOORA: A3 ≻ A12 ≻ A13 ≻ A6 ≻ A7 ≻ A2 ≻ A11 ≻ A5 ≻ A9 = A10 ≻ A8 ≻ A1 ≻ A4.
The ranking orders of six techniques are presented in Table 9.

| Alternative | Method | Value | Rank | Value | Rank | Value | Rank | Value | Rank | Value | Rank | Value | Rank |
|-------------|--------|-------|------|-------|------|-------|------|-------|------|-------|------|-------|------|
| A1          | TOPSIS | 0.068 | 12   | 0.834 | 11   | 0.314 | 12   | 0.087 | 12   | 0.052 | 12   | 35.60 | 12   | 11.8 |
| A2          | VIKOR  | 0.161 | 6    | 0.626 | 6    | 0.386 | 6    | 0.135 | 6    | 0.070 | 6    | 47.68 | 6    | 6.3  |
| A3          | SAW    | 0.870 | 1    | 0.053 | 1    | 0.695 | 2    | 0.345 | 1    | 0.149 | 1    | 100.00 | 1    | 1.3  |
| A4          | MOORA  | 0.031 | 13   | 0.975 | 13   | 0.268 | 13   | 0.053 | 13   | 0.038 | 13   | 25.55 | 13   | 13.0 |
| A5          | ARAS   | 0.083 | 11   | 0.926 | 12   | 0.375 | 7    | 0.098 | 8    | 0.062 | 7    | 39.34 | 7    | 9.3  |
| A6          | Proposed model (AHP-COPRAS) | 0.179 | 5    | 0.846 | 5    | 0.466 | 4    | 0.143 | 4    | 0.084 | 5    | 51.05 | 5    | 4.8  |
| A7          | Final rank | 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 $10 \leq P \leq 50$MW) as the first choice. Whereas, the SAW method proposes A12 (i.e. Biomass (co-combustion in conventional central) $P \leq 50$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 tCO$_2$/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 CO$_2$ 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.

|      | P       | IR      | IP     | OH     | UL     | O&M    | tCO$_2$/y | $P_i$ | $R_i$ | $Q_i$ | $N_i$ | Rank |
|------|---------|---------|--------|--------|--------|--------|-----------|-------|-------|-------|------|------|
| 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 $R_j$ 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. N3 = 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%).
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.

| Alternative | TOPSIS Value | Rank | VIKOR Value | Rank | SAW Value | Rank | MOORA Value | Rank | ARAS Value | Rank | Proposed model (AHP-COPRAS) Value | Rank | Final 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        |

**Fig. 5.** The utility degrees of alternatives obtained by AHP-COPRAS (Case 3)
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 ≤ 50MW) as the best choice and A3 as the second choice. Whereas, TOPSIS suggests A3 (i.e. Wind power 10 ≤ P ≤ 50MW) 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 CO₂ 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 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        | 12.2      | 11.8      | 11.8      |
| A2          | 6               | 6          | 6        | 6         | 7         | 7         | 7         | 6         | 6         | 6         | 6.8       | 6.3       | 6.2       |
| A3          | 2               | 1          | 1        | 2         | 2         | 2         | 2         | 2         | 2         | 2         | 2.0       | 1.3       | 1.8       |
| A4          | 13              | 13         | 13       | 9         | 13        | 13        | 13        | 13        | 13        | 13        | 12.3      | 13.0      | 13.0      |
| A5          | 7               | 11         | 7        | 5         | 12        | 7         | 7         | 7         | 7         | 7         | 7.2       | 9.3       | 7.5       |
| A6          | 4               | 5          | 4        | 5         | 5         | 3         | 4         | 5         | 4         | 5         | 4.0       | 4.8       | 4.7       |
| A7          | 3               | 4          | 3        | 4         | 4         | 4         | 5         | 4         | 5         | 4         | 3         | 4         | 3         | 3         | 3         | 3         | 4         | 3.5       | 4.3       | 3.5       |
| A8          | 11              | 10         | 11       | 12        | 10        | 12        | 11        | 11        | 11        | 11        | 10.3      | 9.7       | 10.3      |
| A9          | 9               | 8          | 9        | 10        | 8         | 9         | 9         | 9         | 9         | 9         | 8.8       | 8.3       | 8.7       |
| A10         | 9               | 8          | 9        | 10        | 8         | 9         | 9         | 9         | 9         | 9         | 8.8       | 8.3       | 8.7       |
| A11         | 8               | 7          | 8        | 7         | 8         | 8         | 8         | 8         | 8         | 8         | 8.2       | 7.8       | 8.3       |
| A12         | 1               | 2          | 2        | 1         | 2         | 1         | 1         | 2         | 1         | 2         | 1.0       | 1.7       | 1.2       |
| A13         | 5               | 3          | 4        | 7         | 3         | 6         | 5         | 3         | 3         | 3         | 5         | 3         | 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.

References

Anagnostopoulos, K.; Doukas, H.; Psarras, J. 2007. A logic-based fuzzy multicriteria decision support system using the ideal and the anti-ideal solutions: assessing the sustainability of renewable energy polices, *Advances in Fuzzy Sets and Systems* 2(3): 239–266.

Aras, H.; Erdogmus, S.; Koc, E. 2004. Multi-criteria selection for a wind observation station location using analytic hierarchy process, *Renew Energy* 23(13): 83–92.

Azimi, R.; Yazdani-Chamzini, A.; Fouladgar, M. M.; Zavadskas, E. K.; Basiri, M. H. 2011. Ranking the strategies of mining sector through ANP and TOPSIS in a SWOT framework, *Journal of Business Economics and Management* 12(4): 670–689. http://dx.doi.org/10.3846/16111699.2011.626552

Balezentiene, L.; Streimikiene, D.; Balezentis, T. 2013. Fuzzy decision support methodology for sustainable energy crop selection, *Renewable and Sustainable Energy Reviews* 17(1): 83–93. http://dx.doi.org/10.1016/j.rser.2012.09.016

Banaitiene, N.; Banaitis, A.; Kaklauskas, A.; Zavadskas, E. K. 2008. Evaluating the life cycle of a building: a multivariant and multiple criteria approach, *Omega* 36: 429–441. http://dx.doi.org/10.1016/j.omega.2005.10.010

Beccali, M.; Cellura, M.; Mistretta, M. 2003. Decision-making in energy planning. Application of the Electre method at regional level for the diffusion of renewable energy technology, *Renewable Energy* 28(13): 2063–2087. http://dx.doi.org/10.1016/S0960-1481(03)00102-2
Brauers, W. K. M.; Zavadskas, E. K. 2006. The MOORA method and its application to privatization in a transition economy, *Control and Cybernetics* 35(2): 443–468.

Braune, I.; Pinkwart, A.; Reeg, M. 2009. Application of mult-criteria analysis for the evaluation of sustainable energy systems – a review of recent literature, in *5th Dubrovnic Conference on Sustainable Development of Energy, Water and Environment Systems*. ISBN 978-953-6313-97-6.

Cavallaro, F. 2005. An Integrated multi-criteria system to assess sustainable energy options: an application of the Promethee method. *FEEM Working Paper* No. 22 [online], [cited 11 October 2012]. Available from Internet: http://ssrn.com/abstract=666741

Cristóbal, J. R. S. 2011. Multi-criteria decision-making in the selection of a renewable energy project in Spain: the Vikor method, *Renewable Energy* 36: 498–502. http://dx.doi.org/10.1016/j.renene.2010.07.031

Doukas, H.; Karakosta, Ch.; Psarras, J. 2009. A linguistic TOPSIS model to evaluate the sustainability of renewable energy options, *International Journal of Global Energy Issues* 32(1–2): 102–118. http://dx.doi.org/10.1016/j.ijgie.2009.027976

Evans, A.; Strezov, V.; Evans, T. J. 2009. Assessment of sustainability indicators for renewable energy technologies, *Renewable and Sustainable Energy Reviews* 13(5): 1082–1088. http://dx.doi.org/10.1016/j.rser.2008.03.008

Fouladgar, M. M.; Yazdani-Chamzini, A.; Zavadskas, E. K.; Yakhchali, S. H.; Ghasempour-abadi, M. H. 2012a. Project portfolio selection using fuzzy AHP and VIKOR techniques, *Transformations in Business & Economics* 11(25): 213–231.

Fouladgar, M. M.; Yazdani-Chamzini, A.; Lashgari, A.; Zavadskas, E. K.; Turskis, Z. 2012b. Maintenance strategy selection using AHP and COPRAS under fuzzy environment, *International Journal of Strategic Property Management* 16(1): 85–104. http://dx.doi.org/10.3846/1648715X.2012.666657

Fouladgar, M. M.; Yazdani-Chamzini, A.; Zavadskas, E. K.; Moini, S. H. H. 2012c. A new hybrid model for evaluating the working strategies: case study of construction company, *Technological and Economic Development of Economy* 18(1): 164–188. http://dx.doi.org/10.3846/20294913.2012.667270

Haralambopoulos, D. A.; Polatidis, H. 2003. Renewable energy projects: structuring a multi-criteria group decision-making framework, *Renew Energy* 28(9): 61–73.

Heo, E.; Kim, J.; Boo, K. J. 2010. Analysis of the assessment factors for renewable energy dissemination program evaluation using fuzzy AHP, *Renewable and Sustainable Energy Reviews* 14(8): 2214–2220. http://dx.doi.org/10.1016/j.rser.2010.01.020

Hwang, C. L.; Yoon, K. 1981. *Multiple attribute decision making: methods and applications*, New York: Springer-Verlag. http://dx.doi.org/10.1007/978-3-642-48318-9

Kabir, A. B. M. Z.; Shihan, S. M. A. 2003. Selection of renewable energy sources using analytic hierarchy process, in *Proceedings of the International Symposium on Analytic Hierarchy Process ISAHIP*, August 7–9, 2003, Bali, Indonesia, 267–276.

Kahraman, C.; Cebi, S.; Kaya, I. 2010. Selection among renewable energy alternatives using fuzzy axiomatic design: the case of Turkey, *Journal of Universal Computer Science* 16(1): 82–102.

Kahraman, C.; Kaya, İ. 2011. A fuzzy multicriteria methodology for selection among energy alternatives, *Expert Systems with Applications* 37: 6270–6281. http://dx.doi.org/10.1016/j.eswa.2010.02.095

Kaya, İ.; Kahraman, C. 2011. Evaluation of green and renewable energy system alternatives using a multiple attribute utility model: the case of Turkey, *Soft Computing in Green and Renewable Energy Systems: Studies in Fuzziness and Soft Computing* 269: 157–182. http://dx.doi.org/10.1007/978-3-642-22176-7_6
Kaya, T.; Kahraman, C. 2010. Multicriteria renewable energy planning using an integrated fuzzy VIKOR and AHP methodology: the case of Istanbul, *Energy* 35: 2517–2527. [http://dx.doi.org/10.1016/j.energy.2010.02.051](http://dx.doi.org/10.1016/j.energy.2010.02.051)

Kaya, T.; Kahraman, C. 2011. Multicriteria decision making in energy planning using a modified fuzzy TOPSIS methodology, *Expert Systems with Applications* 38: 6577–6585. [http://dx.doi.org/10.1016/j.eswa.2010.11.081](http://dx.doi.org/10.1016/j.eswa.2010.11.081)

Kaltschmitt, M.; Streicher, W.; Wiese, A. 2007. *Renewable energy: technology, economics and environment*. Springer-Verlag Berlin Heidelberg.

Lashgari, A.; Fouladgar, M. M.; Yazdani-Chamzini, A.; Skibniewski, M. J. 2011. Using an integrated model for shaft sinking method selection, *Journal of Civil Engineering and Management* 17(4): 569–580. [http://dx.doi.org/10.3846/13923730.2011.628687](http://dx.doi.org/10.3846/13923730.2011.628687)

Lashgari, A.; Yazdani-Chamzini, A.; Fouladgar, M. M.; Zavadskas, E. K.; Shafiee, S.; Abbate, N. 2012. Equipment selection using fuzzy multi criteria decision making model: key study of Gole Gohar iron mine, *Inzinerine Ekonomika – Engineering Economics* 23(2): 125–136.

Lee, S. K.; Mogi, G.; Kim, J. W. 2009. Decision support for prioritizing energy technologies against high oil prices: a fuzzy analytic hierarchy process approach, *Journal of Loss Prevention in the Process Industries* 22(6): 915–920. [http://dx.doi.org/10.1016/j.jlp.2009.07.001](http://dx.doi.org/10.1016/j.jlp.2009.07.001)

Lee, S. K.; Mogi, G.; Lee, S. K.; Kim, J. W. 2011. Prioritizing the weights of hydrogen energy technologies in the sector of the hydrogen economy by using a fuzzy AHP approach, *International Journal of Hydrogen Energy* 36(2): 1897–1902. [http://dx.doi.org/10.1016/j.ijhydene.2010.01.035](http://dx.doi.org/10.1016/j.ijhydene.2010.01.035)

MacCrimmon, K. R. 1968. *Decision making among multiple-attribute alternatives: a survey and consolidated approach*. RAND Memorandum, RM-4823-ARPA.

Nigim, K.; Munier, N.; Green, J. 2004. Pre-feasibility MCDM tools to aid communities in prioritizing local viable renewable energy sources, *Renewable Energy* 29(11): 1775–1791. [http://dx.doi.org/10.1016/j.renene.2004.02.012](http://dx.doi.org/10.1016/j.renene.2004.02.012)

Oberschmidt, J.; Geldermann, J.; Ludwig, J.; Schmehl, M. 2010. Modified PROMETHEE approach for assessing energy technologies, *International Journal of Energy Sector Management* 4(2): 183–212. [http://dx.doi.org/10.1108/17506221011058696](http://dx.doi.org/10.1108/17506221011058696)

Opacic, S. 1998. *Multicriteria optimization of civil engineering systems*. Belgrade: Faculty of Civil Engineering (in Serbian).

Renewable Energy Policy Network for the 21st Century (REN21). 2011. Renewables 2011: global status report. 17 p.

Reza, B.; Sadiq, R.; Hewage, K. 2011. Sustainability assessment of flooring systems in the city of Tehran: an AHP-based life cycle analysis, *Construction and Building Materials* 25: 2053–2066. [http://dx.doi.org/10.1016/j.conbuildmat.2010.11.041](http://dx.doi.org/10.1016/j.conbuildmat.2010.11.041)

Saaty, T. L. 1980. *The analytic hierarchy process*. New York: McGraw-Hill.

Saaty, T. L. 1994. How to make a decision: the analytic hierarchy process, *Interfaces* 24: 19–43. [http://dx.doi.org/10.1287/inte.24.6.19](http://dx.doi.org/10.1287/inte.24.6.19)

Shen, Y. Ch.; Chou, Ch. J.; Lin, G. T. R. 2011. The portfolio of renewable energy sources for achieving the three E policy goals, *Energy* 36(5): 2589–2598. [http://dx.doi.org/10.1016/j.energy.2011.01.053](http://dx.doi.org/10.1016/j.energy.2011.01.053)

Sola, A. V. H.; Mota, C. M. M.; Kovaleski, J. L. 2011. A model for improving energy efficiency in industrial motor system using multicriteria anglysi, *Energy Policy* 39(6): 3645–3654. [http://dx.doi.org/10.1016/j.enpol.2011.03.070](http://dx.doi.org/10.1016/j.enpol.2011.03.070)

Streimikiene, D.; Balezentis, T. 2013. Multi-objective ranking of climate change mitigation policies and measures in Lithuania, *Renewable and Sustainable Energy Reviews* 18: 144–153. [http://dx.doi.org/10.1016/j.rser.2012.09.040](http://dx.doi.org/10.1016/j.rser.2012.09.040)
Streimikiene, D.; Balezentis, T.; Krisciukaitiene, I.; Balezentis, A. 2012. Prioritizing sustainable electricity production technologies: MCDM approach, Renewable and Sustainable Energy Reviews 16(5): 3302–3311. http://dx.doi.org/10.1016/j.rser.2012.02.067

Virtanen, M. 2011. Choosing the optimal energy system for buildings and districts. Master’s thesis, Lappeenranta University of Technology.

Yazdani-Chamzini, A.; Yakhchali, S. H. 2012. Tunnel Boring Machine (TBM) selection using fuzzy multicriteria decision making methods, Tunnelling and Underground Space Technology 30: 194–204. http://dx.doi.org/10.1016/j.tust.2012.02.021

Yi, S. K.; Sin, H. Y.; Heo, E. 2011. Selecting sustainable renewable energy source for energy assistance to North Korea, Renewable and Sustainable Energy Reviews 15: 554–563. http://dx.doi.org/10.1016/j.rser.2010.08.021

Zavadskas, E. K.; Kaklauskas, A. 1996. Determination of an efficient contractor by using the new method of multicriteria assessment, in D. A. Langford, A. Retik (Eds.). International Symposium for “The Organisation and Management of Construction”, Shaping Theory and Practice, vol. 2: Managing the Construction Project and Managing Risk. CIB W 65. London, Weinheim, New York, Tokyo, Melbourne, Madras. London: E and FN SPON: 94–104.

Zavadskas, E. K.; Turskis, Z. 2010. A new additive ratio assessment (ARAS) method in multicriteria decision making, Technological and Economic Development of Economy 16(2): 159–172. http://dx.doi.org/10.3846/tede.2010.10

Zavadskas, E. K.; Turskis, Z. 2011. Multiple criteria decision making (MCDM) methods in economics: an overview, Technological and Economic Development of Economy 17(2): 397–427. http://dx.doi.org/10.3846/20294913.2011.593291

Abdolreza YAZDANI-CHAMZINI. Master of Science in the Department of Mining Engineering, research assistant of Tehran University, Tehran-Iran. Author of more than 46 research papers. In 2011, he graduated from the Science and Engineering Faculty at Tarbiat Modares University, Tehran-Iran. His research interests include decision making, forecasting, modeling, and optimization.

Mohammad Majid FOULADGAR. PhD student of future study in Amirkabir University of Technology, Tehran-Iran. Author of 13 research papers. In 2007 he graduated from the science and engineering Faculty at Tarbiat Modares University, Tehran-Iran. His research interests include decision support system, fuzzy logic, water resource, and forecasting.

Edmundas Kazimieras ZAVADSKAS. Prof., the Head of the Department of Construction Technology and Management at Vilnius Gediminas Technical University, Lithuania. PhD in Building Structures (1973). Dr Sc. (1987) in Building Technology and Management. A member of Lithuanian and several foreign Academies of Sciences. Doctore Honoris Causa from Poznan, Saint-Petersburg and Kiev universities. A member of international organizations; a member of steering and programme committees at many international conferences; a member of the editorial boards of several research journals; the author and co-author of more than 400 papers and a number of monographs in Lithuanian, English, German and Russian. Research interests: building technology and management, decision-making theory, automation in design and decision support systems.

S. Hamzeh Haji MOINI. Master of Science of Project Management, research assistant of Fateh Research Group, Tehran-Iran. He is the author of 7 research papers. His interests include decision support system, portfolio selection, and artificial intelligence.