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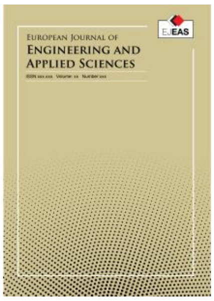

Research Article

A Decision Support System Based on Hybrid Approach With Copras And Interval Type-2 Fuzzy Topsis For Evaluation Of Renewable Energy Alternatives

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Abstract: Renewable energy (RE) is a vital source for the sustainable development of society and economy. It plays a significant role in meeting energy requirements of both developed and developing countries. Moreover, renewable energy creats multiple benefits such as environmental improvement, increases fuel diversity, reduction of energy price, volality effect on their economy, national economic security, and increases in economic productivity. Selection of the most appropriate RE alternatives for any country can provide guidelines to planners of regional, national and global energy systems. The issue of ranking renewable energy sources involves many conflicting criteria and is a complicated problem since it needs to simultaneously incorporate technical, economic, cost, social-political, and environmental criteria. In this study, an integrated multi criteria decision making (MCDM) aproach consisting of interval type-2 fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Compressed Proportional Assessment (COPRAS) method is conducted to prioritize RE alternatives in order to direct planning of the national RE investments. A real case application for Turkey has been presented via expert evaluations to demonstrate applicability of the proposed methodology.

Keywords: *COPRAS, Interval type-2 fuzzy sets, Multi criteria decision making, Renewable energy, TOPSIS.*

Yenilenebilir Enerji Alternatiflerinin Değerlendirilmesinde Copras ve Interval Type-2 Fuzzy Topsis ile Hibrit Yaklaşıma Dayalı Bir Karar Destek Sistemi

Öz: Yenilenebilir enerji (YE), toplumun ve ekonominin sürdürülebilir gelişimi için hayati bir kaynaktır. Hem gelişmiş hem de gelişmekte olan ülkelerin enerji ihtiyacının karşılanmasında önemli rol oynamaktadır. Ayrıca yenilenebilir enerji, çevrenin iyileştirilmesi, yakıt çeşitliliğinin artması, enerji fiyatlarının düşmesi, ekonomilerde değişiklik etkisi, ulusal ekonomik güvenlik ve ekonomik verimliliğin artması gibi birçok fayda yaratmaktadır. Herhangi bir ülke için en uygun yenilenebilir enerji alternatiflerinin seçimi, bölgesel, ulusal ve küresel enerji sistemleri planlamacılarına yol gösterici olabilir. Yenilenebilir enerji kaynaklarının sıralanması konusu, birbiriyle çelişen birçok kriteri içermekte olup; teknik, ekonomik, maliyet, sosyo-politik ve çevresel kriterlerin eş zamanlı olarak bir araya getirilmesi bakımından karmaşık bir sorundur. Bu çalışmada, ulusal yenilenebilir enerji yatırımlarının doğrudan planlanmasında YE alternatiflerini önceliklendirmek amacıyla Aralıklı Tip-2 Bulanık TOPSIS Tekniği ve COPRAS yönteminden oluşan entegre çok kriterli karar verme (MCDM) yaklaşımı kullanılmıştır. Önerilen metodolojinin uygulanabilirliğini göstermek amacıyla uzman değerlendirmeleri yoluyla Türkiye için gerçek bir vaka uygulaması sunulmuştur.

Anahtar kelimeler: *Aralıklı tip-2 bulanık kümeler, COPRAS, Çok kriterli karar verme, TOPSIS, Yenilenebilir enerji.*

1. Introduction

Renewable energy (RE) sources such as hydroelectricity, biomass, solar energy, wind energy and geothermal energy play an important role in meeting the energy requirements around the World [1, 2]. RE is the inevitable choice for

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sustainable economic growth, for the harmonious coexistence of human and environment as well as for the sustainable development. In order to determine a set of RE sources to meet the energy requirements in an optimal way, ranking the alternatives and selection of the optimum one for any country is crucially important for the investment decisions involving social, economic, environmental and political factors [2, 3].

The decision making process consists of options derived from hierarchical comparisons among alternatives based mostly on conflicting criteria. MCDM is used for the solution of decision making problems for this reason. MCDM is within the scope of operational research models that help sort alternatives or choose the best among multiple criteria [4]. Decisions are made on the basis of compromise or compromise among a large number of conflicting criteria. There are many MCDM approaches and these approaches can be used by combining with fuzzy set theory under uncertainty.

In the literature, there are several studies that addressed the selection of the best RE project [2, 5] using MCDM methods. On the other hand, some studies considered the geographic region to a higher level, yielding cost/benefit studies of RE sources for different countries such as Pakistan [6], Malaysia [7], Indonesia [8], North Korea [9], Iran [10], and Germany [11]. Turkey has been one of the geographic locations for which such RE source cost/benefit studies have been undertaken [e.g., 3, 12, 14, 15, 16, 17], A summary of these studies carried out for selection of the best RE source in Turkey is presented in Table 1.

As it can be followed in the Table 1, most the relevant studies that took Turkey as the case, implemented various MCDM methods in the identification of best sub-set of RE sources. Interestingly, results of these prior studies had differing results; while hydroelectric power led the ranks in some cases, wind energy was found to be the top-ranked alternative in many others.

In this study, a methodology consisting of combined interval type-2 fuzzy (IT2FS) TOPSIS and COPRAS aproach is proposed to obtain ranking of RE alternatives in order to the planning of national RE investments in future [18]. TOPSIS method is applied to determine the positive ideal solution and negative ideal solution. The COPRAS method presented, uses an evaluating of the RE sources with respect to significance and utility degree [11, 19].

The reminder of this study is structured as follows: Turkey's current RE context and future projections, the criteria for evaluating RE sources, brief background information about TOPSIS and COPRAS methods and the proposed methodology are described in Section 2. The illustrative case for the context of Turkey is discussed to show the benefits of the proposed method, followed by the results in Section 3. Concluding remarks and future research directions are provided in Section 4.

2. Material and Methods

2.1. Background of Turkey Based on RE Resources

Depending on the economic growth and population growth in Turkey, the energy demand is constantly increasing [20]. Turkey's primary energy supply increased from 53 million tons of oil equivalent (Mtoe) in 1990 to 144 Mtoe in 2018 (see Figure 1).

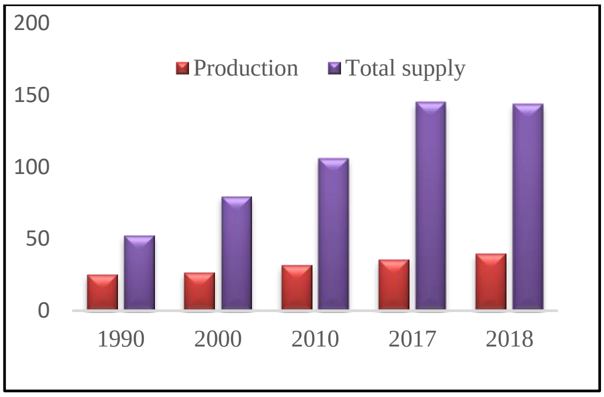

Figure 1. *Total Primary Energy Production (Mtoe) And Supply (Mtoe) In Turkey Between Years 1990 And 2018 [27]*

As it can be seen from Figure 2, around 27.6% of the total energy supply has been met by the domestic energy production in 2018 while the domestic energy production has met 47.8% of the primary energy supply in 1990 [27]; Turkey has an increasing dependency on energy imports.

The COPRAS method presented uses an evaluating of the RE sources with respect to significance and utility degree.

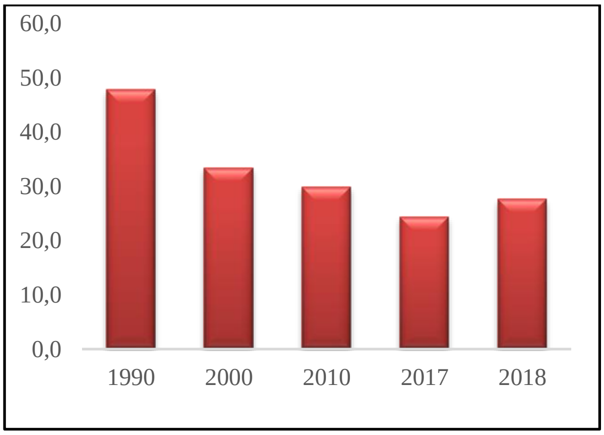

Figure. 2. *The Coverage Ratio (%) Of Energy Production To Total Primary Energy Supply In Turkey Between Years 1990 And 2018 [27]*

The share of energy sources in Turkey's primary energy production in 2018 is shown in Figure 3. As it can be observed from this figure, coal production constitutes 39.8% of the total energy production with 17.7 Mtoe energy production. The coal is followed by a renewable source geothermal (8.3 Mtoe production and 21% share) and geothermal is followed by hydraulic (5.1 Mtoe production and 13% share). Other renewable energy sources like bioenergy and wastes, wind and solar have a total production of 6.2 Mtoe and 15.8% share. The rest of the production comes from oil, asphalt and natural gas with a total production of 3.8 Mtoe and 10.4% share [27].

Table 1. A Literature Summary For Selecting The Best RE Source For Turkey

Author(s)	**Year**	**Based on Fuzzy**	**Types**	**Methodology**	**Ranking of energy sources**
Topcu and Ulengin [16]	2004	-	-	PROMETHEE	Wind > Hydro > PV > Biomass > Nuclear > Natural gas > Fossil fuels
Ulutaş [17]	2005	-	-	ANP and BCOR analysis	Biomass > Geothermal > Coal > Wind > Hydropower > Solar > Petroleum > Nuclear > Natural gas
Kahraman et al. [13]	2009	Yes	Type 1	AD	Wind > Solar > Biomass > Geothermal > Hydropower
		Yes	Type 1	AHP	
Kahraman and Kaya [3]	2010	Yes	Type 1	Fuzzy AHP	Wind > Solar > Biomass > Geothermal > Hydro > Natural gas > Coal and lignite > Nuclear > Oil
Kaya and Kahraman [21]	2011	Yes	Type-1	AHP and modified TOPSIS	Wind > Biomass > Solar > Combined heat and power > Hydraulic > Nuclear > Conventional
Atmaca and Basar [22]	2012	-	-	ANP	Nuclear > Natural gas > Geothermal > Wind > Hydro > Coal/Lignite
Ertay et al. [23]	2013	Yes	Type 1	MACBETH and AHP	Wind > Solar > Biomass > Geothermal > Hydropower
Kabak and Dağdeviren [12]	2014	-	-	ANP and BCOR analysis	Hydro > Solar > Wind > Geothermal > Biomass
Pak et al. [14]	2015	-	-	ANP and TOPSIS	Hydraulic > Wind > Biomass > Geothermal > Solar
Şengül et al. [15]	2015	Yes	Type 1	TOPSIS and AHP	Hydro > Geothermal > Regulator > Wind
Büyüközkan and Güleryüz [24]	2016	-	-	DEMATEL and ANP	Wind > Solar > Biomass > Hydraulic > Geothermal
		-	-	ANP	Wind > Solar > Geothermal > Biomass > Hydraulic
Çelikbilek and Tüysüz [25]	2016	Yes	Type-1	GREY, ANP, DEMATEL and VIKOR	Solar > Wind > Hydro > Biomass > Geothermal
Balin and Baraçli [26]	2017	Yes	Type-2/ Type-1	TOPSIS and AHP	Solar > Biomass > Geothermal > Hydraulic > Hydro
Colak and Kaya [18]	2017	Yes	Type-2/ Type-1	AHP and TOPSIS	Wind > Solar >Hydraulic > Biomass > Geothermal > Wave > Hydro

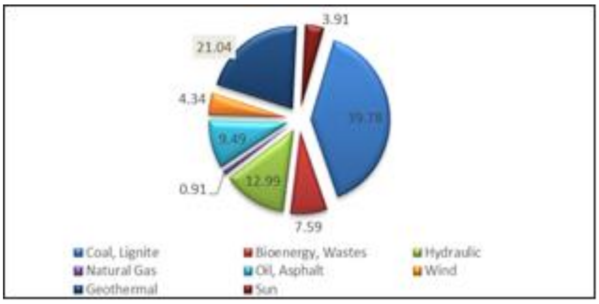

Figure 3. *The Percent Share Of Energy Sources In Turkey's Primary Energy Production In 2018 [27]*

The share of energy sources in Turkey's primary energy production in 2010 and 2018 is shown in Figure 4. This figure shows that the percent share of renewable energy sources in the energy production of Turkey has been increasing significantly.

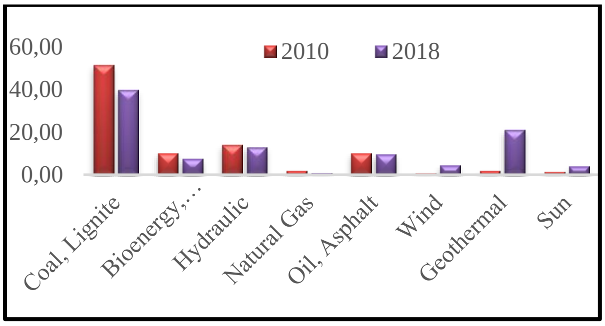

Figure 4. *The Percent Share Of Energy Sources In Turkey's Primary Energy Production In Years Of 2010 And 2018 [27]*

According to the pertinent energy demand estimation studies [e.g., 28, 29], the energy requirement of Turkey will continue to grow in the future. Currently, Turkey imports a large quantity of energy, and hence it is expected that it will invest in the energy sector to reduce its dependency on foreign energy sources [30]. Turkey is ranked to be second for geothermal and solar energy potential in the European Union while ranking to be the third for hydro and wind energy potential. Its available biomass sources are also considerable [12, 20]. Table 2 shows the installed renewable energy source capacities between years 2012 and 2017 for electricity production in Turkey.

Given the significant level of energy imports and the potential for various renewable energy sources, a prioritization of renewable energy investment alternatives such as hydropower, biomass, geothermal energy, wind energy and solar energy is important for policy makers and investors. Today, Turkey aims to increase its renewable energy sources. In its strategic goals for 2023, renewable energy is mentioned to be increased to a share of 40% of the total energy production [27].

Table 2. Total Renewable Energy Installed Capacity (MW) Between Years 2012 To 2017 For Electricity Production In Turkey (Turkey General Directorate of Renewable Energy)

Energy Source	**Installed Capacity (MW)**					
	2012	2013	2014	2015	2016	2017
Sun			40.2	248.8	832.5	3420
Bioenergy	158.5	224	288.1	362.4	488.7	634.2
Geothermal	162.2	310.8	404.9	623.9	820.9	1063.7
Wind	2260.5	2759.6	3629.7	4503.2	5751.3	6516.2
Hydraulic	19609.4	22289	23643.2	25867.8	26681.1	27273.1

2.2. Research Framework

In this study, firstly, 85 criteria based on our literature review are examined. After eliminating some of those criteria by the experts, the most crucial top 18 criteria are fixed (see Table 3).

The proposed methodology includes a combination of TOPSIS and COPRAS methods based on type-2 range sets. Figure 5 shows the steps of the proposed method. TOPSIS and COPRAS are multi-criteria decision-making approaches used in different fields [31, 32, 33, 34]. TOPSIS method is selected due to its advantages like simplicity and ability to evaluate the relative performance for each alternative in a simple mathematical form. The obtained criteria weights of FPIS and FNIS are used as an input to COPRAS method as well as alternative evaluations with respect to each criterion which are determined from literature. By combining these two MCDM methods based on interval type-2 fuzzy sets, it is intended to reveal the factors and their relations related to RE investments and provide guidelines for policy makers and investors in determining investments priorities.

The steps of TOPSIS method can be described as follows [32, 35, 36]:

Step 1. Construct the decision matrix (D). The structure of matrix can be expressed as given in Eq. (1).

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} X_1 & X_1 & \cdots & X_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \end{array} = \left[x_{ij}\right]_{m\times n} \qquad (1)$$

$$i = 1, 2, \dots, m; \; j = 1, 2, \dots, n$$

where Ai denotes i. alternative, (i = 1, 2, …, m); Xj represents jth attribute or criterion, (j = 1, 2, …, n). Also, Xij is the performance rating of ith alternative Ai with respect to attribute Xj.

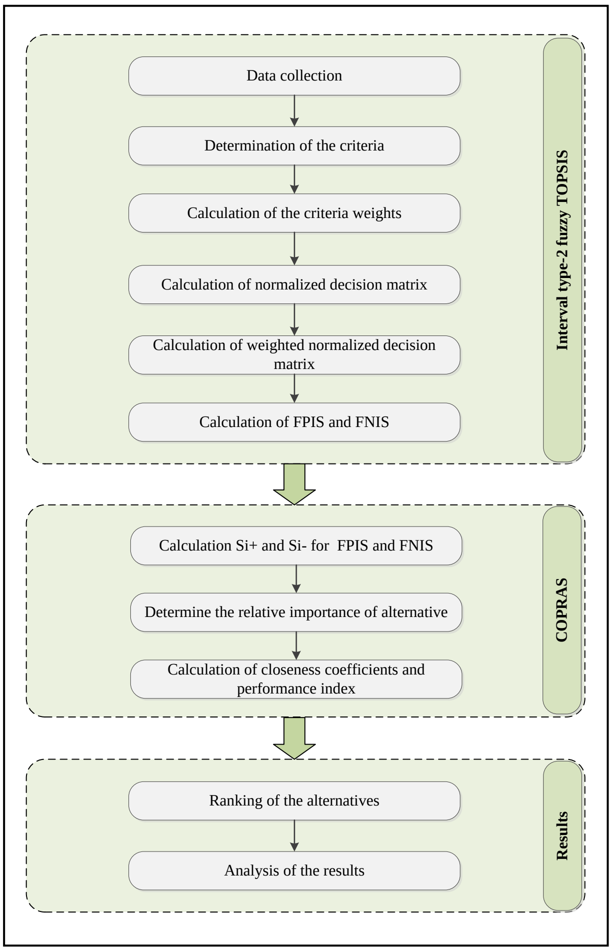

Figure 5. *The Steps Of The Proposed Methodology*

Step 2. Construct the normalized decision matrix (*R*) using Eq. (2). The normalized values (r_{ij}) of the decision matrix are calculated using Eq. (3).

$$\mathrm{R}=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} = \left[r_{ij}\right]_{m\times n} \tag{2}$$

$i = 1, 2, \dots, m;$

$j = 1, 2, \dots, n$

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{3}$$

$(\, i = 1, 2, \dots, m; \;\; j = 1, 2, \dots, n)$

Step 3. Calculate the weighted normalized decision matrix (*V*) using Eq. (4). w_j represents the weight of j^{th} attribute. The weighted normalized value v_{ij} is calculated by multiplying the normalized decision matrix by its corresponding value as given Eq. (5).

$$V=\begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} = \left[v_{ij}\right]_{m\times n} \tag{4}$$

$i = 1, 2, \dots, m; \;\; j = 1, 2, \dots, n$

Table 3 The Criteria For RE Alternatives

Main Criteria		**Sub-criteria**	**References**
Technical factors	C_1	Efficiency	Afgan and Carvalho (2002) [37], Theodorou et al. (2010) [38], Ahmad and Tahar (2014) [7], Amer and Daim (2011) [6], Sengül et al. (2015) [15], Al Garni et al. (2016) [39], Shmelev and Jeroen (2016) [40], Gitinavard et al. (2017) [10], Lee and Chang (2018) [41], Ghose et al. (2019) [42], Hassan et al. (2019) [43], Seddiki and Bennadji (2019) [44], Ayağ and Samanlioglu (2020) [45], Colak and Kaya (2020) [46], Ghenai et al. (2020) [47], Rani et al. (2020) [48]
	C_2	Maturity	Theodorou et al. (2010) [38], Amer and Daim (2011) [6], Ahmad and Tahar (2014) [7], Troldborg et al. (2014), Shmelev and Jeroen (2016) [40], Al Garni et al. (2016) [39], Colak and Kaya (2017) [18], Martín-Gamboa et al. (2017) [49], Lee and Chang (2018) [41], Hassan et al. (2019) [43], Li et al. (2019) [50], Naicker and Thopil (2019) [51] , Zhang et al. (2019) [52], Colak and Kaya (2020) [46]
	C_3	Setup (Installation) time	San Cristóbal (2009) [5], Kahraman et al. (2009) [13], Kahraman and Kaya (2010) [3], Ahmad and Tahar (2014) [7], Shmelev and Jeroen (2016) [40], Colak and Kaya (2017) [18]
	C_4	Energy production capacity	Colak and Kaya (2017) [18], Lee and Chang (2018) [41], Seddiki and Bennadji (2019) [44], Ghenai et al. (2020) [47], Nsafon et al. (2020) [53]
	C_5	Risk	Kahraman et al. (2009) [13], Kahraman and Kaya (2010) [3], Tasri and Susilawati (2014) [8], Shmelev and Jeroen (2016) [40], Colak and Kaya (2017) [18], Colak and Kaya (2020) [46], Deveci and Güler (2020) [54]
	C_6	Ease of access to source	
Economic factors	C_7	Operational life (Service life)	San Cristóbal (2011) [5], Ahmad and Tahar (2014) [7], Sengül et al. (2015) [15], Al Garni et al. (2016) [39] , Shmelev and Jeroen (2016) [40], Colak and Kaya (2017) [18], Martín-Gamboa et al. (2017) [49], Hassan et al. (2019) [43], Zhang et al. (2019) [52], Colak and Kaya (2020) [46]
	C_8	Contribution to economy	Kahraman et al. (2009) [13], Kahraman and Kaya (2010) [3], Tasri and Susilawati (2014) [8], Troldborg et al. (2014) [55], Colak and Kaya (2017) [18], Pasaoglu et al. (2018) [56], Li et al. (2019) [50], Deveci and Güler (2020) [54]
Cost factors	C_9	Investment cost	Amer and Daim (2009) [6], Kahraman and Kaya (2010) [3], Theodorou et al. (2010) [38] , Kabak and Dagdeviren (2014) [12], Tasri and Susilawati (2014) [8], Troldborg et al. (2014) [55], Sengül et al. (2015) [15], Al Garni et al. (2016) [39], Shmelev and Jeroen (2016) [40], Gitinavard et al. (2017) [10], Martín-Gamboa et al. (2017) [49], Lee and Chang (2018) [41], Pasaoglu et al. (2018) [56], Yang et al. (2018) [57], Ghose et al. (2019) [42], Hassan et al. (2019) [43], Seddiki and Bennadji (2019) [44], Zhang et al. (2019) [52], Alizadeh et.al. (2020) [58], Colak and Kaya (2020) [46], Nsafon et al. (2020) [53], Rani et al. (2020) [48]
	C_{10}	Operation and Maintenance costs	Amer and Daim (2009) [6], San Cristóbal (2011) [5], Kabak and Dagdeviren (2014) [12], Sengül et al. (2015) [15], Al Garni et al. (2016) [39], Shmelev and Jeroen (2016) [40], Gitinavard et al. (2017) [10], Martín-Gamboa et al. (2017) [49], Lee and Chang (2018) [41], Pasaoglu et al. (2018) [56], Diemuodeke et al. (2019) [59], Hassan et al. (2019) [43], Li et al. (2019) [50], Seddiki and Bennadji (2019) [44], Alizadeh et al. (2020) [58], Colak and Kaya (2020) [46], Deveci and Güler (2020) [54], Rani et al. (2020) [48]

Table 3 The Criteria For RE Alternatives (continue)

Socio-political factors	C_{11}	Social acceptability	Amer and Daim (2009) [6], Theodorou et al. (2010) [38] , Ahmad and Tahar (2014) [7], Tasri and Susilawati (2014) [8],

Environmental factors			Troldborg et al. (2014) [55], Sengül et al. (2015) [15], Shmelev and Jeroen (2016) [40], Al Garni et al. (2016) [39], Colak and Kaya (2017) [18], Lee and Chang (2018) [41], Ghose et al. (2019) [42], Hassan et al. (2019) [43], Li et al. (2019) [50], Seddiki and Bennadji (2019) [44], Colak and Kaya (2020) [46], Deveci and Güler (2020) [54], Rani et al. (2020) [48]
	C_{12}	Job creation potential	Amer and Daim (2009) [6], Kahraman et al. (2009) [13], Ahmad and Tahar (2014) [7], Kabak and Dagdeviren (2014) [12], Tasri and Susilawati (2014) [8], Sengül et al. (2015) [15], Al Garni et al. (2016) [39], Shmelev and Jeroen (2016) [40], Lee and Chang (2018) [41], Ghose et al. (2019) [42], Hassan et al. (2019) [43], Li et al. (2019) [50], Naicker and Thopil (2019) [51], Zhang et al. (2019) [52], Alizadeh et.al. (2020) [58], Colak and Kaya (2020) [46], Nsafon et al. (2020) [53], Rani et al. (2020) [48]
	C_{13}	Political acceptance	Kahraman and Kaya (2010) [3], Tasri and Susilawati (2014) [8], Al Garni et al. (2016) [39], Colak and Kaya (2017) [18], Ayağ and Samanlioglu (2020) [45], Colak and Kaya (2020) [46], Deveci and Güler (2020) [54]
	C_{14}	Impact on environment	Ahmad and Tahar (2014) [7] , Kabak and Dagdeviren (2014) [12], Sengül et al. (2015) [15], Al Garni et al. (2016) [39], Shmelev and Jeroen (2016) [40], Colak and Kaya (2017) [18], Gitinavard et al. (2017) [10], Pasaoglu et al. (2018) [56], Seddiki and Bennadji (2019) [44], Diemuodeke et al. (2019) [59], Zhang et al. (2019) [52], Alizadeh et.al. (2020) [58]
	C_{15}	Sustainable	San Cristóbal (2011) [5], Tasri and Susilawati (2014) [8], Colak and Kaya (2017) [18], McKenna et al. (2018) [11], Li et al. (2019) [50], Ayağ and Samanlioglu (2020) [45]
	C_{16}	Land requirement	Amer and Daim (2009) [6], Kahraman and Kaya (2010) [3], Ahmad and Tahar (2014) [7], Tasri and Susilawati (2014) [8], Troldborg et al. (2014) [55], Al Garni et al. (2016) [39], Colak and Kaya (2017) [18], Lee and Chang (2018) [41], Ghose et. al. (2019) [42], Hassan et al. (2019) [43], Zhang et al. (2019) [52], Alizadeh et.al. (2020) [58], Deveci and Güler (2020) [54], Rani et al. (2020) [48]
	C_{17}	Requirement for waste disposal	Kahraman et al. (2009) [13], Kahraman and Kaya (2010) [3], Tasri and Susilawati (2014) [8], Al Garni et al. (2016) [39], Shmelev and Jeroen (2016) [40], Colak and Kaya (2017) [18], Martín-Gamboa et al. (2017) [49], Deveci and Güler (2020) [54]
	C_{18}	Proximity to user	Tasri and Susilawati (2014) [8], Colak and Kaya (2017) [18], Yang et al. (2018) [57], Seddiki and Bennadji (2019) [44]

$$v_{ij} = w_j \times r_{ij} \quad (i = 1,2,\ldots,m;\ j = 1,2,\ldots,n) \tag{5}$$

Step 4. Determine PIS (A*) and NIS (A-) using Eqs. (6) and (7), respectively.

$$A^* = \{v_1^*, v_2^*, \ldots, v_n^*\} = \left\{\left(\max_i v_{ij} | j \in J\right), \left(\min_i v_{ij} | j \in J'\right)\right\} \tag{6}$$

$$A^- = \{v_1^-, v_2^-, \ldots, v_n^-\} = \left\{\left(\min_i v_{ij} | j \in J\right), \left(\max_i v_{ij} | j \in J'\right)\right\} \tag{7}$$

where J corresponds to the benefit criteria and J' corresponds to the cost criteria**.**

Step 5. Calculate the distance of each alternative from PIS and NIS using Eqs. (8) and (9), respectively.

$$S_i^* = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^*\right)^2} \qquad (i = 1,2,\ldots,m) \tag{8}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2} \qquad (i = 1,2,\ldots,m) \tag{9}$$

The COPRAS method [60,61,62] steps are given as in the following [61]:

Step 6. The sums B_{i+} (benefit criteria) and C_{i-} (cost criteria) of weighted normalized values are calculated for FPIS and FNIS. For beneficial criteria, a higher value is better and for non-beneficial criteria, lower value is better to achieve the goal. These sums B_{i+} and C_{i-} are calculated using Eqs. (10) and (11), respectively as follows:

$$B_{i+} = \sum_{i=1}^{k} v_{ij} \tag{10}$$

$$C_{i-} = \sum_{i=k+1}^{m} v_{ij} \tag{11}$$

C_b and C_n are the sets of benefit and cost criteria.

Step 7. Calculate the relative importance (α_i) of each alternative using Eq. (12).

$$\alpha_i = B_{i+} + \frac{\sum_{i=1}^{m} C_{i-}}{C_{i-} \sum_{i=1}^{m} \frac{1}{C_{i-}}} \tag{12}$$

Among the alternatives, one with the highest degree of relative importance is the best choice.

Step 8. Calculate the closeness coefficient (*CCi**) of each alternative using Eq. (13). *CCi** takes value between 0 and 1. The larger *CCi** value stands for the better performance of the alternative.

$$CC_i^* = \frac{\alpha_i^-}{\alpha_i^- + \alpha_i^*} \qquad 0 \leq CC_i^* \leq 1 \qquad i = 1,2,\ldots,m \tag{13}$$

Step 9. Or the performance index (β_i) of each alternative is calculated using Eq. (14) as follows:

Step 9. Or the performance index (β_i) of each alternative is calculated using Eq. (14) as follows:

$$\beta_i = \left[\frac{\alpha_i}{\alpha_{max}}\right] \times 100\% \tag{14}$$

where β_{max} is the maximum relative importance value. Rank the alternatives according to decreasing values of β_i.

3. Results and Discussion

In this study, the proposed methodology is used to prioritize and evaluate RE sources for Turkey. Interval type-2 fuzzy TOPSIS is carried out to determine the weights of the evaluation criteria and COPRAS method for performance evaluation of RE sources. The output of the interval type-2 fuzzy TOPSIS is the input to the COPRAS method. COPRAS method is integrated because of its various advantages such as less computational time, very simple and transparent, high possibility of graphical interpretation, etc.) over other MCDM methods such as VIKOR, TOPSIS and AHP [61] . A committee of five decision makers (experts) DM1, DM2, DM3, DM4 and DM5 are formed to select the best renewable energy source using the 18 criteria which are selected from litrature. The average subjective fuzzy weights of the 18 criteria are given in Table 4. The average fuzzy weights for each criterion with respect to alternatives are calculated by using Eq. (1). The weighted normalized decision matrix for the RE alternatives is calculated using Eqs. (4) and (5).

In this study, the determination of criteria and their weights and the ranking of the alternatives are carried out based on 5 experts' evaluations. It should be noted that enhancing the study by including other experts from various disciplines and institutions (2 experts from universities and 3 experts from private companies) may cause different results and conclusions. It is difficult to get the opinion of several experts working in different institutions. It is important to carefully select the experts. Because result of the study is directly affected by the knowledge and experience of the experts. In this study five RE alternatives are determined: A1 (Biomass), A2 (Geothermal), A3 (Hydropower), A4 (Solar) and A5 (Wind). In order to determine relationship between the criteria with respect to alternatives, the experts define each relationship by means of verbal expressions as given in [19]. After calculating the normalized decision matrix and weighted normalized decision matrix, PIS and NIS are calculated using Eqs. (6) and (7). The distance of each alternative from FPIS and FNIS of each alternative are detailed in Table 5 using Eqs. (8) and (9).

The relative values of the alternative for FPIS and FNIS are computed using Eq. (12). The closeness coefficients and performance index of each alternative are computed using Eqs. (13) and (14). Results of combined TOPSIS and COPRAS methods is given in Table 6.

Based on the combined TOPSIS and COPRAS methodology, the alternatives are ranked in the descending order from the most preferred to least preferred RE source. According to the β values, the best RE source and primary investment area is determined as hydropower energy. Wind is determined as the second most suitable RE source. The order of the remaining alternatives is solar energy, geothermal energy and biomass. Prospectively, the obtained ranking of RE sources aids policy makers and investors to determine investment priorities. The results of this study showed that, hydropower energy is determined to be the most RE energy supply system in Turkey. It is declared that, all of the hydropower potential which it will technically and economically be possible to use, shall be used to produce electric power until 2023 [63]. The share of energy sources in according to Turkey's primary energy production in 2018, hydropower energy is the second energy source with 13% share [27]. The present study also supports the decision taken by ministry. Also the results obtained from this study are similar to some studies applied to different methods in the literature [15].

Table 4 The Average Subjective Fuzzy Weights Of Criteria

Criteria			**Weights**
C1	:	Efficiency	((0.82;0.96;0.96;1;1;1),(0.89;0.96;0.96;0.98;0.9;0.9))
C2	:	Maturity	((0.66;0.84;0.84;0.96;1;1),(0.75;0.84;0.84;0.9;0.9;0.9))
C3	:	Setup (Installation) time	((0.28;0.46;0.46;0.64;1;1),(0.37;0.46;0.46;0.55;0.9;0.9))
C4	:	Energy production capacity	((0.78;0.94;0.94;1;1;1),(0.86;0.94;0.94;0.97;0.9;0.9))
C5	:	Risk	((0.54;0.74;0.74;0.9;1;1),(0.64;0.74;0.74;0.82;0.9;0.9))
C6	:	Ease of access to source	((0.78;0.92;0.92;0.98;1;1),(0.85;0.92;0.92;0.95;0.9;0.9))
C7	:	Operational life (Service life)	((0.58;0.78;0.78;0.94;1;1),(0.68;0.78;0.78;0.86;0.9;0.9))
C8	:	Contribution to economy	((0.66;0.84;0.84;0.96;1;1),(0.75;0.84;0.84;0.9;0.9;0.9))
C9	:	Investment cost	((0.82;0.96;0.96;1;1;1),(0.89;0.96;0.96;0.98;0.9;0.9))
C10	:	Operation and Maintenance costs	((0.62;0.82;0.82;0.96;1;1),(0.72;0.82;0.82;0.89;0.9;0.9))
C11	:	Social acceptability	((0.36;0.52;0.52;0.68;1;1),(0.44;0.52;0.52;0.6;0.9;0.9))
C12	:	Job creation potential	((0.36;0.54;0.54;0.7;1;1),(0.45;0.54;0.54;0.62;0.9;0.9))
C13	:	Political acceptance	((0.18;0.32;0.32;0.5;1;1),(0.25;0.32;0.32;0.41;0.9;0.9))
C14	:	Impact on environment	((0.82;0.96;0.96;1;1;1),(0.89;0.96;0.96;0.98;0.9;0.9))
C15	:	Sustainable	((0.82;0.96;0.96;1;1;1),(0.89;0.96;0.96;0.98;0.9;0.9))
C16	:	Land requirement	((0.38;0.58;0.58;0.74;1;1),(0.48;0.58;0.58;0.66;0.9;0.9))
C17	:	Requirement for waste disposal	((0.7;0.88;0.88;0.98;1;1),(0.79;0.88;0.88;0.93;0.9;0.9))
C18	:	Proximity to user	((0.36;0.52;0.52;0.68;1;1),(0.44;0.52;0.52;0.6;0.9;0.9))

Table 5 Distances d(Aj, A*) and d(Aj, A-) Of The Alternatives From Fuzzy Positive Ideal Solution (FPIS) And Fuzzy Negative Ideal Solution (FNIS) (i,j=1,2,3,4,5)

Criteria	FPIS					FNIS				
	A1	A2	A3	A4	A5	A1	A2	A3	A4	A5
C1	0.338	0.000	0.094	0.216	0.216	0.000	0.338	0.245	0.122	0.122
C2	1.818	0.509	0.305	0.815	0.000	0.000	1.309	1.513	1.003	1.818
C3	0.000	0.112	0.466	0.502	0.592	0.592	0.481	0.127	0.090	0.000
C4	1.402	0.000	0.211	0.211	0.092	0.000	1.402	1.192	1.192	1.311
C5	0.358	1.064	0.995	0.600	0.000	0.706	0.000	0.069	0.464	1.064
C6	0.406	0.000	0.259	0.618	0.877	0.471	0.877	0.618	0.259	0.000
C7	1.540	0.999	0.645	0.185	0.000	0.000	0.541	0.895	1.355	1.540
C8	1.157	0.668	0.293	0.000	0.083	0.000	0.489	0.864	1.157	1.075
C9	0.000	0.650	0.452	0.955	0.816	0.955	0.305	0.504	0.000	0.139
C10	0.523	0.782	0.000	0.655	0.891	0.368	0.108	0.891	0.235	0.000

Table 5 Distances d(Aj, A*) and d(Aj, A-) Of The Alternatives From Fuzzy Positive Ideal Solution (FPIS) And Fuzzy Negative Ideal Solution (FNIS) (i,j=1,2,3,4,5) (continue)

C11	0.089	0.073	0.000	0.101	0.095	0.011	0.027	0.101	0.000	0.005
C12	0.259	0.000	0.000	0.451	0.397	0.192	0.451	0.451	0.000	0.054
C13	0.681	0.681	0.000	0.213	0.102	0.000	0.000	0.681	0.468	0.579
C14	1.475	2.971	0.000	1.239	0.694	1.495	0.000	2.971	1.732	2.277
C15	1.024	0.461	0.583	0.000	0.122	0.000	0.564	0.441	1.024	0.902
C16	0.233	0.765	0.000	1.140	1.219	0.986	0.454	1.219	0.078	0.000
C17	0.000	0.740	0.730	2.528	2.528	2.528	1.788	1.798	0.000	0.000
C18	0.528	0.521	0.953	0.000	0.186	0.425	0.432	0.000	0.953	0.767

Table 6 Closeness Coefficients (CC_i) Of The Five Alternatives

RE alternatives	α^*	α^-	CC_i^*	β	Ranking
Biomass	11.310	6.146	0.352	0.466	5
Geothermal	8.510	8.782	0.508	0.673	4
Hydropower	4.238	13.049	0.755	1.000	1
Solar	7.832	9.469	0.547	0.725	3
Wind	6.748	10.532	0.609	0.807	2

4. Conclusions

During the last decade, RE investments in Turkey have been increasing. Because Turkey has a significant potential of RE sources such as solar energy, wind energy, hydroelectric, geothermal energy and biomass in terms of electricity energy and heat production. The prioritization and thus ranking of RE alternatives assist policy makers and investors in determination of investment priorities for sustainable energy planning in Turkey. In this study, a methodology consisting of combined TOPSIS and COPRAS methods is proposed considering technical, cost, economic, social-political, and environmental aspects in order to plan for national RE investments. The results achieved suggest that hydropower energy is the most promising investment area with the highest priority for Turkey. The remaining order of the alternatives in descending order is: wind energy, solar energy, geothermal energy and biomass. Hydropower energy is one of the most technologically advanced renewable energy sources among renewable energy sources. Hydropower plants are a high efficiency, fuel-free, long-lasting, clean, low-risk energy source with a low operating cost. For this reason, it is preferred in meeting the reliable and sustainable electricity needs of developed countries with the effect of increasing environmental awareness. In the further research, other multi criteria decision making methods may be used to test and compare the results obtained in this study.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Contribution of Researchers

In this research, Author1 and Author2 are responsible for scientific literature research, data collection, research design and implementation, and creation of the article; Authors3 contributed to the research design and implementation and the creation of the article.

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