Chapter 3
Assessment of Green Energy Alternatives Using Fuzzy ANP

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Abstract Sustainability has gained tremendous importance and has been an important issue both for policy makers and practitioners. Realizing that the resources on the earth are limited, green energy (GE) alternatives have flourished and started to replace the conventional energy alternatives. Energy planning using different energy alternatives, for the long term becomes a vital decision. In this study, fuzzy multi criteria decision- making methodology, fuzzy analytic network process (FANP) are utilized for the ranking GE alternatives. The ANP is a multi criteria decision-making (MCDM) technique which enables feedback and replaces hierarchies of relationships with networks of relationships. In ANP technique, not only does the importance of the criteria determine the importance of the alternatives, as in a hierarchy, but also the importance of the alternatives may have impact on the importance of the criteria. Fuzzy ANP allows measuring qualitative factors by using fuzzy numbers instead of crisp numbers in order to make decisions easier and obtain more realistic results. A case study is presented for the assessment of GE alternatives in Turkey with respect to various perspectives such as; technical, economical, and environmental. According to the outcome of the BO/CR method, hydropower has the highest priority which is followed by geothermal and biomass energy sources. Though the hydropower is not the best alternative from Benefits and Opportunities viewpoint, because of low costs and risks it comes into view to be the best alternative for Turkey.

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3.1 Introduction

Economic development is aligned together with energy use, which is one of the main inputs as well as a consequence. High economic development, increased population of the world, and rapid technological advances have increased the demand for energy globally. Over many years, the main resource for energy has been fossil fuels. However, fossil fuels such as petroleum, natural gas are estimated to be exhausted in a near future with the increasing need of energy. Another issue with the excess consumption of the fossil fuels is their irreversible hazards on the ecological environment as well as human health.

Realizing that the resources on the earth are limited, sustainability has gained tremendous importance and has been an important issue both for policy makers and practitioners. Sustainability is described as the long-term maintenance of responsibility, which has environmental, economic, and social dimensions, and encompasses the concept of responsible management of resource use. As sustainable sources of energy gained importance, green energy (GE) alternatives have flourished and started to replace the conventional energy alternatives.

Sustainable energy is the sustainable provision of energy that meets the needs of the present without compromising the ability of future generations to meet their needs. Together with goal of sustainability, specifically GE includes natural energetic processes that can be harnessed with little pollution. Technologies that promote GE include renewable energy sources (RES) such as geothermal power, wind power, small-scale hydropower, solar energy, biomass power, tidal power, and wave power. On the other side, fossil fuels are non-renewable resources because it takes millions of years to form, and reserves are being depleted much faster than new ones are being made. The production and use of fossil fuels raise environmental concerns. Even so, fossil fuels had a great importance for many years because they can be burned, producing significant amounts of energy per unit weight.

The complex relations of the energy issue with the ecological environment, socio-economical environment, and energy production technologies reveal a multifaceted assessment problem. Besides, evaluation of energy issues is a complex problem due to conflicting objectives and a large number of stakeholders with different aims and preferences. This complexity of the problem leads to apply multi criteria decision making (MCDM) as a methodology used to resolve the emerging conflicts by summing up the performances of each criterion weighted with their importance.

On the other side, energy planning generally involves many sources of uncertainty and a long time frame. The source of uncertainty exists mainly due to external factors closely related to energy issues as well as unknown future conditions need to be considered because of the long time frame of planning. Thus, judgments of decision makers are prone to a high degree of uncertainty rising from the nature of energy issues. Under these conditions, it is relatively difficult for the decision makers to provide exact numerical values for the criteria or attributes.

Besides, ambiguity often exist among decision makers' judgments with respect to the criteria that they evaluate. Fuzzy logic which resembles human thoughts is effectively used in many areas in order to model these types of uncertainty. Fuzzy logic uses fuzzy set theory to deal with imprecise information by using membership functions. In fuzzy set theory, an element of a fuzzy set naturally belongs to the set with a membership value from the interval [0, 1].

In this study, we employ analytical network process (ANP) in order to evaluate and select the primary GE alternatives for the case of Turkey. The network structure of ANP is particularly suitable to incorporate the multi criteria evaluation of different GE alternatives by aggregating views and preferences of multiple participants. The conflicting criteria used in the evaluation process have been classified through the use of benefits, opportunities, costs, and risks (BOCR) framework which help to systematically consider the multifaceted nature of energy planning.

The chapter is organized as follows: the next section gives a brief summary about GE alternatives and their assessment. Literature review on multi criteria decision approaches about energy alternative is given in Sect. 3.3. Section 3.4 contains the fuzzy multi attribute approach that is used in this study. A numerical energy alternatives assessment application is supplied in Sect. 3.5. Finally, the results of the study are discussed and suggestions about future studies are given in conclusion section.

3.2 Assessment of Green Energy Alternatives

Prior to the presentation of the evaluation framework for selecting the primary GE alternatives of Turkey, we will discuss the GE alternatives with their present use and potential both globally and locally in Turkey. Then, we will identify the advantages and disadvantages of GE alternatives in the following subsections.

3.2.1 GE Alternatives

Together with goal of sustainability, GE is characterized by the natural energetic processes that can be harnessed with little pollution. Technologies that promote GE consists of RES such as hydropower, geothermal power, wind power, solar energy, biomass power (small-scale hydropower, tidal power, and wave power).

3.2.1.1 Hydropower

Hydro energy is obtained by allowing water to fall on a turbine to turn a shaft. Electricity is produced from the kinetic energy of falling water. The water in rivers and streams can be captured and turned into hydroelectric power, also called hydropower. Hydropower is inexpensive, and like many other RES, it does not produce air pollution (Erdogdu 2011). Hydropower is a source of energy with long viability, low operation, and maintenance cost. Moreover, it promotes energy safety, independence, and price stability (Yuksel and Kaygusuz 2011).

Hydropower is certainly the largest and most mature application of RES. In 2007, the electricity output of hydropower installations was 3,078 terawatt-hours (TWh), which covered, approximately, 15.5 % of the world's entire electricity demand.

3.2.1.2 Geothermal Power

Geothermal energy sources include both low-temperature ground source heating and deep thermal wells to exact high temperatures for electricity generation (Harmon and Cowan 2009). It is widely accessible globally and realized as an important RES which allows direct and indirect use. The common direct use is residential and thermal facility heating whereas indirect use of geothermal resources is generally for electrical power generation.

3.2.1.3 Wind Power

Wind was one of the first energy sources to be harnessed by early civilizations. Ever since, it has furnished an abundant resource and one of the least expensive methods of power generation. Wind power has been used to propel sailboats and sail ships, to provide mechanical power for grinding grain in windmills, and for pumping water (Angelis-Dimakis et al. 2011).

Since then, Wind energy in electricity generation has developed and spread widely. The development in wind energy technology, despite the uncertain nature of the wind energy source, has made it one of the most promising alternative to conventional energy systems in recent years (Castronuovo et al. 2007). As a result of this development, total installed capacity of the world reached to 120.791 MW in 2008 (Baris and Kucukali 2012).

3.2.1.4 Solar Energy

Solar power uses heat energy from the sun both to generate electricity and to distribute heat for industrial and residential use. Today, the most common technologies for utilizing solar energy are photovoltaic (PV) and solar thermal systems. PV systems use specific wavelengths of light to produce electricity directly. The advantage is they are small, simple, with no moving parts but presently it offers the most expensive forms of power generation (Harmon and Cowan 2009).

One of the main influencing factors for an economically feasible performance of solar energy systems (besides of installation costs, operation costs, and lifetime of system components) is the availability of solar energy on ground surface that can be converted into heat or electricity. Therefore, precise solar irradiation data are of utmost importance for successful planning and operation of solar energy systems. Solar irradiation means the amount of energy that reaches a unit area over a stated time interval, expressed as Wh/m^2 (Angelis-Dimakis et al. 2011).

3.2.1.5 Biomass Power

Biomass is defined as the biodegradable fraction of products, wastes and residues from agriculture, forestry, and related industries, as well as the biodegradable fraction of industrial and municipal wastes. Moreover, biomass can be grown on purpose in dedicated energy crops (Angelis-Dimakis et al. 2011). Residual biomasses derive from:

- the agricultural sector, both in the form of crop residues and of animal waste;
- the forestry sector, from forests' thinning and maintenance;
- the industrial sector of wood manufacture and food industries;
- the waste sector, in the form of residues of parks maintenance and of municipal biodegradable wastes.

Biomass energy is derived mainly by burning plants or products made from them. Combustible renewables and waste (CRW) are traditional biomass energy obtained from burning garbage. Advanced biomass involves the creation of more sophisticated fuels, such as ethanol or biodiesel, which can be used in automobiles or for power generation (Harmon and Cowan 2009).

3.3 Literature Review

Assessment of energy alternatives and related policies has been the subject of researches that use different MCDM techniques. Table 3.1 represents a classification of these researches according their approach (crisp or fuzzy) and the methods used.

Among the crisp approaches the mostly used methods are PROMETHEE, ELECTRE, and AHP/ANP. The other MCDM methods used in the assessment of energy alternatives are TOPSIS, VIKOR, MAUT, and DEA.

PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) is an outranking method based on the pairwise comparison of different options against the criteria defined by the decision maker. Using PROMETHEE, Madlener et al. (2007) compared five renewable energy scenarios considering Austria in the year 2020. In their comprehensive study, Terrados et al. (2009) proposed a hybrid methodology using SWOT analysis, Delphi, and PROMETHEE for renewable energy planning for Jae'n Province.Region. The researchers used SWOT analysis to define 28 potential renewable energy strategy,

Table 3.1 Linguistic scales for weight matrix (Hsieh et al. 2004)

Approach	Methods used	References
Crisp	PROMETHEE	Madlener et al. (2007), Terrados et al. (2009), Tsoutsos et al. (2009)
	Electre	Catalina et al. (2011), Georgopoulou et al. (1997), Papadopoulos and Karagiannidis (2008)
	TOPSIS	Streimikiene et al. (2012)
	VIKOR	San Cristóbal (2011a)
	MAUT	Loken et al. (2009)
	AHP	Shen et al. (2011), Wang et al. (2010), Yi et al. (2011) Zangeneh et al. (2009)
	ANP	Dağdeviren and Ergün (2008), Erdoğmuş et al. (2006), Köne and Büke (2007), Ulutaş (2005)
	DEA	San Cristóbal (2011b)
Fuzzy	Fuzzy AHP	Heo et al. (2010), Kahraman et al. (2009), Shen et al. (2010), Talinlia et al. (2010)
	Fuzzy TOPSIS	Boran et al. (2011), Kaya and Kahraman (2011)
	Fuzzy VIKOR	Kaya and Kahraman (2010)
	Fuzzy AD	Kahraman et al. (2009)

then expert opinions are collected via Delphi technique, and PROMETHEE is utilized to select among the alternative actions. Tsoutsos et al. (2009) exploits the PROMETHEE for the sustainable energy planning on the island of Crete in Greece. A set of energy planning alternatives are determined and assessed against economic, technical, social, and environmental criteria.

ELECTRE, developed by Benayoun at late 1960s, is classified as an outranking method in MCDM (Triantaphyllou 2000). In the ELECTRE method concordance and discordance indexes are defined as measurements of satisfaction and dissatisfaction that a decision maker chooses one alternative over the other. These indexes are then used to analyze the outranking relations among the alternatives. Georgopouloe et al. (1997) use ELECTRE III to assess the renewable energy options for energy planning for a Greek Island. Using ELECTRE, Catalina et al. (2011) evaluate and choose the optimal multi source renewable energy alternatives. The same method is also used in the study of (Papadopoulos and Karagiannidis 2008) which assesses different scenarios for using RES for the purpose of electricity generation.

Analytical hierarch process (AHP) and analytic network process (ANP) are the other most commonly used techniques used in assessment of energy alternatives. The AHP, developed by Saaty (1980), structures a decision problem as a hierarchical, containing an overall goal, a group of alternatives, and of a group of criteria. The method is based on the use of pairwise comparisons. Pairwise comparisons are carried out by asking how more valuable an alternative A is to criterion C than another alternative B. These pairwise comparisons are later used to calculate the weights of the alternatives. The ANP is an generalization of AHP and developed by Saaty to deal with dependence and feedback among alternatives and criteria. Shen et. al (2011) assess the renewable energy portfolio using AHP, Wang et al. (2010) build a model to evaluate the energy alternatives for China, Yi et al. (2011) propose a benefits, opportunities, cost, and risks (BOCR) model with AHP. As will be discussed in the forthcoming sections, BOCR is a way of modeling decision problems from different perspectives. The ANP can also be used with BOCR approach, (Ulutaş 2005) determine the appropriate energy policy for Turkey (Dağdeviren and Ergün 2008) build a model to prioritize energy policies, (Erdoğmuş et al. 2006) used the model to evaluate alternative fuels for residential heating in Turkey.

Fuzzy approaches to the problem are relatively limited in number. Fuzzy versions of methodologies such as Fuzzy AHP, Fuzzy TOPSIS, Fuzzy VIKOR, and Fuzzy Axiomatic design are used. Heo et al. propose a model with five criteria and 17 factors to assess the renewable energy dissemination programs. Shen et al. (2010), propose a model to reveal the suitable RES for the purposes of meeting the 3E policy goals which are to pertain to energy, the environment, and the economy. Talinli et al. (2010) build a model using Fuzzy AHP for a comparative analysis of three different energy production process scenarios for Turkey. Kahraman et al. (2009) utilize fuzzy AHP with fuzzy Axiomatic Design to make selection among the RES. In the study, Fuzzy AHP is used to prioritize the criteria and fuzzy AD is used to evaluate the alternatives under objective or subjective criteria with respect to the functional requirements obtained from experts.

Fuzzy TOPSIS enables fuzzy values to be used in the decision problem. Boran et al. (2011) evaluate the renewable energy technologies for electricity generation in Turkey, using intuitionistic fuzzy TOPSIS. PV, hydro, wind, and geothermal energy have been evaluated for long-term renewable technologies for Turkey.

Kaya and Kahraman (2011) propose a modified fuzzy TOPSIS methodology for energy planning decisions by taking into account technical, economic, environmental, and social attributes. They also incorporate fuzzy AHP to determine the weights of the selection criteria. Kaya and Kahraman (2010) propose using AHP and VIKOR together under fuzziness. They apply the model in order to determine the best renewable energy alternative and energy production sites for Istanbul.

The literature review presents that renewable energy assessment problem is a MCDM problem that can be handled with crisp and fuzzy However, there is an absence in using Fuzzy ANP on the area, thus in this study Fuzzy ANP with BOCR approach is used as a case study. The details about the fuzzy multi attribute approach are given briefly in the following section.

3.4 A Fuzzy Multi Attribute Approach

3.4.1 Fuzzy Set Theory

The fuzzy set theory was designed by Zadeh (1965) to deal with real-world uncertainties. In the classical set theory, an element either belongs or does not belong to a set. However, in fuzzy sets each element has degree of membership for a fuzzy set that can get values in the interval [0, 1]. This membership degree is described with a membership function. In classical crisp modeling, the imprecise parameters have to be represented with crisp values, however, using fuzzy representations empowers the process and the results are expected to be more credible (Kahraman et al. 2006). Using membership functions, fuzzy sets can mathematically represent uncertainty and vagueness, thus provide an important problem modeling and solution technique.

Fuzzy sets are represented with a tilde "$\sim$" above the set symbol; a fuzzy set M is represented as $\tilde{M}$ and the membership functions for the fuzzy set is shown as $\mu(x|\tilde{M})$. The term fuzzy number is used to handle imprecise numerical quantities such as "close to 10", "about 7". A fuzzy number may be represented in discrete or continuous forms. One of the commonly used continuous forms is the triangular fuzzy number (TFN). A TFN is denoted simply as (m_1, m_2, m_3). The parameters m_1, $m_{2,}$ and $m_{3,}$ respectively, denote the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event. A TFN $\tilde{M}$ is shown in Fig. 3.1.

The linear representation of membership function can be given as:

$$\mu\left(x|\tilde{M}\right) = \begin{cases} 0, & x < m_1 \\ \frac{x-m_1}{m_2-m_1}, & m_1 \le x \le m_2 \\ \frac{m_3-x}{m_3-m_2}, & m_2 \le x \le m_3 \\ 0, & x > m_3 \end{cases} \tag{3.1}$$

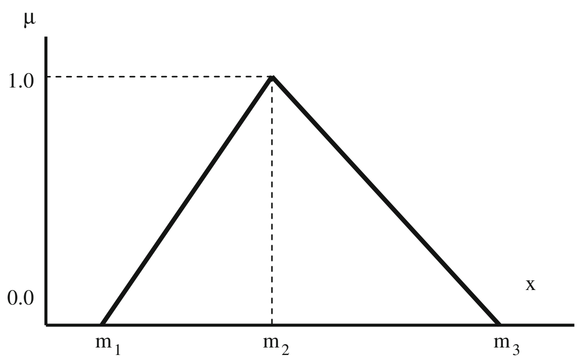

Fig. 3.1 A triangular fuzzy number, MI

Mathematical operations are needed to use the fuzzy numbers in real-world problems. (Chen et al. 1992) give the fuzzy operations for TFNs M (m_1, m_2, m_3) and N (n_1, n_2, n_3) as follows:

$$\text{Addition:}\, M(+)N = (m_1 + n_1, m_2 + n_2, m_3 + n_3)$$

$$\text{Subtraction:}\, M(-)N = (m_1 - n_1, m_2 - n_2, m_3 - n_3)$$

$$\text{Multiplication:}\, A(.)N \cong (m_1 n_1, m_2 n_2, m_3 n_3) \text{ if } M > 0 \text{ and } N > 0$$

$$\text{Division:}\, A(:)N \cong \left(m_1/n_1, m_2/n_2, m_{3/}n_3\right) \text{ if } M > 0 \text{ and } N > 0$$

3.4.2 Fuzzy Analytic Network Process

In many real-world decision-making cases interaction and dependence exist among the decision elements from different levels. ANP is a methodology developed by Saaty (1980) as an alternative to deal with such interactions. Hierarchies and network have different structures (Fig. 3.2), a hierarchy is consist of a goal, levels of elements, and connections between elements, however, a network is composed of element clusters which can influence each other.

The influence between the elements of a network can be classified into two groups: outer and inner. Inner influence specifies the influence of elements in a group on each other. Outer influence is the influence of elements in a cluster on elements in another cluster with respect to a control criterion.

ANP methodology is based on pairwise comparisons of decision elements. In the pairwise comparisons, the decision maker is asked to evaluate the two element with respect to the common property using the smaller element as the unit and estimate the larger element as a multiple of that unit (Saaty and Özdemir 2005). In the original crisp method, each scale is associated with a corresponding crisp

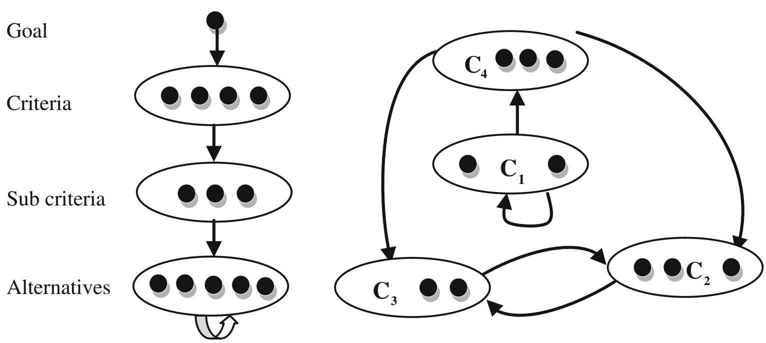

Fig. 3.2 Hierarch and network structures

Table 3.2 Linguistic scales for weight matrix (Hsieh et al. 2004)

Linguistic scales	Scale of fuzzy number	
(1,1,3)	Equally important	(Eq)
(1,3,5)	Weakly important	(Wk)
(3,5,7)	Essentially important	(Es)
(5,7,9)	Very strongly important	(Vs)
(7,9,9)	Absolutely important	(Ab)

number, however, in the fuzzy case linguistic scales can be used and each judgment is represented as a TFN (Table 3.2).

As the pairwise comparison matrix is formed, the next step is to determine the relative importance/priorities of each decision element. There are different methods proposed for Fuzzy ANP in the literature (Buckley 1985; Chang 1996). Using one of these methods, the priorities can be calculated from the pairwise comparison matrix that is composed of linguistic judgments. Table 3.3 presents a sample pairwise comparison matrix, the fuzzy weights calculated using Buckley's method and the defuzzified weights.

In the ANP methodology, matrix is used to represent the flow of influence between decision elements. Each cell in a supermatrix represents the influence priority of the element on the left side of the matrix and on the element at the top of the matrix with respect to a particular control criterion. Zero is assigned to the considered cell if there is no influence between the elements. A supermatrix is shown in formula 3.2 with an example of one of its general entry matrices. Formula 3.3 shows the detail of a component in a supermatrix.

$$
\mathrm{W} = \begin{array}{cc} & \\ & \\ C_1 & \begin{array}{c} e_{11} \\ \ldots \\ e_{1n_1} \end{array} \\ C_2 & \begin{array}{c} e_{21} \\ \ldots \\ e_{2n_2} \end{array} \\ C_1 & \begin{array}{c} e_{11} \\ \ldots \\ e_{1n_1} \end{array} \end{array}
\begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \ldots & C_N \\ e_{11}e_{12}\ldots e_{1n_1} & e_{11}e_{12}\ldots e_{2n_2} & \ldots & e_{N1}e_{N2}\ldots e_{Nn_N} \end{array} \\ \begin{bmatrix} W_{11} & W_{12} & \ldots & W_{1N} \\ W_{21} & W_{22} & \ldots & W_{2N} \\ & & \ldots & \\ W_{N1} & W_{N2} & \ldots & W_{NN} \end{bmatrix} \end{array} \tag{3.2}
$$

Table 3.3 Sample pairwise comparisons, fuzzy and crisp weights

	C1	C2	C3	C4	Fuzzy weights	Crisp weights
C1	Eq	Vs	Ab	Ab	1.56, 1.88, 2.17	0.429
C2	1/Vs	Eq	Es	Wk	0.79, 0.93, 1.18	0.224
C3	1/Ab	1/Es	Eq	Wk	0.63, 0.71, 0.93	0.175
C4	1/Ab	1/Wk	1/Wk	Eq	0.62, 0.79, 0.84	0.172

$$W_{ij} = \begin{bmatrix} W_{i1}^{(j1)} & W_{i1}^{(j1)} & \cdots & W_{i1}^{(jn_j)} \\ W_{i2}^{(j1)} & W_{i2}^{(j2)} & \cdots & W_{i2}^{(jn_j)} \\ \vdots & \vdots & \ddots & \vdots \\ W_{in_1}^{(j1)} & W_{in_1}^{(j2)} & \cdots & W_{in_1}^{(jn_j)} \end{bmatrix} \tag{3.3}$$

The supermatrix is raised to its powers to capture the transmission of influence along all possible paths of the supermatrix. Each power of the matrix captures all transitivities of an order that is equal to that power. For the final results, the steady state priorities are investigated from the limit of the supermatrix. The limit supermatrix is computed according to whether it is irreducible or it is reducible with one being a simple or a multiple root and whether the system is cyclic or not. There are two possible outcomes, each column of the limit matrix can be equal or not. If each column is identical, each one gives the relative priorities of the elements from which the priorities of the elements in each cluster are normalized to one. In the second, the limit cycles in blocks and the different limits are summed and averaged and again normalized to one for each cluster. The limit priorities are put in the idealized form because the control criteria do not depends on the alternatives (Saaty and Özdemir 2005).

3.4.3 BOCR Approach

In decision making, there are criteria that are opposite in direction to other criteria, such as criteria in benefits (B) versus those in costs (C), and criteria in opportunities (O) versus those in risks (R). Saaty (2001) presented BOCR model to analyze a decision problem from four different perspectives and synthesize the priorities of alternatives by combining the priorities of alternatives under these perspectives. Under the BOCR concept, four different subnetworks are structured and pairwise comparison questions ask which alternative is most beneficial, has the best opportunity, which one is riskiest and costliest according to the structured networks. The weights of alternatives are determined first according to the weights of criteria for each network. Later, the weights of the alternatives under *B*, *O*, *C,* and *R* are combined to get a single outcome for each alternative. There are five ways to combine the scores of each alternative under *B*, *O*, *C,* and *R*. The relative priority, P, for each alternative can be calculated using the formulas given below where B, O, C, and R represent, respectively, the synthesized results of alternatives and b, o, c, and r are, respectively, normalized weights of merit B, O, C, and R.

1. Additive:

$$P = bB + oO + c\left[(1/C)_{\text{Normalized}}\right] + r[1/R_{\text{Normalized}}] \tag{3.4}$$

2. Probabilistic additive:

$$P = bB + oO + c[1 - C] + r(1 - R) \tag{3.5}$$

3. Subtractive:

$$P = bB + oO - cC - rR \tag{3.6}$$

4. Multiplicative priority powers:

$$P = B^b O^o \left[(1/C)_{\text{Normalized}}\right]^c \left[(1/R)_{\text{Normalized}}\right]^r \tag{3.7}$$

5. Multiplicative:

$$P = BO/CR \tag{3.8}$$

The steps that should be followed when applying BOCR approach with ANP application as follows (Saaty and Özdemir 2005):

Step 1: Description of the decision problem.

Step 2: Determine the control criteria and subcriteria in the four control hierarchies.

Step 3: For each control criterion or sub-criterion, determine the clusters of the general feedback system with their elements and connect the according to their outer and inner dependence influences. An arrow is drawn from a cluster to any cluster whose elements influence it.

Step 4: For each control criterion, construct the supermatrix.

Step 5: Perform paired comparisons on the elements within the clusters themselves according to their influence on each element in another cluster they are connected to (outer dependence) or o elements in their own cluster (inner dependence).

Step 6: Perform paired comparisons on the clusters as they influence each cluster to which they are connected with respect to the given control criterion.

Step 7: Compute the limit priorities of the stochastic supermatrix.

Step 8: Synthesize the limiting priorities by weighting each idealized limit vector.

3.5 Assessment of Energy Alternatives Using Fuzzy ANP

In this section, a numerical is given using BOCR approach and Fuzzy ANP. Initially, the current and potential situation of the GE alternatives in Turkey is given and then the assessment model is described and the results are discussed.

3.5.1 GE Alternatives in Turkey

Hydropower Energy: Turkey takes place in the first 15 largest hydropower producing countries with a capacity of 35,851 GWh and a percentage of 1.2 by 2007. Turkey's theoretical hydroelectric potential is 1 % of that of the world and 16 % of Europe. The gross theoretical viable hydroelectric potential in Turkey is 433 billion kWh and the technically viable potential is 216 billion kWh. The economically viable potential, however, is 140 billion kWh (Yuksel and Kaygusuz 2011). Among RES in Turkey, hydropower has the highest share with 93.8 % in terms of installed capacity. Turkey has been divided into 26 river basins; however, 97 % of its economically feasible hydropower potential is distributed into 14 river basins.

As of 2009, 172 hydropower plants have been put into operation, 148 are under construction, and a further 1,418 are at various planning stages. Hydropower plants in operation have an installed capacity of 13,700 MW with an annual average generation of 48,000 GWh. Only 34 % of the economically utilizable hydro potential has been developed in Turkey (Erdogdu 2011).

Geothermal Energy: Turkey has a significant geothermal potential owing to its geographical location along Alpine–Himalaya belt. A total of 172 regions having geothermal energy potential have been explored in Turkey. Among them, the most important geothermal systems of Turkey are located in the major grabens of the Menderes Metamorphic Massif, while those that are associated with local volcanism are more common in the central and eastern parts of the country (Yuksel and Kaygusuz 2011).

Turkey's geothermal power potential corresponds to one-eighth of the world's total geothermal potential (Balat 2004). There may exist about 2,000 MW of geothermal energy usable for electrical power generation and about 31,500 MWt for geothermal heating purposes (Yuksel and Kaygusuz 2011). The installed capacity in Turkey currently being used in residential and thermal facility heating is 635 MWt while an installed capacity of 192 MWt is being used for green house heating. Moreover, an installed capacity of 402 MWt is being used for thermal tourism purpose. Hence, the total direct use of geothermal energy in the country is 1,229 MWt (Baris and Kucukali 2012). In recent years, the search for new geothermal sites and projections for new installations have been emphasized in the Turkish governmental plans and the total direct use planned for 2013 is significantly high compared to actual values in 2005 (Baris and Kucukali 2012).

Wind energy: Turkey has one of the richest wind energy potentials among European countries. Turkey's total technical potential for wind power is estimated to be around 114.173 MW. Turkey's total economically feasible potential for wind power is estimated to be 20.000 MW (EIE 2009; MENR 2008). The most attractive regions for wind energy utilization are the Marmara, Aegean, and Black Sea regions possessing, respectively, 38.5, 23, and 12.5 % of the total wind power potential of the country.

Although Turkey has much higher technical wind power potential than other European countries, only a very small percentage of this potential is used when compared to those countries (Baris and Kucukali 2012). As for Turkey's situation related to wind energy utilization, it can be seen that Turkey is rather unsuccessful in using its potentials (Erdem 2010). This is mainly due to the lack of incentive policies which are provided by the governments of EU countries for promoting the utilization of RES. An initiative toward encouraging the utilization of RES in Turkey has been the Renewable Energy Law in Turkey. By the enacting of this law in 2005, the capacity of wind power has started to increase significantly. A total of 93 wind projects with a total installed capacity of 3,363 MW have been licensed after the enactment of the law (Baris and Kucukali 2012).

Solar energy: The climate and geographical location of Turkey highlight the solar energy as an important RES with the yearly average solar radiation 3.6 kWh/m^2-day and the total yearly radiation period being, approximately, 2,640 h in Turkey. The solar energy potential of Turkey is calculated as 380 billion kWh/year. Average solar energy potential of Turkey and corresponding insolation durations on monthly basis (Baris and Kucukali 2012).

In spite of this high potential, solar energy is not now widely used, except for flat-plate solar collectors which turn solar energy into thermal energy. They are only used for domestic hot Water generation, mostly in the sunny coastal regions (Angelis-Dimakis et al. 2011). In 2006, country has about total 7.0 million m^2 solar collectors and it is predicted that total energy production is about 0.390 Mtoe in 2006 (Yuksel and Kaygusuz 2011).

Currently, Turkey does not have an organized commercial and domestic PV program. Taking the high rates of solar irradiation rates and wide area of the land, PV applications are suitable for the energy generation. However, the PV generation application is insignificant and currently, the total PV generation capacity in Turkey is 3 MWp. PV energy is used for signaling purposes and in rural areas such as the watch towers of the Ministry of Environment and Forestry, light houses and lighting of highways (Erdem 2010).

Biomass Energy: Biomass is the major source of energy in rural Turkey since it is available locally and allows widespread production of energy at reasonable costs. The annual biomass potential of Turkey is approximately 32 Mtoe. Among OECD countries, Turkey takes the fourth place from the top in the estimated total energy potential from crop residues with 9.5 Mtoe (Erdem 2010).

Biogas production potential of Turkey is estimated to be 1.5–2 Mtoe. However, the current production capacity is limited with two small operating producers and one new licensed facility. Around 85 % of the total biogas potential is from dung gas, and the remainder is from landfill gas. The dung gas potential is obtained from 50 % sheep, 43 % cattle, and 7 % poultry (Erdem 2010).

Biodiesel production is also limited in Turkey by one bioethanol manufacturer with a total production capacity of 30.000 m^3/year. However, it is projected that the number of producers will increase because there are many production companies waiting for the production licenses to be granted by energy market regulatory authority (EMRA).

3.5.2 The BOCR Model

The BOCR model designed for the assessment of GE alternatives is shown in Table 3.3. For the construction of the BOCR model, first an extended literature review is accomplished and the potential clusters and potential criteria for each network are determined. In the second phase, the determined alternative cluster listed to a group of experts and the ones that the group is agreed on are selected. In the third phase, the alternative criteria are evaluated and with the view of the experts the criteria are picked. In the final BOCR model, each network has the alternatives and participants clusters. Benefits network, however, includes economical, environmental political, technical, and social criteria clusters. The criteria used in the model are also listed in Table 3.4

The steps listed in the previous subsection are followed for the assessment of the GE alternatives but only representative calculations are given. Based on the subnetwork shown in Fig. 3.3 and the criteria listed in Table 3.3, pairwise comparisons are done on the elements within the clusters themselves according to outer and inner dependencies. Buckley's (1985) fuzzy calculations are used to calculate the priorities from the pairwise comparisons. Table 3.5 represents the supermatrix constructed with the eigenvectors of the pairwise comparison matrix.

As the supermatrix is formed, the cluster matrix is constructed. The clusters themselves are compared to establish their importance and use it to weight the corresponding blocks of the supermatrix to make it column stochastic. The clusters that effects target cluster are pairwise compared for the importance of their impact

Table 3.4 Criteria used in the BOCR model

Economical (C1)	*Opportunity criteria* (C6)
• Low and stable energy prices (C11)	• Potential for commercialization (C61)
• Economic life time of the investment (C12)	• Local economic development (C62)
• Incentives and subsidies (C13)	• Low carbon economy integration (C63)
Environmental (C2)	*Cost criteria* (C7)
• Reductions in emission to air (C21)	• Investment cost (C71)
• Environmental sustainability (C22)	• Operating cost (C72)
	• Maintenance cost (C73)
	• Distribution and transmission cost (C74)
	• Grid cost (C75)
	• Social cost (C76)
Technical–Technological (C3)	*Risk criteria* (C8)
• Maturity of the technology (C31)	• Availability (C81)
• Reliability of the technology and operation (C32)	• Social risk (C82)
• Simplicity of construction and installation (C33)	• Environmental risk (C83)
• Technical know-how of local actors (C34)	• Human health risks (C84)
• High learning rate (C35)	• Safety risks (explosion, firing, etc.) (C85)
Social (C4)	*Alternatives* (A1)
• Increase in employment rate (C41)	• Solar (A11)
• Public acceptance (C42)	• Wind (A12)
• Regional benefits (C43)	• Biomass (A13)
• Social sustainability (C44)	• Hydropower (A14)
	• Geothermal (A15)
Political (C5)	*Participants* (P1)
• Security for energy supply (C51)	• Policy Makers (P11)
• Foreign dependency (energy import/export) (C52)	• Suppliers (P12)
• Morality effect (C53)	• Consumers (P13)
• Political acceptance (C54)	• Local Stakeholders (P14)
• Interboarder impacts (C55)	

on it with respect to opportunities control criterion. Table 3.6 represents the cluster matrix for opportunities subnetwork.

The next step is to construct the weighted supermatrix. Weighted supermatrix is obtained by multiplying each entry in a block of the component at the top of the supermatrix by the priority of influence of the component on the left from the cluster matrix shown in Table 3.6. For example, the value 0.251 is used to multiply the nine entries in the block (Opp. Criteria–Opp. Criteria) in the unweighted supermatrix. The weighted supermatrix for the opportunities subnetwork is shown in Table 3.7.

After the weighted supermatrix is constructed, the limit priorities of the supermatrix are calculated. The weighted supermatrix is raised to its powers till the limit supermatrix is reached. Table 3.8 represents the limit supermatrix for opportunities subnetwork.

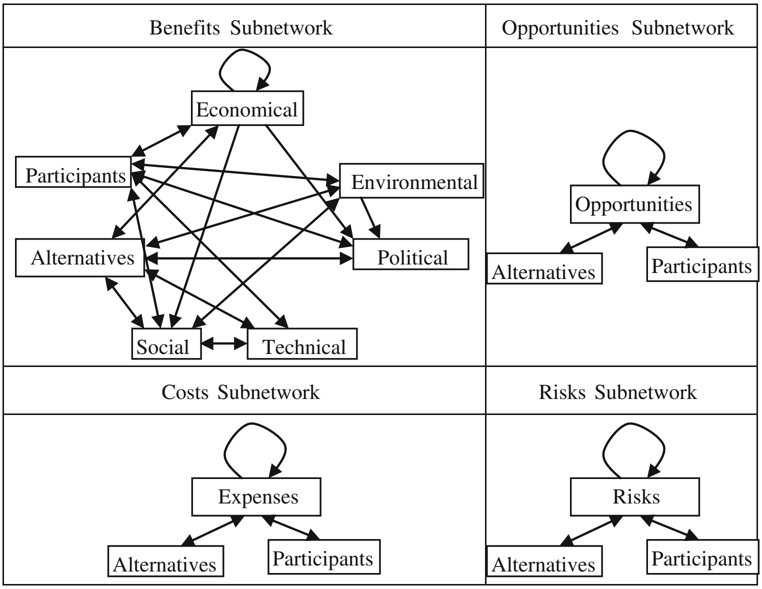

Fig. 3.3 BOCR model for green energy assessment

The values from the limit matrix represent the limit priorities of the decision elements. The values for each alternative can be normalized or idealized for further synthesis. According to the results represented in Table 3.9, biomass has the highest priority in the opportunities subnetwork, followed by geothermal and hydropower.

To complete the BOCR process, the above-mentioned processes are repeated for other control criteria (benefits, costs, risks). The limit priorities of these subnetworks are listed in Table 3.10. For the final synthesis the multiplicative method (Formula 3.7) is used to combine the scores of each alternative under B, O, C, and R. The alternative with the highest outcome score appear to be the best alternative.

3.6 Discussion and Results

In the BOCR application made for Turkey, five different GE alternatives are evaluated from four perspectives. The results show that Biomass energy is ranked as the best GE from the benefits perspective. Solar energy is determined as the source of energy which has the lowest benefits. Just like the benefits, from the opportunities perspective the best alternative is the biomass which is followed by geothermal energy. When compared with the other alternatives solar and wind energy does not provide enough opportunities. When the alternatives are evaluated according to their costs, solar leads the group and is followed by biomass and wind

Table 3.5 The unweighted supermatrix for opportunities subnetwork

	Opp. Criteria			Alternatives					Participants			
	C61	C62	C63	A11	A12	A13	A14	A15	P11	P12	P13	P14
C61	0.000	1.000	1.000	0.333	0.262	0.369	0.251	0.333	0.369	1.000	0.000	0.250
C62	0.000	0.000	0.000	0.333	0.369	0.262	0.251	0.333	0.369	0.000	0.500	0.750
C63	1.000	0.000	0.000	0.333	0.369	0.369	0.498	0.333	0.262	0.000	0.500	0.000
A11	0.144	0.144	0.200	0.000	0.250	0.250	0.250	0.250	0.234	0.118	0.200	0.247
A12	0.144	0.144	0.200	0.250	0.000	0.250	0.250	0.250	0.170	0.226	0.200	0.169
A13	0.284	0.284	0.200	0.250	0.250	0.000	0.250	0.250	0.234	0.226	0.200	0.247
A14	0.144	0.144	0.200	0.250	0.250	0.250	0.000	0.250	0.234	0.312	0.200	0.169
A15	0.284	0.284	0.200	0.250	0.250	0.250	0.250	0.000	0.129	0.118	0.200	0.169
P11	0.287	0.338	0.333	0.000	0.000	0.000	0.292	0.000	0.000	0.262	0.750	0.250
P12	0.425	0.000	0.000	0.662	0.750	0.500	0.369	0.500	0.333	0.000	0.250	0.750
P13	0.000	0.000	0.333	0.000	0.000	0.000	0.000	0.000	0.333	0.389	0.000	0.000
P14	0.287	0.662	0.333	0.338	0.250	0.500	0.369	0.500	0.333	0.369	0.000	0.000

Table 3.6 The cluster matrix

	Opp. criteria	Alternatives	Participants
Opp. criteria	0.251	0.251	0.333
Alternatives	0.498	0.251	0.333
Participants	0.251	0.498	0.333

Table 3.7 Weighted supermatrix for opportunities criteria

	Opp. Criteria			Alternatives					Participants			
	C61	C62	C63	A11	A12	A13	A14	A15	P11	P12	P13	P14
C61	0.000	0.251	0.251	0.084	0.066	0.093	0.062	0.084	0.123	0.331	0.000	0.083
C62	0.000	0.000	0.000	0.084	0.093	0.066	0.062	0.084	0.123	0.000	0.167	0.250
C63	0.251	0.000	0.000	0.084	0.093	0.093	0.123	0.084	0.087	0.000	0.167	0.000
A11	0.072	0.072	0.100	0.000	0.063	0.063	0.062	0.063	0.078	0.039	0.067	0.082
A12	0.072	0.072	0.100	0.063	0.000	0.063	0.062	0.063	0.057	0.075	0.067	0.056
A13	0.141	0.141	0.100	0.063	0.063	0.000	0.062	0.063	0.078	0.075	0.067	0.082
A14	0.072	0.072	0.100	0.063	0.063	0.063	0.000	0.063	0.078	0.103	0.067	0.056
A15	0.141	0.141	0.100	0.063	0.063	0.063	0.062	0.000	0.043	0.039	0.067	0.056
P11	0.072	0.085	0.084	0.000	0.000	0.000	0.143	0.000	0.000	0.087	0.250	0.083
P12	0.107	0.000	0.000	0.330	0.374	0.249	0.181	0.249	0.111	0.000	0.083	0.250
P13	0.000	0.000	0.084	0.000	0.000	0.000	0.000	0.000	0.111	0.129	0.000	0.000
P14	0.072	0.166	0.084	0.168	0.125	0.249	0.181	0.249	0.111	0.122	0.000	0.000

Table 3.8 Limit matrix for opportunities criteria

	Opp. Criteria			Alternatives					Participants			
	C61	C62	C63	A11	A12	A13	A14	A15	P11	P12	P13	P14
C61	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132	0.132
C62	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071
C63	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078
A11	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063
A12	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064
A13	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082
A14	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069
A15	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072
P11	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063
P12	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150
P13	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
P14	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123	0.123

energy. From the risks perspective the most risky GE alternative is found as biomass and geothermal, wind carry risk when compared to others.

Table 3.9 Alternative values from the limit matrix

	Values from limit matrix	Normalized values	Idealized values
Biomass	0.0817	0.233	1.000
Geothermal	0.0715	0.204	0.876
Hydropower	0.0694	0.198	0.850
Wind	0.0641	0.183	0.785
Solar	0.0633	0.180	0.775

Table 3.10 Limit priorities for BOCR and the synthesized outcome

	Benefits	Opportunities	Costs	Risks	Outcome *BO*/*CR*
Solar	0.157	0.180	0.251	0.181	0.625
Wind	0.176	0.183	0.204	0.214	0.789
Biomass	0.242	0.234	0.217	0.222	1.134
Hydropower	0.198	0.198	0.152	0.161	1.612
Geothermal	0.227	0.205	0.176	0.222	1.149

When the alternatives are evaluated one by one from the mentioned perspectives, Solar energy is found as an expensive investment with low levels of benefits, opportunities, and risks. Wind on the other hand, is a risky investment that needs a medium level of investment, and generates below medium benefits. Biomass, is the best alternative from benefits and opportunities perspective, however, the costs are high and it is has the highest level of risk. Hydropower has a medium level of benefits and offers a medium level of opportunities but the cost and the risks are in the lowest level. Geothermal energy generates high level of benefits and also provides opportunities; however, it is the most risk alternative when compared with the others.

According to the aggregated outcome of the *BO*/*CR* method, hydropower has the highest priority which is followed by geothermal and biomass energy sources. Although the benefits score of biomass is higher than all others when considering the high risk and costs, biomass is moved to third place. Although the hydropower is not the best alternative from Benefits and Opportunities perspectives, because of low costs and risks it appears to be the best alternative for Turkey.

3.7 Conclusion

Energy is one of the scarce sources that will be tremendously needed. Preferring RES for this need seems to be a solution to this problem. Hydropower, geothermal, wind, solar, and biomass are among the GE alternatives of the future.

The evaluation criteria and the energy alternatives have a network structure since they have internal and external dependencies. ANP is an excellent method to handle this structure. The considered network in this chapter is composed of four subnetworks which are Benefits, Opportunities, Costs, and Risk.

The evaluation process has been realized under fuzzy environment since humans prefer linguistic expressions rather than numerical ones in this process. Linguistic expressions have been converted to corresponding numerical values using the fuzzy set theory.

The application made for Turkey shows that the hydropower energy alternative is the most suitable one. Hydropower is the energy alternative with minimum risk and minimum cost but not the best from benefits and opportunities perspective. The synthesis gave the hydropower the first rank. The following alternatives are geothermal, biomass, wind, and solar, respectively.

For further research, we suggest the other synthesis approaches such as additive, probabilistic additive, subtractive, and multiplicative priority powers to be used and the results obtained by these approaches to be compared with the results in this chapter.

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