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Prioritization of renewable energy alternatives by using an integrated fuzzy MCDM model: A real case application for Turkey

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ABSTRACT

Nowadays, energy demand is increasing as a result of growing population all over the world. Current conventional sources are not an adequate level in order to meet this energy requirement. Therefore, it is necessary to consider economic and clean alternative energy sources. In this context, renewable energy sources can be contemplated as a solution for this energy problem. On the other hand, selection among energy alternatives is a multi-criteria decision making (MCDM) problem and it is necessary to make an assessment in terms of several conflicting criteria. Sometimes, it may not be easy to evaluate these criteria by using crisp numbers and we need to evaluate by using human judgements and linguistic terms that can be used for a more flexible and sensitive evaluation. However, the fuzzy sets enable to cope with vagueness of evaluations in decision making process. In this study, an integrated MCDM model based on the fuzzy sets is proposed for prioritization of renewable energy alternatives in Turkey. The suggested fuzzy MCDM model combines analytic hierarchy process (AHP) based on interval type-2 fuzzy sets and hesitant fuzzy TOPSIS methods. Since the type-2 fuzzy sets whose membership functions are also fuzzy and hesitant fuzzy sets that enable to handle situations that an element has several membership value are more able to model uncertainties in decision making process, in this paper a MCDM methodology based on these two methods are suggested to evaluate renewable energy alternatives for Turkey. Interval type-2 fuzzy AHP method is applied to determine the weights of decision criteria, and hesitant fuzzy TOPSIS method is applied to prioritize renewable energy alternatives. A real case application has been presented via expert evaluations to indicate applicability of the proposed model. Besides, a sensitivity analysis has been performed to examine the effects of main criteria weights in ranking.

1. Introduction

Energy can be defined as ability to do a job and it is evaluated as a life source for people. Energy can be obtained from primary energy sources such as coal, oil, natural gas, uranium, biomass, geothermal, hydro, solar and wind in nature. Energy sources named oil, natural gas, coal and nuclear energy are known as fossil energy sources. On the other hand, wind, solar, biomass, hydraulic, geothermal, wave and hydrogen energy named as renewable energy. Renewable energy causes less greenhouse gas emission and renews itself continuously [1]. In a globalized world, energy has vital importance for countries as an important indicator of economic development. It is necessary to have abundant energy sources to provide sustainable development in a society. These energy sources should be obtained with a reasonable cost and should be used for all requirements of society without causing any negative social effects. Although fossil energy sources are finite, renewable energy sources like hydropower, solar and wind are found in the nature in the long run [2]. The population of world has increased by 2,5 times since 1950. Energy demand has increased seven-fold as a result of this increment. It is anticipated to increase of energy consumption more than %100 in Turkey, in 2030 compared to the present. Therefore, it is aimed to make the transition to renewable energy sources instead of conventional energy sources in Turkey [1]. In this paper, a new multi-criteria decision making (MCDM) model based on type-2 fuzzy sets and hesitant fuzzy sets is proposed to evaluate renewable energy alternatives for Turkey. By the way, multi-criteria decision making (MCDM) is a concept that used to select the best one among a set of alternatives by evaluating them in terms of several criteria [3]. MCDM methods enable to evaluate alternatives and make a selection among them. Although, selection among renewable energy alternatives is seen an easy process, it is necessary to make an assessment in terms of technical, economical, technological, socio-political and environmental aspects. Making evaluation with crisp numbers is not always possible. Therefore, sometimes linguistic

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variables are used to evaluate selection criteria [3]. Fuzzy sets which was developed by Zadeh [4], provides easiness to deal with uncertainties in decision making problems. Some new generalizations of fuzzy sets are developed to express uncertainties better in decision making process such as type-2 fuzzy sets, intuitionistic fuzzy sets, fuzzy multisets and hesitant fuzzy sets. Type-2 fuzzy sets are improved by Zadeh [5] as an extension of type-1 fuzzy sets. Type-2 fuzzy sets enable to minimize the effects of uncertainties in rule-based fuzzy logic systems. Type-1 fuzzy sets are not able to model uncertainties because their membership functions are crisp. On the other hand, type-2 fuzzy sets are able to model uncertainties in decision making process because their membership functions are also fuzzy [6]. Hesitant Fuzzy Sets (HFS) developed by Torra [7] enable to have several membership values for each element. In this paper, interval type-2 fuzzy sets and hesitant fuzzy sets are used with MCDM methods to evaluate renewable energy alternatives for Turkey. The seven alternatives named as hydraulic, wind, solar, geothermal, biomass, wave and hydrogen energy are evaluated in terms of six main criteria and twenty-nine sub-criteria. Interval type-2 fuzzy AHP method is utilized to calculate weights of criteria. Afterwards, TOPSIS method is applied with hesitant fuzzy sets to rank renewable energy alternatives. It is aimed to prioritize renewable alternatives and to propose energy roadmap for Turkey by means of this study.

In this paper, an integrated MCDM methodology consists of analytic hierarchy process (AHP) based on interval type-2 fuzzy sets and TOPSIS based on hesitant fuzzy sets. This integration based on hesitant and type-2 fuzzy sets has been suggested for prioritization of renewable energy alternatives for Turkey. Hesitant fuzzy sets can be successfully used when experts being hesitate among a set of membership degrees. It is possible to model these cases by using different membership values. In this manner, it is possible to increase the ability and flexibility of decision making process. By the way, in this paper the type-2 fuzzy sets are used to overcome incapability of traditional fuzzy sets in representing uncertainty through their membership functions. These two new methods are integrated into MCDM to increase flexibility and sensitiveness of decision making.

The rest of this paper is organized as follows: Section 2 gives some information about renewable energy alternatives and presents a literature review for renewable energy decision problems. Section 3 mentions about the proposed multi-criteria decision making model. Section 4 includes a real case application to rank renewable energy alternatives for Turkey. Section 5 presents obtained results and the future research suggestions.

2. Renewable energy alternatives

Turkey is located in the northern hemisphere between the 36–42 northern parallels and the 26–45 eastern meridians as one of the largest countries in both Europe and the Middle East. The surface of Turkey is 783.562 square km. Turkey has high population growth and quick urbanization. As a result of these situations, Turkey's energy demand is continuously increasing during last years. The total energy consumption of Turkey is nearly 150 Mtoe in 2010 and it is anticipated to reach 280 Mtoe until 2020. On the other hand, Turkey is an energy-importing country and need alternative energy sources to decrease the country's dependence on imported energy. In fact, Turkey has abundant renewable energy sources that can be a solution for its dependence on energy. Therefore, the Turkish government encourages energy users to prefer renewable energy sources such as solar, wind and hydropower because of inadequate quantity of domestic oil and natural gas [8].

The Turkish government desires to increase usage of renewable energy in all parts of life. For example, the share of renewable energy in electricity production is not at the desired level in Turkey. It is seen that the big part of electric power is provided from imported fossil energy sources. There are some negative effects of these imported energy sources to national economy. Therefore, Ministry of Energy and National Resources (MENR) aims to increase the ratio of renewable energy sources in electricity production. The percentages of resource based electric power production according to 2015–2019 strategic plan of MENR are given in Fig. 1.

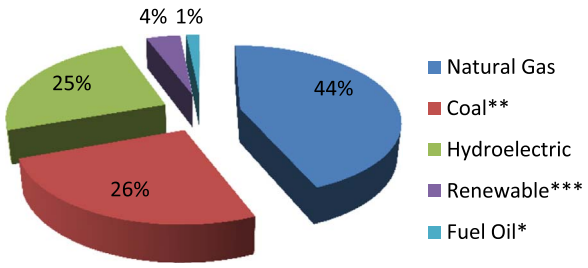

Fig. 1. Resource-based electric power production percentages [9], *Diesel and naphtha plants are included. **Domestic and imported coal are included. Asphaltites are included. ***It includes wind, geothermal, biomass and other renewable energy plants.

Table 1
Planned installed capacity values based on renewable energy sources [9].

Planned Installed Power Values Based on Renewable Energy Sources (MW)	2013	2015	2017	2019
Hydraulic	22,289	25,000	27,700	32,000
Wind	2759	5600	9500	10,000
Geothermal	311	360	420	700
Solar	–	300	1800	3000
Biomass	237	380	540	700

Planned installed capacity values based on renewable energy sources according to 2015–2019 strategic plan of MENR are given in Table 1. It is understood from Table 1 that Turkish government plans to increase the usage of renewable energy sources at strategic level.

The short explanations of renewable energy alternatives are given as follows:

2.1. Hydraulic energy

Hydraulic energy is obtained by transforming potential energy of water to kinetic energy. Obtained kinetic energy is initially transformed to mechanical energy with water turbines, afterwards mechanical energy is also transformed to electricity by means of a generator system [10]. Hydraulic energy has a big share in the renewable energy potential of Turkey. While theoretical hydroelectric potential of Turkey is 433 billion kWh, technical and economic potential are 216 and 140 billion kWh/year respectively. It is aimed to evaluate all of the hydroelectric potential defined as technical and economic for electricity generation by the year 2023 [11].

2.2. Solar energy

Solar energy is another type of renewable energy that obtained by collecting sunlight through solar or photovoltaic cells. High-intensity heat source is created by focusing sunlight with mirrors to generate electricity. Solar energy can be utilized for cooling, lighting, heating and other energy demands [8]. Turkey has high solar energy potential as a result of its geographic position. Total installed solar collector field has been calculated approximately as 18.640.000 m^2 by the year 2012 in Turkey. 768,000 tons of oil equivalent (toe) thermal energy was produced with solar collectors in 2012. 500,000 toe of produced thermal energy was used in housing and the rest of generated energy was utilized in industry. The installed capacity of 861 solar power plants has been calculated as 660,2 MW by the end of September 2016 [11].