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Evaluation of renewable energy sources for generating electricity in province of Yazd: a fuzzy MCDM approach

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Abstract

Iran with considerable amount of oil and gas resources is one of the exporters of primary energy. However, during the past three decades, due to the ongoing process of social and economical developments, revising the present strategy of utilizing energy resources in the country is largely met through imports. Iran is potentially one of the best regions for utilization of most alternative sources of renewable energies. The aim of this study is to propose a Fuzzy multi-criteria decision-making approach (FMCDM) in order to evaluate 4 alternative renewable energies (solar, geothermal, hydropower and wind energies) in Yazd province in Iran. Two FMCDM methods are proposed for this problem: Fuzzy Analytic Hierarchy Process (FAHP) is applied to determine the relative weights of the evaluation criteria and the extension of the Fuzzy TOPSIS is applied to rank the alternatives. Results indicate that solar energy is the most appropriate renewable energy source for the studied area.

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1. Introduction

Like other developing countries, Iran has been encountered with significant challenges in energy and environmental policies. Economical growth in Iran depends on electricity consumption. Due to its rapid economic growth; energy production and also consumption in Iran have been increased in recent years. Consumption has grown eleven-times within the last 30 years in Iran (Mazandarani, Mahlia et al. 2011). The increase in electricity consumption is expected to be in upcoming years around 10% based on country's economic growth (Mazandarani, Mahlia et al. 2010).

Comparing the share of energy resources used in world electricity generation with the types used in Iran, shows that world's energy sources benefits from a more diverse energy sources portfolio. This variation can be easily observed in using both fossil fuels and other sources of electricity generation (like hydropower, nuclear energy, etc.).

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Although there are vast resources of oil and gas in Iran, employing these two sources of energy and ignoring other economic resources are not recommendable. The real value of fossil fuels is much more precious than simply burning them for their heat and due to limited life of oil reserves, the share of the next generations is also to be considered so that they may have better option to utilize these badly treated treasures (Ghorashi 2007).

On the other hand, the combustion of fossil fuels causes serious environmental pollution, therefore it is important to explore the opportunities for clean renewable energy for long term energy supply (Mostafaeipour 2010).

Though Iran has great potentials for harnessing renewable energy sources, at present, most of Iranian power plants are using nonrenewable sources such as natural gas, fuel oil and diesel to generate electricity.

Iran is in a constant battle to use its energy resources more effectively in the face of subsidization and the need for technological advances in energy production. In order to achieve this goal and to increase energy security, the Iranian government plans to increase power plant diversity by using new types such as nuclear, coal and more renewable energies.

This study aims to evaluate four alternative renewable energy sources, namely solar energy, geothermal energy, hydropower and wind energy for Yazd province in Iran. Many conflicting qualitative and quantitative criteria play role in evaluating alternative energy resources. Since Qualitative criteria are often accompanied by ambiguities and vagueness, an integration of TOPSIS and AHP with fuzzy set theory suggested in this study. The crisp judgments in the conventional TOPSIS seem to be insufficient and imprecise to capture the right judgments of decision-maker(s). Therefore, in this study, a fuzzy logic is employed to cope with this deficiency.

2. Yazd and its potential for renewable energies

Yazd is the capital of Yazd province in Iran. The city is located some 175 miles southeast of Isfahan. Located in the center of Iranian plateau, Yazd province accounts for 6.3% of the whole area of Iran. Yazd is the driest major city in Iran and also the hottest north of the Persian Gulf coast (Mostafaeipour 2010). There are many different sources of renewable energy in Yazd, but wind and solar energies are more available and accessible than other kinds (Mostafaeipour 2010). The province is experiencing power generation by a 12 kW off grid PV system for electrification of Dorbid village for many years. Besides, the biggest solar energy utilization project in the Middle East, the installation of 467MW combined gas-steam-solar power plant is dedicated to the power generation of this province (Mostafaeipour 2010; Dehghan 2011). Also, based on the local wind data, the province can benefit wind energy for running small wind turbines or driving wind pumps for water irrigation purposes.

3- Methodology

The purpose of this study is to determine the best renewable energy source for generating electricity in Yazd province of Iran. For this aim, we propose Fuzzy AHP to determine the relative weights of evaluation criteria and Fuzzy TOPSIS to rank the 4 alternatives renewable energies.

Analytic hierarchy process (AHP), introduced by Saaty (Saaty 1980) is a powerful method for tackling multi-criteria decision making problems in real situations. The process makes it possible to incorporate judgments on intangible qualitative criteria alongside tangible quantitative criteria (Badri 2001). But a crisp scale of conventional AHP does not take into account the uncertainty associated with the mapping of one's perception or judgment to a number. As a result, fuzzy AHP and its extensions are developed to solve alternative selection and justification problems. In the literature there are various fuzzy AHP methods developed by various authors. In this paper, we make use of Chang's fuzzy extent analysis for AHP. Chang (Chang 1992; Chang 1996) developed a fuzzy extent analysis for AHP, which has similar steps as that of Saaty's crisp AHP. However, his approach is relatively easier in computation than the other fuzzy AHP approaches.

Also, we propose a fuzzy extension of TOPSIS method to determine the importance weight of alternative renewable energies. The theoretical levels of the fuzzy TOPSIS method used in this study can be found in (Chen 2000).

Here, we are not going to explain all the intricacies and details of the methodology due to space limitations. Below we give enough of the general approach to enable the reader to follow the paper with ease.

The evaluation procedure in this paper consists of three main steps. These steps can be outlined as follows:

Step 1- Identifying the selection (evaluation) criteria. These criteria selected by reviewing the literature and interviewing with experts.

The hierarchical structure of the decision model of the paper with the alternatives and the criteria is portrayed InFigure 1.

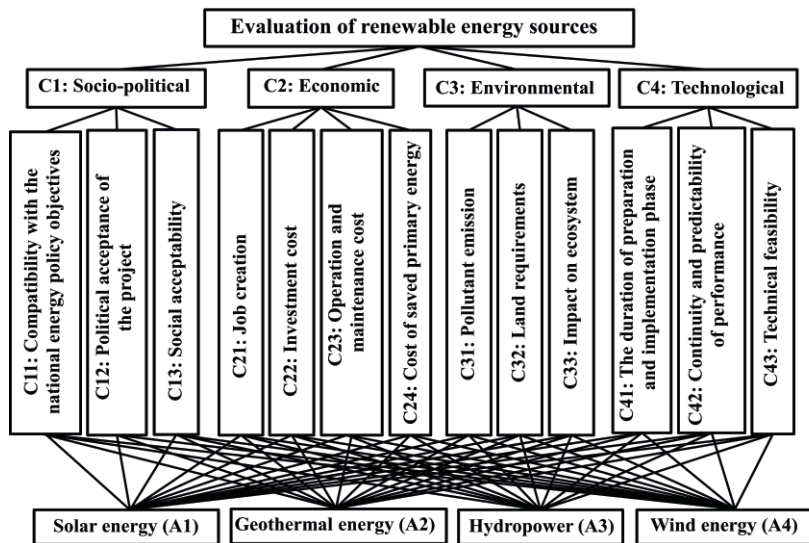


Figure 1 The hierarchy of the energy resources evaluation problem.

Step 2- After constructing the evaluation criteria hierarchy, calculating the weights of criteria through applying FAHP method. The fuzzy scale regarding relative importance to measure the relative weights is given inTable 1This scale is proposed by Kahraman et al. (Kahraman, Ertay et al. 2006).

Table 1 The linguistic scale for relative dominance and their corresponding triangular fuzzy numbers.

Linguistic scale a	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Just equal	(1,1,1)	(1,1,1)
Equal dominance	(1/2,1,3/2)	(2/3,1,2)
Weak Dominance	(1,3/2,2)	(1/2,2/3,1)
Strong dominance	(3/2,2,2.5)	(2/5,1/2,2/3)
Very strong dominance	(2,2.5,3)	(1/3,2/5,1/2)
Absolute dominance	(2.5,3,7/2)	(2/7,1/3,2/5)

The priority weights among the 4 main criteria and 13 sub-criteria and their ranking have been depicted in Table 2.

Table 2Weights of Criteria and sub-criteria

Main Criteria	Sub-Criteria	Local Weights	Global Weights
C1: Socio-political (0.196)	C11	0.421	0.082
	C12	0.366	0.072
	C13	0.213	0.042
C2: Economic (0.328)	C21	0.085	0.028
	C22	0.351	0.115
	C23	0.317	0.104
	C24	0.246	0.081
C3: Environmental (0.174)	C31	0.106	0.019
	C32	0.574	0.100
	C33	0.319	0.056
C4: Technological	C41	0.242	0.073

(0.302)	C42	0.329	0.099
	C43	0.429	0.130

Step 3- Conducting FTOPSIS method to achieve the final ranking results. The fuzzy scale to measure the relative weights of alternatives is given in Table 1. The decision matrix of Table 4 is used for the TOPSIS analysis. This required the criteria weight information to calculate the weighted normalized rating. These criteria weights calculated former with Fuzzy AHP.

Table 3 Fuzzy linguistic terms and correspondent fuzzy numbers for each alternative.

Linguistic variable	Corresponding triangular fuzzy number
Very poor (VP)	(0, 0, 20)
Poor (P)	(0, 20, 40)
Fair (F)	(30, 50, 70)
Good (G)	(60, 80, 100)
Very good (VG)	(80, 100, 100)

Table 4 Integrated fuzzy decision matrix

	C11	C12	C13	C21	C22	C23	C24	C31	C32	C33	C41	C42	C43
Solar	(80,100,100)	(80,100,100)	(80,100,100)	(60,80,100)	(0,30,70)	(30,50,70)	(60,80,100)	(0,6,7,40)	(0,20,40)	(0,6,7,40)	(30,50,70)	(80,100,100)	(80,100,100)
Geothermal	(0,30,70)	(0,40,70)	(30,76,7,100)	(30,70,100)	(60,86,7,100)	(60,80,100)	(30,60,100)	(0,6,7,40)	(30,50,70)	(0,6,7,40)	(60,86,7,100)	(0,20,40)	(0,30,70)
Hydropower	(30,70,100)	(30,70,100)	(80,100,100)	(80,100,100)	(80,100,100)	(80,100,100)	(30,76,7,100)	(0,23,3,70)	(80,100,100)	(0,40,70)	(80,100,100)	(0,23,3,70)	(80,100,100)
Wind	(80,100,100)	(80,100,100)	(80,100,100)	(60,80,100)	(30,70,100)	(60,80,100)	(30,50,70)	(0,6,7,40)	(0,20,40)	(0,6,7,40)	(60,80,100)	(30,50,70)	(30,70,100)

In this study 6 criteria (C22, C23, C31, C32, C33, and C41) are cost attribute and the other criteria are benefit attribute.

For fuzzy data denoted by triangular fuzzy number as (a_{ij}, b_{ij}, c_{ij}) the normalized values for benefit-related criteria and cost-related criteria are calculated as follows (Chen, Hwang et al. 1992):

$$\tilde{r}_{ij} = \begin{cases} \tilde{x}_{ij}(\cdot) \tilde{x}_j^+ = \left(\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{b_j^+}, \frac{c_{ij}}{a_j^+} \right) & \forall j, x_j \text{ Is a benefit attribute} \\ \tilde{x}_{ij}(\cdot) \tilde{x}_j^+ = \left(\frac{a_j^-}{c_{ij}}, \frac{b_j^-}{b_{ij}}, \frac{c_j^-}{a_{ij}} \right) & \forall j, x_j \text{ Is a cost attribute} \end{cases}$$

After normalizing the fuzzy decision matrix, we should calculate the weighted fuzzy decision matrix. This matrix has been calculated using the weights calculated by fuzzy-AHP. The resulting fuzzy weighted decision matrix is shown as Table 5.

Table 5 Weighted normalized fuzzy decision matrix.

	C11	C12	C13	C21	C22	C23	C24	C31	C32	C33	C41	C42	C43
Solar	(0.07,0.08,0.1)	(0.06,0.07,0.09)	(0.03,0.04,0.05)	(0.02,0.02,0.04)	(0.0,0.12,0.12)	(0.04,0.1,0.1)	(0.05,0.08,0.14)	(0.0,0.02,0.02)	(0.0,0.1,0.1)	(0.0,0.06,0.06)	(0.03,0.07,0.17)	(0.08,0.1,0.12)	(0.1,0.13,0.16)
Geothermal	(0.0,0.02,0.07)	(0.0,0.03,0.06)	(0.01,0.03,0.05)	(0.01,0.02,0.04)	(0.0,0.04,0.13)	(0.03,0.07,0.12)	(0.02,0.06,0.14)	(0.0,0.02,0.02)	(0.0,0.04,0.13)	(0.0,0.06,0.06)	(0.02,0.04,0.09)	(0.0,0.02,0.05)	(0.0,0.04,0.11)
Hydro power	(0.02,0.06,0.1)	(0.02,0.05,0.09)	(0.03,0.04,0.05)	(0.02,0.03,0.04)	(0.0,0.03,0.1)	(0.03,0.07,0.09)	(0.02,0.08,0.14)	(0.0,0.01,0.02)	(0.0,0.02,0.05)	(0.0,0.01,0.01)	(0.02,0.04,0.06)	(0.0,0.02,0.09)	(0.1,0.13,0.16)
Wind	(0.07,0.08,0.1)	(0.06,0.07,0.09)	(0.03,0.04,0.05)	(0.02,0.02,0.04)	(0.0,0.05,0.27)	(0.03,0.07,0.12)	(0.02,0.08,0.09)	(0.0,0.02,0.02)	(0.0,0.1,0.1)	(0.0,0.06,0.06)	(0.02,0.04,0.09)	(0.03,0.05,0.09)	(0.04,0.09,0.16)

The results of analyzing decision matrix including distance of each alternative from fuzzy positive ideal reference (S^+), distance of each alternative from fuzzy negative ideal reference (S^-), closeness coefficient (CC_i) and

final ranking of the firms are summarized in Table 6. For ranking alternatives using CC_i index, we can rank alternatives in decreasing order. The alternative with the highest CC_i value will be the best choice.

Finally, ranking the alternatives according to Table 6 is as follows:

$$A1 > A4 > A3 > A2$$

Table 6 Distance of each initial alternative to FRIP and FNIRP and final closeness coefficient of alternatives

	S^+	S^-	CC_i
A1: Solar	0.666239	0.905045	0.575991
A2: Geothermal	1.024867	0.609633	0.372979
A3: Hydropower	0.924444	0.612248	0.398419
A4: Wind	0.817693	0.816037	0.499493

Conclusion

Based on the government policies, which emphasize on minimum extraction of fossil fuels and also coping with technological progress with a view to the environmental consideration, it undoubtedly necessitates developing the utilization of alternative sources of energy towards establishing an energy mix policy in the country.

Iran is potentially one of the best regions for utilization of most alternative sources of renewable energies such as hydroelectric, solar, wind and geothermal.

In this paper we made use of Fuzzy TOPSIS in order to evaluate alternative renewable energy sources and select the best one for Yazd province in Iran. The proposed approach is useful to come up with the best choice among energy sources. Another important finding is that this model reflects the relative importance of criteria used to evaluate these sources.

Here, the alternatives in concern are ranked from most suitable to the less. Solar energy is found to be the most attractive source to use. The results are consistent with the outputs of other studies and also with the experts' opinion. Wind energy source is ranked as second. The hydropower and geothermal energy, follows wind energy respectively. There are important justifications to be found for promoting different sources of renewable energy in Yazd such as wind, and solar. These power generators can be a suitable alternative to the steam and gas plants.

On the other hand based on this study this research hydropower and geothermal energy are not appropriate options for studied regions.

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