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# Multicriteria decision making in energy planning using a modified fuzzy TOPSIS methodology

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ABSTRACT

Energy planning is a complex issue which takes technical, economic, environmental and social attributes into account. Selection of the best energy technology requires the consideration of conflicting quantitative and qualitative evaluation criteria. When decision-makers' judgments are under uncertainty, it is relatively difficult for them to provide exact numerical values. The fuzzy set theory is a strong tool which can deal with the uncertainty in case of subjective, incomplete, and vague information. It is easier for an energy planning expert to make an evaluation by using linguistic terms. In this paper, a modified fuzzy TOPSIS methodology is proposed for the selection of the best energy technology alternative. TOPSIS is a multicriteria decision making (MCDM) technique which determines the best alternative by calculating the distances from the positive and negative ideal solutions according to the evaluation scores of the experts. In the proposed methodology, the weights of the selection criteria are determined by fuzzy pairwise comparison matrices. The methodology is applied to an energy planning decision-making problem.


## 1. Introduction

Energy planning is the process of developing long-range policies to help guide the future of a local, national, regional or even the global energy system. The energy planning discipline takes political, social and environmental aspects into consideration and is carried out taking into account the historical data collected in the previous energy plans of the country under examination (Cormio, Dicorato, Minoia, & Trovato, 2003). The planning endeavor involves finding a set of sources and conversion devices so as to meet the energy requirements/demands of all the tasks in an optimal manner (Hiremath, Shikha, & Ravindranath, 2007).

Energy planning using multi-criteria analysis has attracted the attention of decision-makers for a long time. During the 1970s, dealing with energy problems with a single criterion approach which aimed at identifying the most efficient supply options at a low cost was popular. However, in the 1980s, growing environmental awareness modified the above decision framework and the need to incorporate environmental and social considerations in energy planning resulted in the increasing use of multicriteria approaches (Meirer & Mubayi, 1983; Pohekar & Ramachandran, 2004; Samouilidis & Mitropoulos, 1982).

Multiple criteria decision-making (MCDM) is an operational evaluation and decision support approach suitable for addressing complex problems featuring high uncertainty, conflicting objectives, multi interests and perspectives. MCDM methodologies are capable of providing solutions to a wide range of energy management and planning problems (Løken, 2007; Tsoutsos, Drandaki, Frantzeskaki, Iosifidis, & Kiosses, 2009; Wang, Jing, Zhang, & Zhao, 2009). The literature on the area mainly focuses on renewable energy planning, electric utility planning, energy resource allocation, energy management building, and project planning issues. Several MCDM methods based on weighted averages, priority setting, outranking, fuzzy principles, and their combinations are employed for energy planning decisions. It is observed that AHP is the most popular MCDM technique followed by outranking techniques PROMETHEE and ELECTRE. Weighted sum, weighted product, compromise programming and TOPSIS are also among the methodologies that are widely utilized in energy planning area (Pohekar & Ramachandran, 2004).

Due to the availability and uncertainty of information as well as the vagueness of human feeling and recognition, it is relatively difficult to provide exact numerical values for the criteria and to make an exact evaluation and to convey the feeling and recognition of objects for decision-makers. Therefore, most of the selection parameters cannot be given precisely and the evaluation data of the alternatives' suitability for various subjective criteria and the weights of the criteria are usually expressed in linguistic terms by the decision-makers (Wang et al., 2009). The transition from vagueness provided by linguistic values like "very low", "low", "medium", "high", "very high", etc. to quantification is performed

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by applying the fuzzy set theory (Pochampally, Gupta, & Kamarthi, 2004). Hence, many researchers have attempted to use fuzzy MCDM methods like TOPSIS and AHP for selection problems.

TOPSIS is a widely accepted multi-attribute decision-making technique due to its simultaneous consideration of the ideal and the anti-ideal solutions, and easily programmable computation procedure. In fuzzy TOPSIS, linguistic preferences can easily be converted to fuzzy numbers which are allowed to be used in calculations (Chen, 2000; Önüt & Soner, 2008). For the determination of the relative importance of selection criteria, fuzzy AHP can be used since it is based on pairwise comparisons and it allows the utilization of linguistic variables and tracks the inconsistency of the decision-makers.

In this study, a modified fuzzy TOPSIS methodology is proposed to make a multicriteria selection among energy alternatives. In the proposed methodology, the decision-makers' opinions on the relative importance of the selection criteria are determined by a fuzzy AHP procedure. In order to demonstrate the potential of this methodology, an application in the energy planning area will be presented.

The rest of the paper is organized as follows: In Section 2, energy alternatives and commonly used selection criteria in energy planning are briefly given. In the third section, a modified fuzzy TOPSIS methodology is presented. In Section 4, the proposed methodology is applied to an energy planning problem. In Section 5, a sensitivity analysis is realized. Finally, conclusions are given in the last section.

## 2. Energy planning

An energy planning process usually consists of a study of demand and supply, forecasts of the trends of input–output items, based on economics and technological models, and a list of actions, collecting several measures voted to fulfill the main objectives of the energy plan (Beccali, Cellura, & Mistretta, 2003).

One of the most common problems of energy planning is to choose among various alternative energy sources and technologies to be promoted. Technologies based on solar energy (photovoltaic and thermal), wind energy, hydraulic energy, biomass, animal manure, combined heat and power (CHP), energy saving in residential and industry sectors, tide/wave/ocean energy are among the most popular alternatives (Beccali, Cellura, & Ardente, 1998; Dicorato, Forte, & Trovato, 2008; Krukanont & Tezuka, 2007; Tsoutsos et al., 2009). Despite environmental drawbacks, nuclear and conventional energy resources like coal, oil and natural gas may still be included in the list of alternative technologies to be promoted (Dicorato et al., 2008; Tan & Foo, 2007).

Since an energy resource selection problem has a multi-objective nature, there is a vast multi-criteria decision-making literature on the issue. Keeney, Renn, and Winterfeldt (1987) structured a hierarchical representation of criteria and then aggregated them into a combined 'value tree' in order to evaluate future energy systems of West Germany. Hamalainen and Karjalainen (1992) utilized AHP to determine the relative weights of the evaluation criteria of Finland's energy policies. Mirasgedis and Diakoulaki (1997) compared the external costs of power plants which used different energy sources with the outcome of a multi-criteria analysis. Mavrotas, Diakoulaki, and Papayannakis (1999) presented a multiple objective linear programming model and applied to the Greek electricity generation sector. Taking energy resources, environment capacity, social indicators, and economic indicators into account, Afgan and Carvalho (2002) defined energy indicators used in the assessment of energy systems which met the sustainability criterion. Haralambopoulos and Polatidis (2003) used PROMETHEE II to achieve group consensus in renewable energy projects and applied the decision framework to a geothermal resource usage case in the island of Chios. Beccali et al. (2003) utilized ELECTRE-III under fuzzy environment to assess an action plan for the diffusion of renewable energy technologies at regional scale. Polatidis and Haralambopoulos (2004) proposed a new methodological framework of multi-participatory and multi-criteria decision-making to evaluate renewable energy options in Greece. Providing an integrated decision aid framework, Topcu and Ulengin (2004) dealt with the problem of selecting the most suitable electricity generation alternative for Turkey. Cavallaro and Ciraolo (2005) proposed a multi-criteria method in order to support the feasibility analysis of installing alternative wind energy turbine configurations in a site in Italy. Zhou et al.'s (2006) literature review showed that the importance of multiple criteria decision-making methods and energy-related environmental studies have increased substantially since 1995. Begic and Afgan (2007) evaluated the options of energy power systems for Bosnia Herzegovina under a multi-criteria sustainability assessment framework. Burton and Hubacek (2007) compared the perceived social, economic, and environmental cost of small-scale energy technologies to larger-scale alternatives. Afgan, Pilavachi, and Carvalho (2007) evaluated the potential natural gas usage in energy sector. Önüt, Tuzkaya, and Saadet (2008) employed analytic network process (ANP) to solve an energy resource selection problem for the manufacturing industry. Patlitzianas, Pappa, and Psarras (2008) developed an information decision support system, which contains a MCDM subsystem and applied to 13 accession member states of the European Union. Kahraman, Kaya, and Cebi (2009) used axiomatic design (AD) and AHP for the selection of the best renewable energy alternative under fuzzy environment.

Wang et al.'s (2009) literature review on the application of the MCDM techniques to the energy issues shows that evaluation criteria for alternative energy sources can be grouped into four main

**Table 1**
List of evaluation criteria used in MCDM studies conducted on energy issues.

| Aspects | Criteria |
|---|---|
| Technical | Efficiency* |
| | Exergy (rational) efficiency* |
| | Primary energy ratio |
| | Safety |
| | Reliability |
| | Maturity |
| | Others |
| Economic | Investment cost* |
| | Operation and maintenance cost* |
| | Fuel cost |
| | Electric cost |
| | Net present value |
| | Payback period |
| | Service life |
| | Equivalent annual cost |
| | Others |
| Environmental | $NO_x$ emission* |
| | $CO_2$ emission* |
| | CO emission |
| | $SO_2$ emission |
| | Particles emission |
| | Non-methane volatile compound |
| | Land use* |
| | Noise |
| | Others |
| Social | Social acceptability* |
| | Job creation* |
| | Social benefits |
| | Others |

* Most frequently used.