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Fuzzy MCDM framework for locating a nuclear power plant in Turkey

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HIGHLIGHTS

- Fuzzy MCDM approach is developed to select nuclear power plant location in Turkey.
- The proposed framework employs fuzzy entropy and fuzzy compromise programming.
- A criterion set was developed using a map by The Turkish Atomic Energy Authority.
- Cilingoz is found to be the best with the index values 0.6584 and 0.0838.
- The proposed tool can be considered a tool to evaluate the alternative sites.

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ABSTRACT

Turkey has recently initiated a project to revise its nuclear policy. The revised nuclear energy policy considers searching for possible alternative locations for future nuclear power plants in Turkey. At the most basic level, the public cannot accurately evaluate whether it is willing to support nuclear energy unless it has an idea about where the power plants are likely to be located. It is argued that the selection of a facility location is a multi-criteria decision-making problem including both quantitative and qualitative criteria. In this research, given the multi-criteria nature of the nuclear facility location selection problem, a new decision tool is proposed to rank the alternative nuclear power plant sites in Turkey. The proposed tool is based on fuzzy Entropy and *t* norm based fuzzy compromise programming to deal with the vagueness of human judgments. Finally, a discussion and some concluding remarks are provided.

1. Introduction

With one of the highest economic growth rates among OECD countries, the Turkish economy has been transforming rapidly. In particular, the Customs Union paves the way for streamlining the Turkish economy and its integration into the world trade system. The Customs Union process between Turkey and the European Union (EU) came into effect on January 1, 1996. With the Customs Union, free circulation of industrial goods and processed agricultural products between Turkey and the EU has been guaranteed without being subject to customs duties. Since 1996, Turkey's gross domestic product has increased 4-fold, making it one of the fastest growing economies in the world. Accordingly, the manufacturing industry in Turkey sustained an annual average growth rate of 6% between 1990 and 1998. In 1999 and 2001, the manufacturing industry growth rate declined to −5.7% and −9.9%, respectively. In 2002, the economy recovered, and the manufacturing industry growth rates reached 9.1% in 2002, 7.8% in 2003, 9.4% in 2004, 6.5% in 2005, 5.8% in 2006 and 5.6% in 2007 (IGEME, 2008). In 2008 and 2009, due to the global economic turmoil, the annual manufacturing growth rate declined down to −0.6% and −11.8%, respectively. Finally, in 2010, 2011 and 2012, it improved and the manufacturing growth rate increased by 9.2%, 8.8% and 2.2%, respectively.

Due in large part to the above-mentioned high manufacturing industry growth rates, Turkey is one of the fastest growing energy markets in the world. It is predicted that Turkish industrial electricity demand will be somewhere between 97 and 148 TWh by 2020 (Dilaver and Hunt, 2011). Given the projected high growth rates in electricity consumption, it is likely that Turkey will have to increasingly rely on foreign sources of energy. Meeting this anticipated energy need largely depends on how the country shapes its energy policy. In the new policy, it is essential that Turkey secure a

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safe and diverse energy supply. To this end, nuclear energy projects may be considered particularly due to the following advantages of nuclear energy: (1) it does not lead to carbon emissions, (2) its fuel can be obtained easily, economically, and be stored, (3) as long as appropriate security measures are taken and implemented, the risks to humans or nature are low (Jewell, 2011).

The Turkish Atomic Energy Authority (TAEA) is responsible for determining the basis of national policy and the related plans and programs regarding the peaceful utilization of atomic energy for the benefits of the state. TAEA has recently initiated a project to revise the nuclear policy of the country, including applications in nuclear energy associated with each sector (Kılıç, 2008). Based on the project, the Turkish government plans to begin construction on three nuclear plants by 2015. The first unit will be built at Akkuyu, which is located on the Mediterranean coast, because the site already has a license. Government officials have stated that the locations of the other two plants had not yet been decided.

One of the key issues that must be addressed as a part of the revised Turkish nuclear policy is establishing a framework to guide the selection of locations for future power plants. At the most basic level, the public cannot accurately evaluate whether it is willing to support the nuclear industry unless it has an idea about where the power plants are likely to be located. In the absence of this information, the Turkish Government would be asking the community to make decisions in the abstract without being fully informed.

A location problem, such as locating a nuclear power plant, must deal with the choice of a set of points for establishing certain facilities by taking into account different criteria and verifying a given set of constraints so that the needs of the users are optimally fulfilled (Perez et al., 2004; Gamper and Turcanu, 2007). It is argued that the selection of a facility location among multiple alternatives is a multi-criteria decision-making problem including both quantitative and qualitative criteria. It is also argued that the determination and evaluation of positive and negative characteristics of one location relative to others using miscellaneous criteria is a difficult task (Tuzkaya et al., 2008).

Kirkwood (1982) suggests that the nuclear power plant location problem has a number of challenging features, including: (1) the potential sites may be seismically active or have other natural features that might make them unacceptable for a nuclear power plant, (2) power plants require large quantities of water for cooling purposes, and water may be in short supply in the area, (3) there are significant uncertainties, including uncertainties about geology, water availability and future socioeconomic developments in the area, (4) in addition to system costs, other siting concerns include licensing requirements, public health and safety, environmental and socioeconomic effects and public acceptance, (5) nuclear power plants may have responsibilities to both its shareholders and its rate payers, and a variety of other groups may not be interested in nuclear power, (6) there may be data that could not be collected within a realistic budget and schedule or that may not be available, and (7) regulations of some institutions and other government bodies may impose requirements on the selection of sites for nuclear power plants.

In this research, given the above-mentioned concerns and the multiple criteria nature of the nuclear power plant site selection problem, a new multi-criteria-based framework is proposed in order to select the most appropriate location to build a nuclear power plant in Turkey. In a nuclear power plant problem, exact assessments can be obtained for some criteria, but not others. Since human judgments and preferences are often vague and complex, and decision makers cannot estimate their preferences with an exact scale, linguistic assessments can only be given instead of exact assessments. Therefore, fuzzy set theory is introduced into the proposed multi-criteria decision making (MCDM) framework, which is put forward to solve such uncertainty problems.

The structure of this paper is organized as follows: First, existing research on facility locations based on multi-criteria methods is reviewed. Second, a fuzzy entropy model is developed to identify the weights of the relevant criteria. Next, the fuzzy t norm based compromise programming framework is proposed. The framework is based on obtaining the minimum fuzzy distance to the fuzzy ideal solution of the nuclear power plant location selection problem. Then, Turkey's power plant selection problem is discussed using the proposed model. Finally, a discussion and some concluding remarks are provided.

2. Ranking facility location alternatives using multi-criteria methods

Location analysis has become a very active field of research in the last few decades. In this section, a survey of the most representative multi-criteria location research is provided. First, two studies on nuclear power plant site selection are discussed. Kirkwood (1982) discusses a multi-disciplinary study conducted to select a site for a nuclear power plant. A series of screening steps were carried out to identify candidate sites for the plant, as well as candidate water sources. Then, multi-objective decision analysis methods were used to evaluate and rank these candidate sites and water sources. Ford et al. (1979) present a study to evaluate the appropriateness of alternative methodologies for analyzing a specified problem. This procedure is illustrated by identifying desirable characteristics of nuclear power plant site selection methodologies and evaluating the adequacy of methodologies that have been used to select nuclear power plant sites. The objectives of such siting methodologies are specified and attributes are developed to measure the degree of attainment of each objective. Finally, several siting methodologies are rated on the various attributes, and these ratings are analyzed to determine the adequacy of each methodology.

In addition to the research focused specifically on nuclear power plant site selection, examples of location selection problems in miscellaneous industries are also available. For example, Yang and Lee (1997) present an analytical hierarchy process (AHP) decision model for facility location selection from the view of organizations contemplating the construction of a new facility or relocation of existing facilities. The AHP model provides a framework to assist managers in analyzing various location factors, evaluating location site alternatives, and making final location selections. An example problem is used to illustrate the solution process and address potential managerial implications.

Hokkanen and Salminen (1997) describe an application of a multi-criteria decision aid to the location of a waste treatment facility in eastern Finland. The alternative locations for the facility were considered based on 14 criteria evaluated by 28 decision makers. They make use of the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) decision aid, which was found to fit well with certain constraints in this type of problem with multiple criteria and multiple decision makers.

Kahraman et al. (2003) solve facility location problems using fuzzy multi-attribute group decision-making. The paper includes four different fuzzy multi-attribute group decision-making approaches. The first one is a fuzzy model of group decisions. The second is fuzzy synthetic evaluation. The third is the weighted goals method, and the last one is fuzzy AHP. These approaches are extended to select the best facility location alternative by taking into account quantitative and qualitative criteria. A short comparative analysis among the approaches is provided, and a numeric example to each approach is given.

Bailey et al. (2003) present an application of a new fuzzy algorithm for finding and exploring potential solutions to group