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Decision analysis application intended for selection of a power plant running on renewable energy sources

1. Introduction

Energy is one of the essential aspects of our lives. When the things that can't be done without energy in our daily lives are considered, the term "energy" becomes more significant. The need for energy is increasing with each passing day in accordance with technological advancements and human needs. Therefore, due precautions should be taken before potential future energy problems emerge. In parallel with the energy consumption, environmental pollution and the greenhouse effect in our atmosphere are also rapidly increasing. As a solution to this problem, a shift to renewable and clean energy sources is occurring worldwide. Fossil fuels provide the majority of world's energy need, and due to the fact that these fuels will deplete in time and they are harmful for the environment, renewable energy sources are becoming more and more vital.

In recent years, different levels of policy and legislation were promulgated to encourage renewable energy in developed countries. As of 2013, at least 144 countries which have set different renewable energy targets and policies have been supported at the national level for renewable energy development. The number of supported countries was only 55 in 2005. In 2012, an investment totaling $244 billion was made on renewable energy; global investment increased by 8% compared to 2010. Approximately 19% of the world's energy consumption was provided by renewable energy sources in 2012 [1].

2.33% of Turkey's energy was obtained from renewable energy sources in 2011. Turkey obtained 44.7% from natural gas, 28.2% from coal, 22.8% from hydroelectric and 1.7% from liquid fuels in 2011 [2]. The Ministry of Energy aims to ensure that 30% of the total energy production will be obtained from renewable energy sources by 2023.

Within the literature, there are many studies to answer the question "which renewable energy resource should be utilized?" Many types of Multi-Criteria Decision Making (MCDM) techniques were applied to answer this question for Turkey and other countries. Georgopoulou et al. [3] used the ELECTRE method in Greece; they took 15 criteria into account for eight energy-efficient alternatives. Onut et al. [4] assessed fuel oil, coal, electricity, LPG and NG which are the most common energy sources in the manufacturing industry. The authors used the Analytical Network Process (ANP) method to determine ranking of these sources for the manufacturing industry. Hawila et al. [5] developed and disseminated an assessment framework to find North African countries' readiness for deployment of renewable energy technologies. Tahri et al. [6] studied the outcome of combining both Geographic Information System (GIS) tools and the Analytical Hierarchy Process (AHP) method to assess the suitability of a certain set of locations to carry out a renewable energy project. Zhang et al. [7] improved a MCDM method based on fuzzy measurements and integral. Four primary clean energy options for the Jiangsu Province in China were developed and applied to assess through the MCDM method. As a result, the preferred clean energy option for Jiangsu is solar photovoltaic, followed by wind, biomass and finally nuclear energy.

This study discusses meeting Turkey's constantly increasing energy needs using renewable energy sources. The current situation, technical and economic potential, environmental effects, sustainability, technological maturity and social impacts of renewable energy sources in Turkey and worldwide were discussed in detail. Anderson et al. [8] provided an overview for regulators and stakeholders concerned with wind energy/bird interactions. These interactions were assessed in the environmental effects section. Various alternatives were proposed in order to meet Turkey's energy demands. Current situation of these alternatives were assessed by using the SWOT analysis method, and the criteria were determined and explained by using the data obtained as a consequence of the research. In terms of our criteria, all potential and existing values that could be essential for a power plant running on a renewable energy resource were considered and one of these power plant types was selected. PROMETHEE, one of the multiple criteria decision making models was used for the selection of these alternatives. After the decision-making problem was solved, results were interpreted and the study was concluded with various suggestions.

2. Energy and renewable energy sources in Turkey

Turkey, a developing country turning into a developed one, has to deal with the constantly growing energy demand. Production based on fossil sources is both not sustainable and dependent on external sources.

When Turkey's foreign trade deficit was analyzed, it can be seen that the exportation as of 2009 is 706 billion USD, and the total importation is 1.083 billion USD. Coal, natural gas and crude oil importation was 154 billion USD. 377 billion USD, or 41% of the total foreign trade deficit arose from importing energy [9].

The fact that the majority of Turkey's foreign trade deficit is due to energy importation has economic consequences as well as strategical ones. The energy bottleneck in 2007 was an important warning for Turkey's future strategies. Contributions of procuring energy from different sources on the strategical position of the country were also realised. Equal energy supply and demand in 2007 was avoided thanks to the global crisis. Turkey needs to invest in various energy sources rapidly and meet the growing energy demand. In order to achieve this, the country should invest in foreign renewable energy technology, and rely on its own renewable energy sources.

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According to the Strategic Plan of Ministry of Energy and Natural Sources for the years 2010–2014, increasing the rate of renewable energy production in terms of power generation to a minimum of 30% by 2023 was planned. At the end of 2009, wind power was approximately 803 MW, and geothermal energy level was approximately 78 MW. Completion of the 5000 MW hydroelectric power plants were expected by the end of 2013 [10]. By 2015, installed wind power will be enhanced to 10.000 MW and geothermal energy will be enhanced to 300 MW.

In order to achieve these goals, the Ministry designated the following strategies: (1) With regard to renewable energy sources with economic potential, due precautions will be taken for the finalization of licensed projects within projected time. (2) Production planning will be prepared after considering the advancements in the potential of renewable resource use in accordance with technological developments and legislative arrangements. (3) Progress towards more wind energy plants will enable more energy to be transmitted, leading to greater electricity transmission than today. (4) Regeneration of geothermal sources will be carried out in accordance with the preservation rules regarding the use of sources and their renewable characteristics. (5) Works related to the privatization of geothermal areas convenient for electricity production will be accelerated. (6) Works intended for technological development in the field of renewable energy sources will be carried out.

Total installed power in Turkey is 44.767 MW. 29.333 MW of this is obtained from thermal energy, 14.553 MW is obtained from hydroelectric energy, 803 MW is obtained from wind energy, and 78 MW is obtained from geothermal energy. When compared with OECD states, Turkey's energy density is more than the average value of OECD states although less energy is consumed. Turkey is one of the countries with a higher energy density with 0.38 t of oil equivalent (toe) of energy use per 1000 USD of GDP among OECD states. This shows that the existing energy is not used efficiently.

3. PROMETHEE method

More than one criterion should be taken into account to solve various economic, industrial, financial and political decision-making problems. Nobody buys a car in our day only based on the price. Various criteria such as comfort, quality, spare parts, prestige and performance should also be considered. However, values of these criteria assigned differ from person to person.

Many decision-making methods were developed for selection of the best alternative in compliance with the designated criteria in recent years. PROMETHEE (Preference Ranking Organization Method for Enrichment of Evaluations) is an abbreviation formed with the initials of the method definition and is known by this name in the literature. PROMETHEE is a multiple criteria prioritization method developed by Jean-Pierre Brans in 1982. The PROMETHEE method has been developed based on the difficulties in the application of existing prioritization methods and was used in some studies before this one.

The PROMETHEE method is known as one of the most effective and easiest method in solving MCDM problems. Also, the PROMETHEE I and PROMETHEE II methods were developed in addition to PROMETHEE method. It's possible to determine partial priorities between alternatives based on the designated criteria by using PROMETHEE I and to determine explicit priorities based on the designated criteria by using PROMETHEE II method [11].

Various MCDM problems have been solved by utilizing the PROMETHEE method. Bois, Brans, Cantraine and Mareschal performed a study where they used the PROMETHEE method with Medicis, an expert system developed to make computer-assisted diagnosis [12]. Briggs, Kunsch and Mareschal performed a study focused on nuclear waste management by using the PROMETHEE method and GAIA's geometric recognition method [13]. The PROMETHEE method was applied in the positioning of production system by Pavic and Babic [14], in the assessment of advanced manufacturing technologies with multiple criteria decision making analysis by Koli and Parsaei [15], in foreign resource use by Araz, Ozfirat and Ozkarahan [16] and in stock management by Albadvi, Chaharsooghi and Esfahanipour [17]. Wei-Xiang and Bang-Yi used linguistic data expressed through the use of generalized fuzzy numbers in order to compare every criteria with other alternatives and to determine weight of every criteria [18].

3.1. Algorithm of PROMETHEE method

The algorithm of the PROMETHEE method used for selection and ranking problems comprised of many criteria, shown in Fig. 1.

3.2. Stages of PROMETHEE method

After the problem is defined and alternatives, criteria and weight of this problem are determined, application of the PROMETHEE method stages could be initiated. The PROMETHEE method consists of 7 stages [19].

Stage 1: Designated alternatives, criteria, criteria weight and values of alternatives according to the relevant criteria are collected as a table in a data matrix. A data matrix is formed through the method shown in Table 1 regarding the alternatives A=(a,b,c,...) assessed by the C criterion $c=(f_1,f_2,...,f_k)$ with the weights of $w=(w_1,w_2,...,w_k)$ in the data matrix below.

Stage 2: Selection functions are determined for the criteria. Selection functions shall be determined in accordance with the structure of criterion and the characteristics sought based on criteria in the alternatives. 6 distinct selection functions were determined for the application of the method. Relevant functions are shown in Table 2.

Stage 3: Common selection functions are determined for the alternative pairs in the alternative set based on selection functions determined for the criteria. Schematic representation of the common selection functions determined for the alternatives are given in Fig. 2, and the common selection function for a and b alternatives is determined through (1), (2) and (3).

$$P(a,\ b) = \begin{cases} 0, \ \& f(a) \le f(b) \\ P[f(a), f(b)], \& f(a) > f(b) \end{cases} \tag{1}$$

$$p[f(a), f(b)] = p(x) \tag{2}$$

$$p[x] = f(a) - f(b) \tag{3}$$

Stage 4: Selection indexes are determined for every alternative based on common selection functions. Selection indexes of alternatives a and b assessed by the criteria C with the weight w_i (i=1, 2,...c) in the alternative set are calculated by the use of (4).