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Site selection for hydrogen underground storage using interval type-2 hesitant fuzzy sets

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ABSTRACT

This study presents an interval type-2 hesitant fuzzy set (IT2HFS) based multi-criteria decision making (MCDM) method for selecting hydrogen underground storage sites in Turkey. The proposed method is utilized in a case study that aims to determine the best site among three alternatives. The results show that the proposed method can effectively and flexibly handle the interval type-2 hesitant fuzzy MCDM site selection problems. Finally, the sensitivity analysis is also demonstrated for the proposed method.

Introduction

Using organic fuels to meet the increased energy demand leads to problems, such as global environmental pollution, the greenhouse effect and lack of oxygen for civilization [1]. Therefore, renewable energy sources play an increasingly important role in today's world. In this context, hydrogen is considered to be one of the most promising sources of energy in the future because of its high availability and cleanliness [2,3]. Hydrogen is a fuel used for different purposes, for example, as fuels and chemicals [1]. As a raw material, it is important to maintain its weight and developments in production, incineration and storage technologies that become contributory energy carriers. In many countries, national plans and programs are being prepared in the direction of the hydrogen economy, and extensive and intensive research are being conducted for the development and adaptation of related technologies [4].

Safe and economical long-term storage gases particularly of natural gas, in underground geological formations, has been the standard engineering practice for decades [3,5,6]. The most common technique is to store these gases at depleted gas fields and natural aquifer formations. Additionally, salt caverns are the best choice for storing hydrogen [5,7,8], because they are highly impermeable to hydrogen, even under high pressure, and are almost impermeable [9,10]. Hydrogen storage in a depleted gas reservoir or in an aquifer offers the potential for the seasonal storage of naturally variable renewable energy by electrolysis during extreme energy production [11]. Furthermore, the underground storage of hydrogen in aquifers is proposed as a cheap method for storing the necessary energy [9,12]. Hydrogen's underground storage (HUS) is currently considered as the most advantageous method for large scale (GWh) and long term (weekly) electrical energy storage [5,13,14]. There is a great interest in this method (underground storage of hydrogen) to meet the expected electrical energy

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storage demand, especially in Europe and in Germany in the medium-and long-term period [15].

The irregularity of gas consumption depends upon the climate of the industry, the lifestyle of the population and the geographic differences various regions of the country. The most effective way of large-scale hydrogen storage is underground storage in depleted oil and gas fields, groundwater aquifers, and underground deposits of salt. These storage methods should be utilized in locations that neighbour heavy consumers. Due to its lower viscosity and density, hydrogen has greater mobility than natural gas. For this reason, hydrogen leaks are more likely to occur across different seals or storage caps [1].

Hydrogen underground gas storage applications can be utilized to meet hydrogen demand fluctuations and the storage of electrical energy from intermittent renewable energy sources such as wind, sun, and hydrogen in the regeneration of electricity from large-scale compacted geological formations. Hydrogen gas storage application, which is packed in salt solution openings, is similar to natural gas storage application in terms of the storage technology and operating conditions. However, the volumetric energy density of hydrogen is one third of that of natural gas. Therefore, the cost of unit hydrogen energy storage is higher than natural gas storage cost [5,13,14].

As an energy storage medium, hydrogen underground storage (HUS) is necessary for the regulation of energy consumption and seasonal, monthly and daily fluctuations in production [1,9,16–18]. At present, there are three large-scale hydrogen gas storage facilities in the world, all of which are located in underground salt openings. In addition, sediment storage is implemented in order to satisfy the peak demand of the gas industry, and the distribution of hydrogen takes place through pipelines [5,19–21]. Thus, the main objectives of the HUS are the following [17]: (i) regulation of energy supply and demand when the generated energy exceeds the requirements of consumers; (ii) regulation of energy prices in that the energy produced at a time when electricity is cheap can then be saved and sold; and (iii) industry (refineries, etc.).

In Turkey, an important part of this potential has not yet been realised even though the country is fairly rich in renewable energy potential. Dependence on energy can be controlled by increasing the use of domestic and renewable sources [22]. Turkey is dependent on imported natural gas, and underground natural gas storage facility projects have been undertaken to meet seasonal as well as daily and hourly supply-demand imbalances, which are frequent especially during the winter season [23–26]. Underground natural gas storage facilities in Silivri were opened in 2007 in Northern Marmara and Degirmenkoy. Turkey's first underground natural gas storage facility exists in the Silivri plant. It is considered important for the elimination of the winter gas shortages experienced by the country. The facility meets about 5% of Turkey's annual gas consumption needs [27]. Another facility is the Salt Lake underground natural gas storage project, which is located about 40 km from Salt Lake, south of Aksaray Province, Sultanhani Municipality. In the salt layer, which starts at 600–700 m below the ground and 1500 m in the thickness of the salt, fresh water is poured into the well's opening at depth of approximately 1100–1500 m, and a total of 12 caverns (artificial caverns) with a net physical volume of 630,000 m^3 are formed. With the completion of these caverns, about 1 billion m^3 working gas can be stored and; this is adequate to meet the maximum daily capacity of 40 million m^3 of Turkey's gas supply [28].

This study focuses on the hydrogen underground storage site selection problem in Turkey. Most of the strategic decisions regarding site selection involve considering many conflicting factors. For these kinds of decision problems, techniques that take into account all the evaluation factors in the assessment process should be used. To solve such problems, multi-criteria decision making (MCDM) techniques have been developed. MCDM is a decision method that involves selecting the best option from a set of alternatives according to more than one factor depending on the condition of the decision makers [8,29]. Here, we provide an overview of previous underground gas storage work. Iordache et al. [10] conducted an analysis of the potential use of salt caverns for HUS in Romania. Le Duigou et al. [30] investigated economic feasibility of large scale HUS in France. Sáinz-García et al. [18] evaluated feasible strategies for seasonal HUS in a saline aquifer. Some of these studies used multi-criteria for optimum site selection of underground carbon dioxide and natural gas storage [31–34] and only a few of them are based on MCDM [8,35–38]. Although various fuzzy MCDM methods are proposed for site selection problems, to the best of our knowledge, the hydrogen underground storage process has not been applied as an interval type-2 hesitant fuzzy set (HFS) based MCDM problem in the literature.

The aim of this study is to select an optimum location for hydrogen underground storage. In this study, interval type-2 HFS is chosen from among different MCDM techniques for this problem. HFS represent the membership functions of an element with possible values. For this reason, they can be a useful tool to express uncertain information on different group members within MCDM [39]. Therefore, the preferences of decision makers in HUS site selection problem can be better expressed through HFS.

The rest of the study is organized as the following. Section Background gives an extensive literature review about the hydrogen underground storage, fuzzy MCDM and hesitant fuzzy sets. Section Hydrogen Underground Gas Storage presents an overview of underground hydrogen gas storage. The preliminaries and proposed approach explained in Section Preliminaries. Section Case study gives the experimental results and sensitivity analysis. Lastly, the conclusion of this study is presented in Section Conclusion and discussion.

Background

Review of previous research on hydrogen underground storage

The literature regarding hydrogen storage presents many studies, focusing on different aspects of the HUS. Carden and Paterson [12] assessed the physical, chemical and energy aspects of HUS. Although the underground storage of hydrogen seems to be the most promising solution to the problem of large-scale energy storage, researchers are aware