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Screening and ranking framework for underground hydrogen storage site selection in Poland

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ABSTRACT

This paper proposes the use of the Analytic Hierarchy Process (AHP) in order to select the potential underground hydrogen storage sites. The preliminary selection and evaluation of hydrogen storage sites may be considered as a multi-criteria decision-making process. The use of a decision model based on 5 (for aquifers) or 6 geological criteria (in the case of salt and hydrocarbon deposits) has been proposed. A ranking of salt structures, aquifers, and crude oil and natural gas reservoirs, previously identified as the potential hydrogen storage sites in Poland, has been presented. The obtained results have confirmed that the AHP-based approach can be useful for preliminary selection of potential underground hydrogen storage sites. The proposed method enables one to objectively choose the most satisfactory decision, from the point of view of the adopted decision-making criteria, regarding the choice of the best structure.

Introduction

Underground energy storage in the form of heat, compressed air or hydrogen allows it to be stored in various amounts and time intervals [1–6]. Nowadays, energy storage is considered a key element of the energy supply chain. It contributes to improving the stability of energy grids, increasing the share of renewable energies, improving the efficiency of energy systems, fossil fuel resources conservation and reducing the environmental impact of energy generation [2,7,8].

Most analyzes indicate that hydrogen will play an important role in solving technological and ecological problems of energy production and transport. Various methods of hydrogen production and its energy processing are being studied [9–13]. The most promising opportunities are identified as the use of fuel cells for stationary and mobile applications [10,12,14].

The development of hydrogen economy is also focused on using the energy from renewable sources for its production [7,8,15–17]. This will require the development and implementation of new ways of hydrogen storage. Implementation of this technology will allow to regulate the supply and demand for energy and regulate energy prices as well as gas sales to, refineries, transport etc. [18–23]. The use of this technology will also contribute to the decarbonisation of

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energy, which is important in the case of countries such as Poland, which economy is based on coal [24,25].

Geological structures are used in different ways, depending on their depth of deposition and characteristics (e.g. the storage of fuel, natural gas, hazardous or radioactive waste, and, more recently, the storage of carbon dioxide) [26]. From a geological point of view, the underground space is also suitable for the storage of massive amounts of energy in the form of hydrogen [18,23,27,28]. In such a case, the largest possible amount of gas injected to the underground storage facility (artificial accumulation of gas in the subsurface) shall be withdrawn from the storage site without losses due to leakages.

Underground hydrogen storage is increasingly popular, as evidenced by numerous scientific publications. They relate to different aspects, some of which include: the use of underground space for energy storage [2,19,26,29], hydrogen energy storage technologies [7,8,20], technological aspects [23,30–33] and the assessment of the potential and possibilities of large-scale underground hydrogen storage in selected countries [27,28,34,35].

The three basic options (sites) for hydrogen underground storage (HUS) are considered: salt caverns, deep aquifers, and depleted hydrocarbon deposits (crude oil and natural gas) [18,20,34,36,37].

Salt caverns (artificial underground chambers in salt deposits) are suitable for storage of various substances, in particular high pressure gases. These chambers are used worldwide for the storage of natural gas and petroleum products. Salt has physical properties which are suitable for underground hydrogen storage, guaranteeing long-term stability and storage integrity. Salt cavern walls are substantially impermeable to this gas, and the plastic properties of salt protect the cavern against the emergence and spread of cracks and thus the loss of tightness. Hydrogen is already successfully stored in several salt caverns in the United Kingdom and the United States; this technology does not differ significantly from the underground storage of natural gas, practiced on a large scale by the oil companies for about a hundred years, or underground storage of carbon dioxide [18,28].

The aquifers are made of porous and permeable rocks containing the pore water of different mineralization. They are common in all sedimentary basins and can be an alternative to underground storage of hydrogen in the areas where depleted hydrocarbon deposits or salt caverns are not available. They have also been used for many years for natural gas storage.

Natural gas and crude oil reservoirs occur in suitable geological structures, where hydrocarbons are accumulated within the pore spaces between rock grains (e.g. sandstones) or in fractures and fissures (e.g. limestones). Accumulations are sealed with low-permeable, compact and non-fractured rocks. The occurrence in the hydrocarbon deposit confirms the tightness of the geological structure. Depleted oil and gas reservoirs can be used to store hydrogen instead of hydrocarbons. The geological properties of the depleted reservoirs are well known, while the existing production wells and surface equipment can be (at least partially) reused.

Setting the requirements and conditions for choosing the geological structure for the underground hydrogen storage should be based on the detailed geological analysis and reservoir engineering. The most important parameters include: geological structure (depth, area, thickness, tightness, reservoir pressure, reservoir properties - porosity and permeability, geomechanical characteristics of rocks) and the proper characteristics of the overburden rocks. The main criterion that must be met by the hydrogen storage site is geological tightness. In addition, technical, environmental, legal, economic, and other criteria are also of great importance [18,20,38].

Despite the fact that underground gas storage has been used since the beginning of the last century, and years of experience in this field, there are few publications presenting the criteria used when selecting sites for the gas storage. Depleted natural gas reservoirs, which are most often used for underground storage, are selected on the basis of a sufficiently large volume of pore space, tightness, (preferably high) permeability of reservoir rocks, the absence of gas admixtures such as hydrogen sulphide, or the possibility of additional well drilling [39,40]. The situation is much better when it comes to the studies on the selection of sites for underground storage of CO_2; their findings may be useful in identifying similar sites for the storage of hydrogen. This is done based on the geological, reservoir, and technical criteria that must be met by a geological structure in order to be used as a gas storage site, while taking into account the specific properties of carbon dioxide. In the literature, there are no uniform criteria for selection of sites for underground storage of carbon dioxide. In most methodologies, the criteria used when choosing carbon dioxide storage sites include: the depth of reservoir, their thickness, porosity, permeability, water mineralization, and thick, low permeable overburden rocks. These criteria allow for pre-selection of structures not only of adequate capacity but also ensuring the safety of the storage process [41–49]. Some of the methods include additional (technical, environmental, or sociological) criteria [44,49]. Different authors use different (positive, negative, or warning) indicators [41,42,47,48] points (0 – the worst, 1 – the best) [46] or weights [49] assigned to the individual criteria. In a few cases, structuring is based on workflow [43,45]. Some methodologies refer to the assessment and classification of geological structures used for the storage of carbon dioxide and breaking them down by country, sedimentation basin or storage site [45,46]. The latest methodology developed by the National Energy Technology Laboratory in 2017 [44] introduces algorithms for preliminary evaluation, selection, and characterization of geological structures for CO_2 storage according to the CSA Z741 standard (2011). Llamas and Cienfuegos (2012) [50] proposed a different approach to the problems related to the selection of CO_2 storage sites. They propose the use of a multi-criteria decision-making system based on two groups of criteria: technical criteria (geology, tectonics, hydrogeology, capacity, and CO_2 state) and socioeconomic criteria (quality and quantity of geological data, CO_2 sources, location, population density, and environmental aspects). The Analytic Network Process (ANP) method was used to select structures suitable for geological storage of CO_2 in China [51]. A method using fuzzy logic to select carbon dioxide storage sites has also been developed [52].

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