Journal of Natural Gas Science and Engineering 27 (2015) 692–705

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse

Fuzzy multi-criteria decision making for carbon dioxide geological storage in Turkey

Muhammet Deveci [a,*], Nihan Çetin Demirel [a], Robert John [b], Ender Özcan [b]

[a] Department of Industrial Engineering, Faculty of Mechanical Engineering, University of Yildiz Technical, 34349 Yildiz, Istanbul, Turkey
[b] ASAP Research Group, School of Computer Science, University of Nottingham, NG8 1BB Nottingham, UK

ARTICLE INFO

Article history:
Received 9 June 2015
Received in revised form
2 September 2015
Accepted 3 September 2015
Available online 9 September 2015

Keywords:
Location selection
Underground carbon dioxide storage
Fuzzy decision support
Fuzzy TOPSIS
Fuzzy ELECTRE I
Fuzzy VIKOR

ABSTRACT

The problem of choosing the best location for CO_2 storage is a crucial and challenging multi-criteria decision problem for some companies. This study compares the performance of three fuzzy-based multi-criteria decision making (MCDM) methods, including Fuzzy TOPSIS, Fuzzy ELECTRE I and Fuzzy VIKOR for solving the carbon dioxide geological storage location selection problem in Turkey. The results show that MCDM approach is a useful tool for decision makers in the selection of potential sites for CO_2 geological storage.

1. Introduction

According to the IEA World Energy Outlook (WEO) Reference Scenario, CO_2 emission will increase 63% by 2030 from today's level, which is 90% higher than the 1990 CO_2 emission level. This is a global issue. Thus, stronger actions/policies are required and expected from the governments, including generation and utilization of certain technology options (IEA, 2004) to avoid massive CO_2 emission increases. CO_2 capture and storage (CCS) is a successful emission reduction option, which is used for capturing CO_2 generated from fuel use and preventing pollution by storing it. Besides energy supply security benefits, this option has also numerous environmental, economic and social benefits (Blunt, 2010; Liao et al., 2014; Kissinger et al., 2014; IEA, 2004). CCS can make large reductions in greenhouse gas emissions, which involves capturing CO_2 in deep geological formations (Davison, 2007). It is increasingly being considered as a significant greenhouse gas (GHG) mitigation option that allows continuity of the use of fossil fuels and provides time needed for deployment of the renewable energy sources at large scale (Ramirez et al., 2010).

CO_2 can be stored underground in geological formations. Underground depleted reservoirs (depleted oil and gas reservoirs, aquifer reservoirs, salt cavern reservoirs, coal mine and mined cavern) are important types of underground CO_2 storage (Sunjay and Singh, 2010). In some cases, underground storage has a commercial value. For example, the oil and gas companies have used CO_2 extensively for three decades to improve oil recovery. Apart from this, CO_2 can also be used for coal-bed methane recovery (Adams and Davison, 2007). Natural gas reservoirs, due to their proven record of gas production and integrity against gas escape, are obvious candidate sites for carbon sequestration by direct carbon dioxide (CO_2) injection (Sunjay and Singh, 2010). CCS is a method for distilling carbon dioxide and transporting it through pipelines and injecting it into available rock formations to prevent its emission to the atmosphere (Feron and Paterson, 2011; Stasa et al., 2013).

Even with energy efficiency and use of renewable energy resources it is predicted that the dependence on fossil fuels will continue. Despite the fact that in all combustion processes carbon dioxide is an output, it is not possible to get rid of carbon dioxide entirely.

This paper focuses on the CO_2 storage issues in Turkey. Similar to many other countries in the world, the annual increase of CO_2

* Corresponding author.
E-mail addresses: muhammetdeveci@gmail.com, mdeveci@yildiz.edu.tr (M. Deveci), nihan@yildiz.edu.tr (N.Ç. Demirel), robert.john@nottingham.ac.uk (R. John), ender.ozcan@nottingham.ac.uk (E. Özcan).

http://dx.doi.org/10.1016/j.jngse.2015.09.004
1875-5100/

emission in Turkey is quite high. The biggest CO_2 site in this country is in the West Raman area. CO_2 has been transferred through pipelines from the Dodan Area and injected into this site starting from 1985 (Sahin et al., 2012). Most of the real-world strategic decisions require consideration of many conflicting factors. Multi-criteria Decision Making (MCDM) techniques provide the means to solve such problems supporting decision makers with the best option from a set of alternatives with respect to those factors (Alpay, 2010). There are some previous studies proposing a variety of solution methods for finding the optimum location for CO_2 storage (Kissinger et al., 2014; Ramirez et al., 2010; Stasa et al., 2013; Grataloup et al., 2009) and only a few of them are based on MCDM (Hsu et al., 2012; Llamas and Cienfuegos, 2012; Llamas and Camara, 2014).

In this study, we have designed and applied fuzzy-based MCDM approaches, including Fuzzy TOPSIS, Fuzzy ELECTRE I and Fuzzy VIKOR, comparing their performance to decide the best CO_2 storage reservoir in Turkey, which has not been studied before. In fact, this problem can be solved by using any of these three methods, but given the importance of selection of storage location problem, the best alternative is searched by testing many techniques. Furthermore, the elasticity of these methods is also compared to each other.

The rest of the paper is organized as the following. Section 2, provides an overview of the relevant work. Section 3 discusses the location selection criteria for the CO_2 storage and describes the Fuzzy TOPSIS, Fuzzy ELECTRE I and Fuzzy VIKOR methods. Section 4, presents a case study from Turkey and compares the performance of different fuzzy methods applied to this case study. Finally, Section 5 concludes this study.

2. Related work

Although underground CO_2 storage location selection problem is a crucial strategic decision this problem has not been addressed fully by others. On the other hand, there are plenty studies on a variety of facility location problems. Here we provide an overview of previous work. Grataloup et al. (2009) studied on-site selection for CO_2 underground storage in deep saline aquifers. As a case study, the proposed approach was applied to PICOREF, located in Paris Basin, where potential site(s) in deep saline aquifers were investigated. Kissinger et al. (2014) addressed different aspects while considering potential CO_2 storage reservoirs, including safety and economical feasibility of each location. This work is based on the Gravitational Number applied to the North German Basin. Ramirez et al. (2010) presented a methodology to screen and rank Dutch reservoirs suitable for long-term large scale CO_2 storage. The screening was focused on gas, oil and aquifers fields. In total 177 storage reservoirs were taken into consideration (139 gas fields, 4 oil fields and 34 aquifers) from over five hundred suitable locations. The total number of storage reservoirs were reduced by applying preconditions with associated threshold values. Then, linear aggregation was used for deciding on the location. Stasa et al. (2013) investigated into the potential of using principles of Darcy's law and numerical computing for CO_2 capture and storage in Czech Republic.

In recent years, many papers on facility location problems have been published. Many of those previous studies propose multi-criteria decision making (MCDM) techniques as a solution method. Considering that multiple criteria with imperfect and uncertain factors are involved, fuzzy based methods, such as, TOPSIS, VIKOR and ELECTRE I, (Zadeh, 1965) are commonly utilized as approaches to such MCDM problems. An overview of previous work on relevant MCDM studies is provided in Table 1, which covers the MCDM solution methods, particularly focusing on analytic hierarchy/network process, fuzzy ELCTRE I, Fuzzy TOPSIS and Fuzzy VIKOR, applied to given location selection problems. Hsu et al. (2012) presented an analytic network process (ANP) approach for the selection of potential sites for CO_2 geological storage. The results obtained in this study have proven that ANP-based approach is a useful tool in pre-screening potential sites for CO_2 geological storage. Llamas and Cienfuegos (2012) described a methodology for the selection of site areas or structures for CO_2 geological storage based on an analytic hierarchy process (AHP). Ertugrul and Karakasoglu (2008) compared the fuzzy TOPSIS and fuzzy AHP methods for facility location selection. The proposed methods were applied to a facility location selection problem of a textile company in Turkey. The authors illustrated the similarities and differences of two methods. Demirel et al. (2010) proposed Choquet integral for multi-criteria warehouse location selection. This study provides a successful application of multi-criteria Choquet integral to a real warehouse location selection problem for a large Turkish logistics firm. Kahraman et al. (2003) studied four different fuzzy multi-attribute group decision-making approaches, including fuzzy modeling of group decisions and fuzzy analytic hierarchy process. Although four approaches have the same objective of selecting the best facility location, each has a different theoretic basis and relate differently to the discipline of multi-attribute group decision-making. Opricovic (2011) presented a fuzzy VIKOR approach for a dam (water resources) location selection, providing a conceptual and operational validation of the approach on a real-world problem. Ozdagoglu (2011) proposed a fuzzy ANP approach to overcome the problem of facility location selection. Chou et al. (2008) integrated fuzzy set theory, factor rating system and simple additive weighting into fuzzy simple additive weighting system to select the facility locations. Zandi and Roghanian (2013) extended Fuzzy ELECTRE based on VIKOR method. The purpose of this paper is to extend ELECTRE I method based on VIKOR to rank a set of alternatives versus a set of criteria to show the decision maker's preferences. Chu (2002) presented a fuzzy TOPSIS model was developed in which ratings and weights of each alternative location can be aggregated by interval arithmetic and α-cuts of fuzzy numbers. Ulukan and Kop (2009) used fuzzy TOPSIS method in a two step procedure. Firstly, candidate locations were defined by a trapezoidal membership function. Then, this trapezoidal numbers embedded into criteria and alternatives in TOPSIS. Finally, suitable facility location selected for the medical waste disposal company, able to handle the fuzziness of the real world. Tre et al. (2011) considered elementary Logic Scoring of Preference (LSP) suitability map criteria for evaluating a distribution of points of interests (POIs) in a geographical region.

3. Methodology

The proposed methodology consists of three basic stages: (1) Identification of the criteria, alternatives and linguistic variables to be used in the model (2) Analysis of methods using these selected criteria, alternatives and linguistic variables (3) Ranking the alternatives using fuzzy TOPSIS, fuzzy VIKOR, and fuzzy ELECTRE I. The schematic diagram of the proposed methodology for the selection of CO_2 storage location is shown in Fig. 1. The stages are as follows:

Stage 1: Form the fuzzy model using selected criteria, location alternatives and a team of decision makers. Also fuzzy weights of each criterion and alternative are computed.
Stage 2: Analyze different alternatives based on the relevant algorithmic framework.
Stage 3: Rank each alternative based on the outcome from Stage 2.