A Sustainable Approach for the Site Selection of CO_2 Underground Storage.
Application of Fuzzy-Delphi Methodology

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A B S T R A C T

In recent decades, the pace of industrialization has caused an number of environmental problems. A considerable increase in the global energy demand is one of the most important problems in today's world. In fact, fossil fuels are the main source of energy triggering the release of huge amounts of greenhouse gases into the atmosphere. Many efforts have been made by researchers to come up with different strategies to mitigate the global consequences of greenhouse gas emissions such as global warming. One of these strategies is to reduce the amount of greenhouse gas emited into the atmosphere. This study aims to select the appropriate sites for carbon dioxide underground storage facilities. The selection of the best sites for CO_2 underground storage is very important from various perspectives of sustainable development to accelerate the commercialization of such facilities. In this regard, fuzzy-Delphi methodology was used to prioritize the most important criteria in the CO_2 storage process. Nineteen sub-criteria were selected in the technical, health, safety and environmental (HSE), economic and social categories. Specialist questionnaires were prepared, considering all relevant scientific and technical aspects, and experts in the field were invited to participate in the survey. The results were analyzed using SPSS 25.0. According to results, Geology and Lithology, Caprock Permeability, Social Acceptance, Depth, Reservoir Permeability, and Porosity were determined as the highest priorities. Based on the results achieved, it can be concluded that technical criteria are of the highest importance in the site selection of underground carbon dioxide site selection facilities.

1. INTRODUCTION

Rapid industrialization occurred in the 19th century and the reliance on fossil fuels for the revolution in all aspects of human life has resulted in the release of a considerable amount of greenhouse gases into the atmosphere, especially in recent years (Civile et al., 2013; Lothe et al., 2014; Ngoy et al., 2014). Consequences of greenhouse gas release, such as global warming and climate change (Abbasi et al., 2012;

Houghton, 2011) have raised serious concerns among both scientific community and the general public (Zandi et al., 2019). Amongst greenhouse gases, CO_2 is known to play a major role in deteriorating the global climate (Abdulmunem et al., 2017). By analyzing the recorded concentration of atmospheric CO_2, it was revealed that it has increased from 280 to 380 ppm from the pre-industrial period to 2005 (Neele et al., 2013). There is a common consensus in all climatic model predictions upon the direct consequences of CO2 in triggering significant factors leading to global warming in the current decade (Neele et al., 2013).

Recent attempts have proposed the possibility to combine underground coal gasification with CO_2 capture and storage (CCS) to effectively reduce CO_2 in the upcoming decade (Kempka et al., 2011; Roddy and Younger, 2010) and to prepare a sustainable framework to transit from fossil fuel energy to renewable sources (Neele et al., 2013). Transferring the emitted CO_2 in stable geological formations is one of the suggestions found recently in several researches (Davarazar et al., 2019). In other words, underground storage of carbon dioxide (CO_2) by trapping it in natural underground reservoirs (Herzog, 2015) is a widespread solution that can be combined to reduce CO_2 emissions resulted from power generation, large industrial plants and other economic activities. The proposed solution can be considered to reduce the CO_2 emissions not only in the short term, but also as a climate mitigation technique, demanded to bridge towards a renewable energy world in 2050 (Neele et al., 2013).

A correct selection of storage sites combined with careful injection of CO_2 could assure the consistency of underground storage in the long term, as in several investigations it has been reported that almost 99% of the injected CO2 should be retained for a millennium (Herzog, 2015). While there are two different strategies to capture and accumulate CO_2, only natural sources are studied in this research. By taking a brief look at the Earth subsurface, it can be understood that the largest carbon reservoir is still underground in the form of coal, oil, gas, organic-rich shales and carbonate rocks (Davarazar et al., 2019). Therefore, natural accumulation storage can be listed as depleted oil and gas reservoirs, possibly coal formations, and particularly saline formations. Hopefully, studies have proven that the overall capacity of deep geological formations seems to be enough to store CO_2 emissions permanently for several decades (Neele et al., 2013). For instance, depleted oil and gas reservoirs are estimated to provide almost 675–900 Gt CO_2 to be stored, while deep saline formations can have a storage volume of more than 1,000 Gt CO_2 (Herzog, 2015).

The consideration of the substantial possible capacity of storage to store CO_2 for an extended period is not risk-free. There are some disadvantages when

practical applications are intended. First, the cost of geological storage of CO_2 depends directly on factors including the depth of the storage formation, the number of required wells, and also the location of the site (onshore or offshore) (Anderson, 2017). Second, there are definite risks not only to the ecosystem, but also to inhabitants near the storage site, namely probable leakage from the injection wells, abandoned wells, and through fractions and faults (Kim et al., 2018). Leakage of CO_2 has been known to impose severe damage to other available hydrocarbon or mineral resources, degrading underground water, and having lethal effects both on plants and the sub-soil ecosystem (Birkholzer, 2008). Moreover, the released CO_2 into the atmosphere can trigger health issues for the local communities (Herzog, 2015).

Therefore, site selection is a fundamental step to guarantee a safe and secure CO_2 storage operation (Bachu, 2000) as well as to avoid negative impact and further consequences of any leakage. Unlike depleted oil or gas fields, potential aquifer sites must be identified from raw geological data before any possible ranking. Hence, the application of appropriate methods to select proper sites in a systematic way for underground carbon dioxide storage facilities is highly demanded (Neele et al., 2013).

Multi-criteria decision-making (MCDM) systems are among the widely applied methods, through which we are able to consider various parameters when analyzing a problem systematically (Jahanshahi et al., 2019; Kamali et al., 2015; Kamali et al., 2019).

The analytic hierarchy process (AHP) is mostly used to organize a thorough analysis and it is a structured technique to make decisions mathematically. It uses the concept of divide and conquer in which the decision problem is decomposed into a hierarchy of sub-problems that are independent and easily comprehended. Briefly, AHP employs principles for decision-making to analyze, compare and finally combine pairs of consecutive values priorities of the alternatives. Also, an AHP based on fuzzy scales is proposed to determine the importance weights of customer requirements (Saaty, 2008). Instead, Delphi is used to reach decisions from a structured group of individuals, who are more accurate than the unstructured groups. The Delphi method has been originally developed to be a systematic and interactive forecasting method relying on a panel of experts. Via at least two rounds, experts answer questionnaires, while after each round a facilitator provides an anonymous summary of the experts' forecasts from the previous round and justifies their judgments. This technique encourages experts to revise their responses in the direction of the replies of the other panel members. Being widely used in several fields such as business

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forecasting, it is one of the reasons that the Delphi method has been evaluated to have certain advantages for fields such as environmental agents (Wissema, 1982).

In this regard, this research proposes to employ Delphi methodology, to develop a framework based on consensus among experts in the field on the relative value of the relevant parameters of a specific topic. This method has been previously used to determine the relative importance of the involved parameters in various fields (Kamali et al., 2017).

In this study, sustainability criteria were assigned to four main areas (technical, economic, health, safety and environment (HSE) and social), whilst the sub-criteria were identified following previous studies. A specialist questionnaire was prepared and sent to experts.

Then, the suitable sites for the establishment of carbon dioxide storage facilities were selected. Moreover, the most important parameters to be further used in this selection were identified. For analyzing the survey results, the Delphi methodology was used to identify and prioritize the most important parameters involved in the selection of the most suitable sites for accomplishing the objective of the investigation.

2. LITERATURE REVIEW

The concept of sustainability has led to various definitions and understandings for many decades (Ghadimi et al., 2016; Mapar et al., 2017). This concept was first explored at regional and national levels, but more recently, it has been also highlighted at the local level. In 1972, the concept of sustainable development emerged for the first time in the work of Meadows et al (1973) as a concern for the future of the Earth (McGinnis, 1973). Recently, it has been revisited into the list of the seven goals of sustainable development in 2030, to reduce anthropogenic CO₂ emissions and climate change consequences (United Nations, 2015). According to the main criteria of sustainability, the sustainable selection of storage sites can assure the consistency of underground storage of CO₂ for a long time (Nemati et al. 2020).

Some studies have indicated the necessity of considering the technical dimensions of sustainability as a new approach to sustainable development trends, as they are listed in Table 1. It seems that the main reason for subjoining these new dimensions is related to the importance of finding an approach for the site selection of underground CO₂ (Kamali et al., 2019). However, there is no clear understanding of how sustainability domains can be associated with the issue, and the way they can affect the urban communities as well as industrial areas. Studies on both site selection and site evaluation criteria have highlighted that the main aspects to be analyzed should be geological, geothermal, geo-hazards, hydrodynamic, hydrocarbon potential and basin maturity, economic, societal, and environmental (Bachu, 2000, 2002; Kim et al., 2014). The technical dimension of sustainability is associated to the site selection of underground CO₂ focusing on sustainability indicators for biobased chemicals.

The Delphi method is reliable and practical and it has been successfully employed in various projects, such as the study of Van Schoubroeck et al. (2019) on the sustainability of biobased chemicals, or the analysis of Ocampo et al. (2018) on sustainable ecotourism indicators. Also, in another project, the Delphi Expert Process of the German Umbrella Project (AUGE) analysed the status of CO₂ storage in Germany and gave recommendations to the review process of the German CO₂ storage legislation (Pilz et al., 2016). To these we add, linking public acceptance with expert knowledge on CO2 storage: outcomes of a Delphi approach (Wassermann et al., 2011), the sustainability of treatment technologies for industrial bio-wastes effluent (Kamali et al., 2019; Li et al., 2018) and application of the Delphi method to the forecasting of long-term trends in road freight, logistics and related CO2 emissions (Piecyk and McKinnon, 2013), which are some of the successful projects that used the Delphi method.

3. METHODOLOGY

3.1. Identification of criteria and sub-criteria

In this study, four criteria were identified as a result of literature screening for the site selection of underground CO₂ storage facilities using the Fuzzy-Delphi methodology. These criteria include technical, economy, health, safety, environment (HSE) and social sections.

A questionnaire (supplementary information) was designed based on the discussed criteria and it was subsequently carried out to collect the opinions of an expert group with both academic and practical experience in the field of construction, sustainability, health, safety, and environment. A total of 14 responses were received and analyzed to achieve the results of this study (Table 1).

3.2. Fuzzy-Delphi Methodology

The Delphi technique is a frequent method applied to achieve consensus of the experts' opinions on a particular topic (Singh and Sarkar, 2019). In this method, experts share their knowledge, skills, and expertise to reach mutual consensus (Yap et al., 2019). Regarding the subject, the number of experts can be different, but more than five should be considered. In the Delphi method, experts are selected to conduct the first round of a survey.

Table 1. Identified criteria and sub-criteria for the site selection of the CO_2 underground storage facilities extracted from the specialist literature.

Criteria	Sub-Criteria	Definition/ Description	References
Technical	Geology and lithology	The suitability of local rocks for constructing a carbon dioxide storage facility interms of structure and technical specifications	(Deveci, 2018; Llamas and Cámara, 2014; Simon et al., 2015)
	Depth	The depth is required for the carbon dioxide storage facility.	(Deveci, 2018; Lewandowska-Śmierzchalska et al., 2018)
	Area	As an indicator to calculate the carbon dioxide storage capacity, required or available in the geological field	(Deveci et al., 2015; Lewandowska-Śmierzchalska et al., 2018)
	Thickness	Defining the thickness of the reservoir required for carbon dioxide storage	(Deveci, 2018; Deveci et al., 2015; Lewandowska-Śmierzchalska et al., 2018)
	Caprock thickness	Defining the necessity of having caprocks with sufficient thickness for the safe storage of carbon dioxide	(Chadwick et al., 2008; Hsu et al., 2012; Llamas and Cámara, 2014)
	Caprock permeability	Defining the sealing properties capacity of a caprock, which enables successful sealing of the reservoirs	(Chadwick et al., 2008; Hsu et al., 2012; Llamas and Cámara, 2014)
	Reservoir permeability and porosity	Defining the porosity of the reservoir, which reflects the potential volume available for carbon dioxide storage	(Deveci, 2018; Deveci et al., 2015; Lewandowska-Śmierzchalska et al., 2018)
	Storage capacity	Defining total the capacity required for a carbon dioxide storage reservoir	(Deveci, 2018; Hsu et al., 2012; Llamas and Cámara, 2014; Lord, et al., 2014; Reitenbach et al., 2015)
	Distance to CO2 sources	The distance to the carbon dioxide sources	(Llamas and Cámara, 2014)
Economics	Labor	Describing the costs attributed to the human resources required for the operation of carbon dioxide storage facility	(Deveci et al., 2015)
	Proximity to suppliers & resources	Defining the distance to roads, power lines, and accessibility of raw materials	(Deveci et al., 2015)
	Infrastructure availability	Defining the technological availability in terms of the basic infrastructures in the area	(Deveci et al., 2015)
	Storage cost	Defining the total costs of carbon dioxide storage in terms of capturing, transportation, injection, and storage	(Deveci, 2018; Deveci et al., 2015; Hsu et al., 2012)
	Initial investment	The initial investment is required to construct an underground carbon dioxide storage.	(Deveci, 2018; Deveci et al., 2015)
Health, safety and Environment (HSE)	Regional risks	Describingthe potential risks in the region such as earthquake risk, natural risk, etc.	(Deveci, 2018; Deveci et al., 2015; Llamas and Cámara, 2014)
	Legal restrictions	Defining the applicable environmental legislation such as the required distance to protected areas, as well as the applicable occupational health and safety legislation	(Deveci et al., 2015; Llamas and Cámara, 2014)
Social	Social acceptance	Describingthe overall perception of the local communities for the construction of a carbon dioxide storage facility	(Deveci et al., 2015)
	Job creation	The positive effects of the carbon dioxide storage facility on the local communities in terms of new job opportunities created by the construction and operation of the facility	(Jahanshahi et al., 2019)
	Local culture	Describing the local cultural specific features that may need special protection	(Llamas and Cámara, 2014)

Then, according to the gained results, the second round of a survey will be conducted. Finally, the experts' opinions will be integrated to reach consensus.

This procedure will be repeated until consensus on a topic is reached. This method requiresat least 5 respondents (Nemati et al., 2020).

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In this study, we utilized experts' opinions in the field of site selection of the underground CO_2 storage to rank the specific criteria. For this purpose, a questionnaire was designed based on 4 main criteria and 19 sub-criteria that were identified by screening the specialist literature.

The sub-criteria in the technical part includes geology and lithology, depth, area, thickness, caprock thickness, caprock permeability, reservoir permeability and porosity, storage capacity and distance to CO_2 sources. Five sub-criteria relevant to economy were also selected, namely labour, proximity to suppliers and resources, infrastructure availability, storage cost, initial investment.

Regional risks and legal restrictions are defined as sub-criteria of health, safety, and environment. Regarding the social criteria, three sub-criteria were selected, namely social acceptance, job creation, and local culture.

Moreover, experts ranked them from the least to the most significant and then the criteria and sub-criteria were categorized according to their impact on the CO_2 site selection. On the other hand, as a type of fuzzy numbers, a triangular fuzzy number must possess at least the following three properties to qualify as a fuzzy number: A= (a1, a2, a3).

The membership functions that can be used to interpret this representation hold the following conditions (Gani et al., 2012).

$$y = m(x) = \begin{cases} 0 & x < a_1 \\ \frac{x-a_1}{a_2-a_1} & a_1 \leq x \leq a_2 \\ \frac{a_3-x}{a_3-a_2} & a_2 \leq x \leq a_3 \\ 0 & x > a_3 \end{cases}$$

$$(1)$$

All criteria were fuzzed using equation (1), and, according to Table 2, the de-fuzzed numbers were used to rank the criteria. To elaborate the questionnaire, a fuzzy scale containing seven linguistic variables, and the respective triangular fuzzy numbers were used.

Equation (2) was used to compute the fuzzy gravity of criteria, where L, M, and U expressed the fuzzy number ingredients. Equation (3) was also used to defuzzy the values.

$$L_j = Min_i(L_{ij}) \quad M_j = \frac{1}{n}\sum_{i=1}^{n} M_{ij} \quad U_j = Max_i(U_{ij})$$

$$(2)$$

$$df = \frac{1}{4}(L + 2M + U)$$

$$(3)$$

According to the fuzzy scale shown in Table 2, experts were asked to determine the weight of each of the proposed sub-criteria. The average outputs were

achieved by extracting the results of the first round. They were sent to the panel of experts to reach consensus in the second round. The results of the second round were interpreted to represent the most crucial sub-criteria for selecting the most suitable sites for setting up the underground CO_2 storage facilities.

Table 2. Linguistic variables and the relevant fuzzy scales used to rank the criteria for the site selection of CO_2 underground storage.

Linguistic variable	Fuzzy Scale (L, M, U)	df = ¼ (L+2M+U)
Extremely High	(0.9,1.0,1.0)	0.975
Very High	(0.7,0.9,1.0)	0.875
High	(0.5,0.7,0.9)	0.7
Fair	(0.3,0.5,0.7)	0.5
Low	(0.1,0.3,0.5)	0.3
Very Low	(0.0,0.1,0.3)	0.125
Extremely Low	(0.0,0.0,0.1)	0.025

3.3. Data analysis

The obtained data were analyzed using SPSS (25.0) software. The numbers that were processed in SPSS software, were de-fuzzed based on the responses of the expert panel. The descriptive-analytic method was used to analyze the output. Cronbach's alpha was used to examine the internal consistency of the answers provided by experts. Cronbach's alpha (α) is commonly used to analyze the internal consistency or reliability of summated rating scales (Sijtsma, 2016).

To identify the coefficient of responses, they were examined. Finally, the gained coefficient is between 0 and 1. If the coefficient value is closer to 1, it means that the response is more reliable (Trizano-Hermosilla and Alvarado, 2016). If the Cronbach's alpha coefficient is greater than 0.7, it means that the questionnaire can be accounted for being reliable for further analysis (Bland and Altman, 1997).

The Kolmogorov-Smirnov (KS) test is a standard, fast, and general-purpose tool for nonparametric hypothesis testing. This method is used to examine and analyze the non-matching responses and to check whether parameters are parametric (Sadhanala et al. 2019).

Moreover, to examine the responses more precisely, the Shapiro-Wilk test is conducted to figure out the distribution of the data, whether there are normally distributed or not (it should be noted that the sample size was less than 2000) (Razali and Yap, 2011).

According to the results obtained in the previous section, the data in this study were non-parametric. In this study, the Kruskal-Wallis test was used to verify the uniformity of the perceptions of the respondents. In this test, if the score is greater than 0.05, it can be concluded that perceptions of the respondents are similar (Theodorsson-Norheim, 1986).

4. RESULTS

Table 3 and Figure 1 clarify the final ranking of the criteria and sub-criteria based on the opinions of experts.The questionnaire, which was sent and completed in two steps, presented the main sustainability criteria in four sections (technical, economics, health, safety and environment (HSE) and social). According to experts, the first rank was assigned to geology and lithology (in the technical section), and the second and third ranks were assigned to caprock permeability (in the technical section) and social acceptance (in the social section).

The ranking of other sub-criteria is also visible in Table 3 and Figure 1.

Table 3. Linguistic variables and the relevant fuzzy scales employed to rank the criteria used for the site selection of CO_2 underground storage.

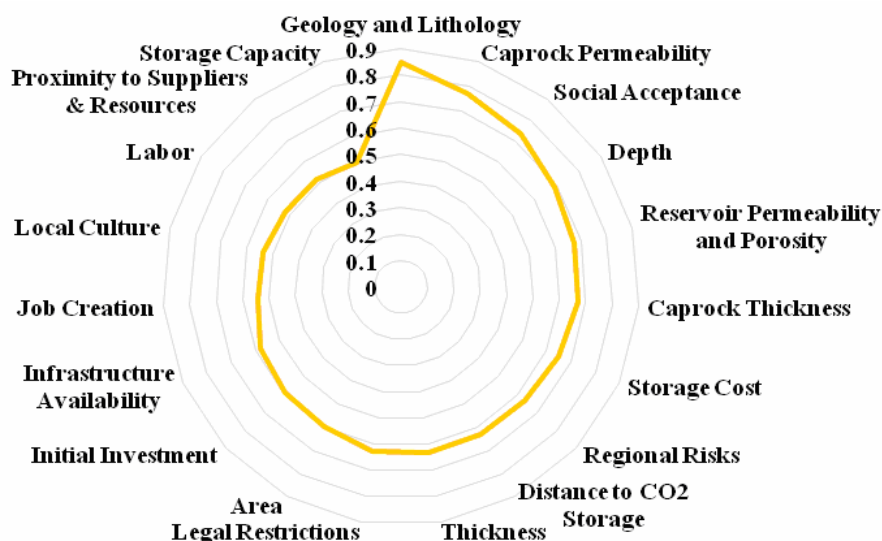| Rating	Criteria	Sub-Criteria	Fuzzy Scale (L, M, U)	df = ¼ (L+2M+U)
1	Technical	Geology and lithology	(0.5,0.95,1.0)	0.850
2	Technical	Caprock permeability	(0.3,0.90,1.0)	0.775
3	Social	Social acceptance	(0.3,0.82,1.0)	0.736
4	Technical	Depth	(0.3,0.74,1.0)	0.693
5	Technical	Reservoir permeability and porosity	(0.1,0.80,1.0)	0.675
6	Technical	Caprock thickness	(0.1,0.79,1.0)	0.671
7	Economics	Storage cost	(0.0,0.80,1.0)	0.650
8	HSE	Regional risks	(0.1,0.73,1.0)	0.639
9	Technical	Distance to CO_2 storage	(0.1,0.72,1.0)	0.637
10	Technical	Thickness	(0.1,0.71,1.0)	0.636
11	HSE	Legal restrictions	(0.0,0.76,1.0)	0.632
12	Technical	Area	(0.1,0.65,1.0)	0.602
13	Economics	Initial investment	(0.0,0.69,1.0)	0.593
14	Economics	Infrastructure availability	(0.0,0.65,1.0)	0.575
15	Social	Job creation	(0.0,0.58,1.0)	0.539
16	Social	Local culture	(0.0,0.57,1.0)	0.536
17	Economics	Labor	(0.0,0.54,1.0)	0.521
18	Economics	Proximity to suppliers & resources	(0.0,0.53,1.0)	0.518
19	Technical	Storage capacity	(0.3,0.50,0.7)	0.500

Fig. 1. Final ranking of the sub-criteria for the site selection of CO_2 underground storage.

4.1. Questionnaire analysis

Cronbach's alpha (α) was measured by using SPSS software to assess the consistency-reliability of the responses. The obtained coefficient was 0.916. Cronbach's alpha value of ≥0.7 is considered satisfactory, as reported in Table 4 (Bland and Altman, 1997).

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Table 4. Case processing summary(SPSS 25.0 software).

Analysis		N	%	No of items	Cronbach's Alpha
Cases	Valid	14	100	19	
	Excluded	0	0	0	
	Total	14	100	19	0.916

Table 5 reports the results of Kolmogorov-Smirnov and Shapiro-Wilk tests that were used to perform parametric and nonparametric analyses of output responses. Given that all outputs were less than 0.05, the responses are normalized and non-parametric.

Table 5. Test of normality (SPSS 25.0 software).

Criteria	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	df	Sig.
CR1	0.370	14	0.000	0.000	14	0.006
CR2	0.217	14	0.007	0.050	14	0.008
CR3	0.211	14	0.009	0.296	14	0.009
CR4	0.226	14	0.005	0.090	14	0.008
CR5	0.261	14	0.010	0.019	14	0.008
CR6	0.346	14	0.000	0.000	14	0.007
CR7	0.230	14	0.044	0.010	14	0.008
CR8	0.274	14	0.006	0.022	14	0.008
CR9	0.342	14	0.000	0.007	14	0.008
CR10	0.209	14	0.008	0.190	14	0.009
CR11	0.195	14	0.006	0.458	14	0.009
CR12	0.230	14	0.044	0.121	14	0.009
CR13	0.351	14	0.000	0.000	14	0.007
CR14	0.175	14	0.020	0.119	14	0.009
CR15	0.206	14	0.019	0.148	14	0.009
CR16	0.325	14	0.000	0.003	14	0.007
CR17	0.256	14	0.013	0.039	14	0.008
CR18	0.202	14	0.012	0.481	14	0.009
CR19	0.200	14	0.013	0.387	14	0.009

The Kolmogorov-Smirnov and Shapiro-Wilk tests clarified that responses were non-parametric. Regarding the non-parametricity of the answers, the uniformity in the perception of respondents to the questionnaire was analyzed by using the Kruskal-Wallis test. In this test, the output number should be higher than 0.05, meaning that the respondents' perception of the criteria is the same.

The value of the calculated coefficient was 0.448, which shows that all respondents have a similar understanding of the questionnaire. This test is usually used to compare the relevance of two or more groups of samples. The hypotheses of this test are based on a statistical comparison of the existence or non-existence of differences between groups and based on responses. If the program output for this test were less than 0.05, there would be a meaningful difference between the respondents' perceptions regarding the questions and criteria.

Table 6. Kruskal-Wallis Final Test (SPSS 25.0 software).

Test Statistics	Answer
Df	14
Asymp. Sig.	0.448

5. DISCUSSION

Environmental protection is a major concern in nowadays world, trigerring various studies to be carried out to avoid further damage to the environment. Moving towards sustainable development is one of the best solutions proposed to control and reduce environmental hazards. In this study, four aspects of sustainable development were considered, which are notable in comparison with previous studies without consideration of the technical section (Kamali et al. 2019). According to the final results, it was found that the technical dimension is the most important criterion

in this field. It is noteworthy that, after many years of researchers' acceptance of sustainable development and various aspects of sustainability, greenhouse gas emissions have increased. The pace of industrialization worldwide has impacted the climate severly. In his recent research on this subject, Kamali (2020) believes that the technical sector is a requirement of sustainable development, of which further ignorance will lead to more discards of the important and influential benchmarks (Kamali, 2020).

Based on the results, the most important criteria were assigned to the technical section, which means that the technical aspect of sustainability is able to play a prominent role in this area. Due to its paramount role, the top 4 rankings out of the top 5 rankings were related to the technical dimension. It clarifies the fact that in the future studies, the technical side should be highly considered by researchers. Moreover, geology and lithology are the top prority and although lithology is a scientific field, and considered as a separate branch of geology, covering characteristics, configuration and evolution of rocks and landforms, they are considered important when deciding the site selection for underground storage of CO_2. It can be said that there is a need for more research and exploration and it can be a considerable research topic in future. Regardless of the technical side, social acceptance as a social dimension is another major factor for site selection, which should be considered as well. It means that scientists have to consider social acceptance for this type of researches.

6. CONCLUSION

The main purpose of this study was to identify the most critical criteria for the site selection of carbon dioxide underground storage. To prioritize the criteria, a professional questionnaire was sent to experts in two steps, and Delphi fuzzy method was used to analyze the final questionnaire and prioritize it. The results showed that geology and lithology were the most essential sub-criteria, along with caprock permeability, social acceptance, depth, and reservoir permeability. Porosity was scored next in the order of priorities and storage cost in the economic section, whilst regional risks in the HSE were also the most important and effective sub-criteria in other sectors of sustainable development.

The technical criteria were more emphasized. It is noteworthy that the technical sector in the field of sustainable development is less considered. Therefore, given the importance of this sector, further studies with emphasis on technical issues are needed. On the other hand, according to results, geology and lithology, caprock permeability, social acceptance, depth, reservoir permeability, and porosity recieved the highest priorities, which means, further studies are

needed to thoroughly conclude their influence and rank in making decisions on the site selection of CO2 storage facilities.

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