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Multi-Criteria Analysis for the Use of Carbon Dioxide Generated In the Gas Plant

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Abstract: CO_2 plays the most important role in pollution due to greenhouse gases, which causes global warming and climate change. Unfortunately, CO_2 emission has increased significantly in recent decades. So, it is crucial to capture CO_2. On the other hand, CO_2 can be utilized for commercial products. There is plenty of CO_2 utilization such as enhanced oil recovery (EOR), producing methanol, salicylic acid, urea, and so on. This paper tries to consider the applications of CO_2 emitted from ethane treatment units of the Asalouyeh gas processing plant. But selecting the best application is a complex issue. A multi-criteria decision-making method, fuzzy TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution), considering economic, technical, and environmental aspects have been used to find the best application for CO_2 utilization. Considering 10 criteria and comparing options with sensitivity analysis in 32 different modes, the results show that methanol production is often the best option and salicylic acid production is the worst option. It should be noted that the increase in the harvest with a very close distance in the majority of cases is the second priority.

keywords: Ethylene Epoxidation, Ethylene Oxide, Rhenium, Silver, Strontium Titanate

1. Introduction

Increasing the emissions of greenhouse gases is the consequence of anthropogenic activities over the past decades. CO_2 is one of the most important constituents of greenhouse gas emissions. CO_2 emission in 2014 is about 41% higher than that in the mid-1800s. (Olivier, Peters, and Janssens-Maenhout 2012) Because CO_2 absorbs some of the infrared radiation from the sun, the effect of increasing CO_2 emission is global warming that is a severe challenge to the global environment and can cause tremendous changes to the global climate (Styring, Quadrelli, and Armstrong 2014). It shows that extra effort is needed to mitigate CO_2 emissions.

To remove CO_2 from the atmosphere at the first step the main resources of CO_2 should be identified (such as oil refineries, chemicals sectors, cement and iron industry, etc.) The next step is the process of CO_2 capturing. This separated CO_2 can be stored or can be utilized.

The difference between carbon capture and storage (CCS) and carbon capture and utilization (CCU) is in the final destination of the captured CO_2. In Fig1 the difference between CCS and CCU has been shown (Cuéllar-Franca and Azapagic 2015).

Carbon capture and storage (CCS) as mentioned above, is defined as the process of capturing CO_2 from an industrial source (such as a power plant) then transfer it into storage (McCoy 2014).

Deveci et al. used fuzzy-based multi-criteria decision making (MCDM) methods that one may find the best CO_2 geological storage location in Turkey. They considered three fuzzy-based MCDM consisting of fuzzy TOPSIS, fuzzy ELECTRE I and fuzzy VIKOR, and compared them with each other. They concluded, MCDM methods are suitable tools for selecting the best CO_2 storage (Deveci et al. 2015). Eshraghi et al. considered injecting CO_2 to storage and using CO2 to enhance oil recovery (EOR) simultaneously. They optimized CO_2 storage and EOR with multi

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objectives optimization methods (Eshraghi, Rasaei, and Zendehboudi 2016).

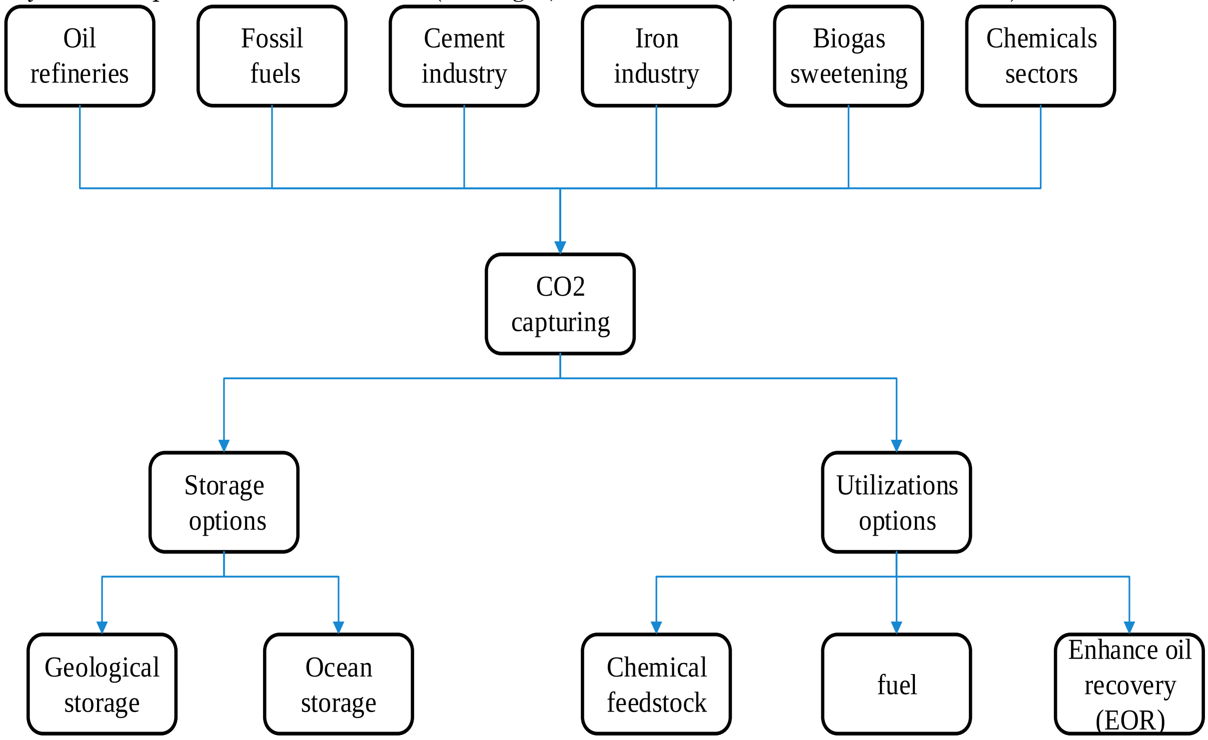

Figure 1. The difference between CCS and CCU

Although CCS can release CO_2 from the atmosphere, research in recent years has shown that CCS has significant problems. The investment cost of capturing CO_2 is high, its operating cost is highly variable, uncertainty for the resistance of the storage is the other drawback, and many countries do not have adequate storage capacity for storing CO_2 or just they have the potential of offshore storage, for offshore storage, transportation cost will be higher (Styring, Quadrelli, and Armstrong 2014). Carbon capture and utilization (CCU) has been offered as a suitable surrogate for CCS. Cullar et al. considered the technologies to release carbon dioxide emitted by power plant counting: carbon capture and storage (CCS) and carbon capture and utilization (CCU) and compared them with life cycle environmental impacts (Cuéllar-Franca and Azapagic 2015). Barzaglic et al. considered CO_2 application as a feedstock to produce urea (Barzagli, Mani, and Peruzzini 2016). Ganesh represented Fundamental challenges and opportunities of converting CO_2 into methanol (Ganesh 2014).

Aresta et al. introduced several applications of using CO_2 and also represented barriers to a large scale conversion of CO_2 then they considered technologies that can make the conversion of CO_2 into fuels be accepted technically and economically (Aresta, Dibenedetto, and Angelini 2013). There is some research about the carbon capture and liquefaction in power plants (Mehrpooya and Ghorbani 2018; Ghorbani, Mehrpooya, and Omid 2020; Shirmohammadi, Soltanieh, and Romeo 2018). The main research in this field has focused on energy and exergy and thermoeconomic analysis. Also, researches have been done in the field of process optimization in gas refineries (Ghorbani et al. 2018). The carbon utilization has been investigated in some processes and costs incurred (Rubin, Davison, and Herzog 2015). (Voldsund et al. 2019; Gardarsdottir et al. 2019) compares different carbon-capturing technologies. Technical and economic analysis of CO2 capturing and utilization has also been performed in the reference (A. W. Zimmermann et al. 2020). This study also provides a structure to model the Life Cycle Cost. The use of CO2 in Europe reviewed in the work of (Patricio et al. 2017). In order to express the potential of European countries in Carbon Capture and Utilization, they are divided into three categories, the most potential of which are the first category and the countries of Germany, England, and France. Analysis of the Life cycle of conversion and storage technologies and the use of CO_2 in work and (Cuéllar-Franca and Azapagic 2015) have been observed.

As mentioned above, it is possible to utilize CO_2 for effective applications. Because of the effect of different factors, electing the best application for CO_2 utilization is a complex issue and needs systematic decision making. This paper has been tried to find the best case for utilizing CO_2 emitted from ethane treatment units of the Asalouyeh gas processing plant by the use of a multi-criteria decision-making method.

2. Fuzzy-Sets Methodology

When there is more than one objective or criteria, multi-criteria decision making (MCDM) methods will be necessary. Usually; there are conflicting objectives. This means that the final decision depends on the decision-maker. Also, there is a certain uncertainty in the data set used by decision-makers. For a data set that is incomplete or uncertain, fuzzy-sets are recommended. Fuzzy-set theory that was introduced by Lotfi Zadeh 50 years ago allows approximate rezoning in such circumstances (Zadeh 1965). Fuzzy-set theory has been used in different fields since then. Fuzzy logic is useful for the representation of imprecise or uncertain information and also processing that information with fuzzy rules and tools (Kaufmann and Gupta 1991).

In many life statuses that are real, frequently the decision that formulated by decision-maker are determined by vagueness. So numerical values cannot describe the performance that is accepted. The lingual variable has been suggested for this situation especially for the criteria that are not well determined and it is easier to determine it as qualitative variables intuitively. In other words, the fuzzy set theory is a useful tool for defining quantitative criteria (Cavallaro 2010; H.-J. Zimmermann 2011).

2.1. Fuzzy TOPSIS

Multi-criteria decision making (MCDM) is a subset process research that has created a great revolution in Decision Science. Many methods for the MCDM problem have been expressed because of its great attractiveness. One of the most classic methods is the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) which represented for initially by Hwang and Yoon for solving MCDM problems (Tzeng and Huang 2011). The main aim of TOPSIS method is determining the (positive-ideal solution (PIS) which refers to the clarification that makes as maximum the advantage criteria and make as a minimum the disadvantage criteria and negative-ideal solution (NIS) which refers the solution that makes as maximum the disadvantage criteria and makes as a minimum the advantage criteria finally compute the distance from each alternative to PIS and NIS, the alternative that has the shortest distance from PIS and longest distance to FIS is the best selection. Fuzzy TOPSIS is similar just scales are used to change the lingual terms to fuzzy numbers. Recently there are a lot of applications of using Fuzzy TOPSIS as the method for solving the problem (Cavallaro 2010). The description of the method is expressed below in detail.

2.2. The Algorithm

Suppose A_i is all the possible alternatives and C_j is the criteria X_{ij} denotes the rating of A_i relates to the criteria

In Equation (1) a classic fuzzy MCDM problem has been shown.

$$\begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_n \end{matrix} \left\{ \begin{matrix} \tilde{X}_{11} & \tilde{X}_{12} & \cdots & \tilde{X}_{1n} \\ \tilde{X}_{21} & \tilde{X}_{22} & \cdots & \tilde{X}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{X}_{m1} & \tilde{X}_{m2} & \cdots & \tilde{X}_{mn} \end{matrix} \right\} \; i = 1,2,\dots,m; \; j = 1,2,\dots,n \tag{1}$$

$$\widetilde{W} = (\widetilde{w}_1, \widetilde{w}_2, \dots, \widetilde{w}_n) \tag{2}$$

w_j is the weight of each criterion C_j.

The steps of fuzzy TOPSIS can be expresses as follows: (Cavallaro 2010).

Step 1: determine alternatives.

Step 2: Identify the appropriate criteria.

Step 3: select the lingual variable.

Step 4: Ascertain the weight of criteria.

In this study, linear triangular fuzzy numbers are used that defined in the interval (0, 1) Lingual variables for the ratings and Lingual variables for the importance weight of each criterion has been shown in Table1 (Chen 2000).

Table 1. Lingual variables and fuzzy numbers

Lingual variables weight of each	for the importance criterion	Lingual variables	For the ratings
Lingual variables	Membership function	Lingual variables	Membership function
Very low (VL)	(0,0,0.1)	Very poor (VP)	(0, 0, 1)
Low (L)	(0, 0.1, 0.3)	poor (P)	(0, 1, 3)
Medium low(ML)	(0.1, 0.3, 0.5)	Medium poor(MP)	(1, 3, 5)
Medium (M)	(0.3, 0.5, 0.7)	Medium (M)	(3, 5, 7)
Medium high (MH)	(0.5,0.7,0.9)	Medium good (MG)	(5, 7, 9)
High (H)	(0.7, 0.9, 1)	good (G)	(7, 9, 10)

Very high (VH)	(0.9, 1, 1)	Very good (VG)	(9, 10, 10)

Because the units of data are different and incomparable, the data should be normalized. In this study, a linear scale changeover is used to transform the scale of criteria into the scales that can be compared with each other.

Step 5: Construct the fuzzy decision matrix.

Step 6: Normalize the fuzzy decision matrix.

For normalizing the fuzzy choice matrix Equation (3, 4) have been uses.

$$\tilde{R}=[r_{ij}]_{mxn} \quad i=1,2,\ldots\ldots, \quad m=1,2,\ldots\ldots\ldots n \qquad (3)$$

Where

$$r_{ij}=\left(\frac{a_{ij}}{c_{ij}^*},\frac{b_{ij}}{c_{ij}^*},\frac{c_{ij}}{c_{ij}^*}\right) \qquad j \in B \qquad (4)$$

$$r_{ij}=\left(\frac{a_j^-}{c_{ij}},\frac{a_j^-}{b_{ij}},\frac{a_j^-}{a_{ij}}\right) \qquad j \in C \qquad (5)$$

$$c_j^* = \max c_{ij} \qquad j \in B \qquad (6)$$

$$a_j^- = \min a_{ij} \qquad j \in C \qquad (7)$$

Where, B and C in Equation (3, 4) are the sets of advantage criteria and cost criteria respectively.

Advantage and cost criteria should be separated in order to be identified that what criteria should be maximized or minimized

Step 7: construct a weighted normalized fuzzy choice matrix

$$\tilde{V} = [\tilde{v}_{ij}]_{mxn} \quad i = 1,2,\ldots.,m \quad j = 1,2,\ldots,n \qquad (8)$$

$$\tilde{v}_{ij} = \tilde{r}_{ij} \otimes \tilde{w}_{ij} \qquad (9)$$

Where w_{ij} expresses the weighted for each criterion.

Step 8: calculate fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solutions (FNIS).

FPIS refers to the solution that makes as maximum all the advantage criteria and make as a minimum all the disadvantage criteria and FNIS is the opposite, it means the solution that makes as maximum all the disadvantage criteria and makes as a minimum all the advantages criteria

For calculating FPIS and FNIS the following equations are used:

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^*) \text{ where } \tilde{v}_j^* = \{(max\ v_{ij} | j \in J), (min\ v_{ij} | j \in J')\} \qquad (10)$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-) \text{ where } \tilde{v}_j^- = \{(min\ v_{ij} | j \in J), (max\ v_{ij} | j \in J')\} \qquad (11)$$

Step 9: The distances between each alternative from FPIS and FNIS should be determined using Equation (12, 13):

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, v_j^*) \qquad i = 1,2,\ldots,m \qquad (12)$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, v_j^-) \qquad i = 1,2,\ldots,m \qquad (13)$$

Where, $d_i^*$is the distance between each alternative from FPIS and $d_i^-$is the distance between each alternative from FNIS.

Step 10: calculate the closeness coefficient of the alternatives

As the last step, the closeness coefficient (CC_i) should be calculated to give a rank to the alternatives.

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \qquad i = 1,2,\ldots,m \qquad (14)$$

Which alternative that has the highest CC_i gets rank one, it means it's the best choice in other words it has the highest closeness to FPIS and longest distance to FNIS.

In Fig 2 structure and steps of fuzzy TOPSIS has been shown.

3. CO2 Utilization

Carbon Capture and Utilization (CCU) consists of two steps, the first step that is similar to CCS is the process of capturing CO_2 from the resources. The next step is utilizing CO_2. Actually in CCU, unlike CCS which emits CO_2 from the cycle of the economy, it uses captured CO_2 directly or after conversion to produce commercial products (Styring, Quadrelli, and Armstrong 2014).

Several industries such as the food or drink industry utilize CO_2 directly.in the decaffeination process, CO_2 is used as a solvent, and also it is used for the extraction of savors (Cuéllar-Franca and Azapagic 2015). The other direct utilization of CO_2 is Enhanced Oil Recovery (EOR) in which CO_2 is used for extracting crude oil from a reservoir. With EOR technology crude oil will be extracted 30-60% more than the conventional way. Because CO_2 is cheap and it is in wide availability, it is more usual than other agents (Cuéllar-Franca and Azapagic 2015), (Ahmadi, Pouladi, and Barghi 2016).

CO_2 can be used after conversion to produce valuable chemicals and fuels; via carboxylation reactions, CO_2 will be converted into commercial chemicals (such as methanol, formic acid, and urea). Methanol compound which is a valuable product requires three equivalents of hydrogen per molecule of CO_2; two is the synthesizing process into the product and at the third, that's the end stage the product will be mixed with water (Cuéllar-Franca and Azapagic 2015), (Miguel et al. 2015). Formic acid is another product of using CO_2. One of the important properties of formic acid is the capability in a more controllable liquid form; the process of producing formic acid requires just a single equivalent of hydrogen. It is crucial to be expressed that when formic acid is being decomposed the hydrogen will be released and unfortunately CO_2 will be released again. Another product of converting CO_2 into a commercial product is urea which is synthesized from ammonia and carbon dioxide, used as fertilizer, in animal feed, and plastics (Styring, Quadrelli, and Armstrong 2014).

Some of the most important conversions of CO2 that have been reported to date have been shown in Figure 3.

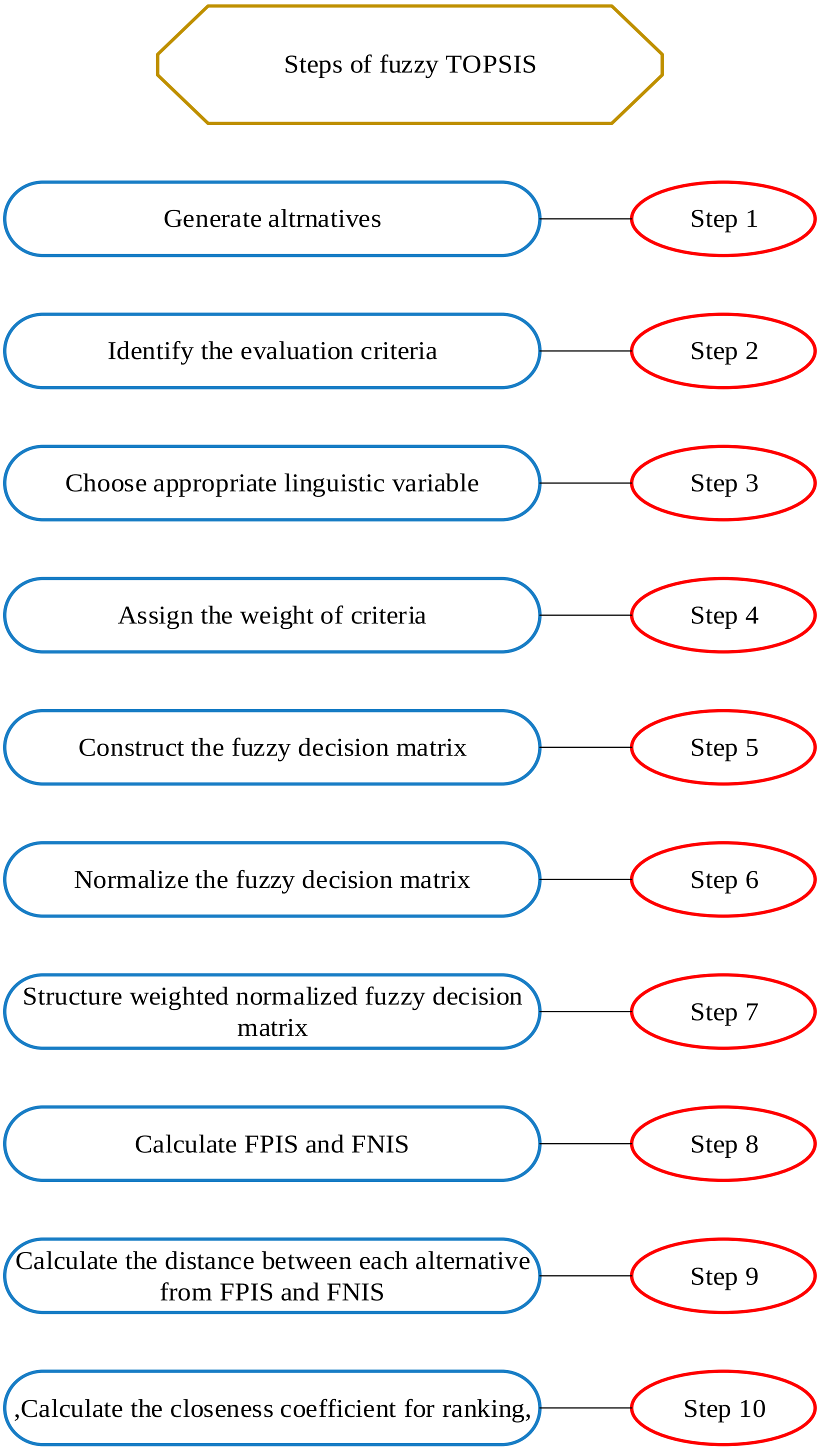

Figure 2. Structure and steps of fuzzy TOPSIS

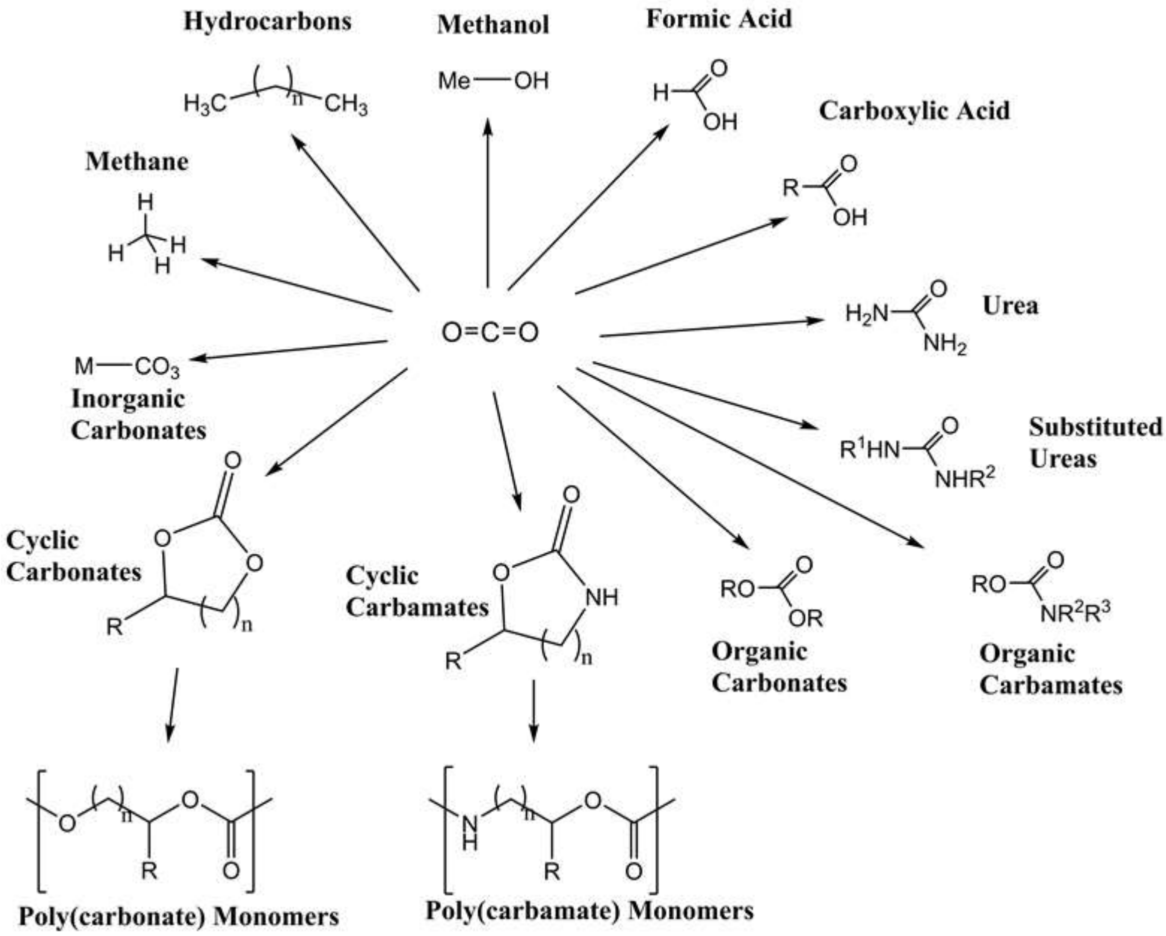

Figure 3. Different chemicals produced by CO_2 (Cuéllar-Franca and Azapagic 2015)

4. Case Study

Iran has one of the world's most massive natural gas reserves. Asalouyeh gas processing plant is the most colossal refinery in the south of Iran. This paper tries to consider the applications of CO_2 emitted from ethane treatment units of the Asalouyeh gas processing plant. It is possible to utilize CO_2 for effective applications. In this study seven applications have been proposed which are producing methanol, enhance oil recovery (EOR), producing soda, dry ice, salicylic acid, urea, and ammonium bicarbonate, they are the alternatives that have been used in this study.

4.1. Criteria

Alternatives can be compared with the criteria. It shows the importance of selecting criteria that should be accurate. Selecting criteria is the most important part of the work that any delinquency will eliminate the effort. The availability of data determines the number of criteria. The more criteria are considered, the more valid project's result is. In this study, 10 criteria were adopted seven of them are technical and others are economic.

C1: The internal mode of technology: It refers to how the internal mode of technology in the country is, whether it exists or not.

C2: accessibility of the technology: This criterion represents how technology is possible to be accessed in the country or foreign countries.

C3: mode of knowledge: it refers that the mode of the complexity of the technology. More complex technology makes the alternative less preferable.

C4: Environmental aspect and safety. This criterion contemplates the risk to the environment for each of the alternatives.

C5: transferring CO_2: it represents and compares the distance between sources of CO_2 production to the co2 consumption places.

C6: purification of CO_2: The wasted CO_2 produced by power plants is highly impure; this criterion refers to the need for purification for each alternative and compares them with each other.

C7: the amount of CO_2 consumption: It refers to the amount of CO_2 that each alternative needs in its optimum mode of production. This criterion is measured in tone per year.

C8: Investment costs. Investment costs relate to the cost of purchasing mechanical equipment, technology for installations, etc. which should be invested at the beginning of the project. This criterion is measured in million dollars per year.

C9: Operating and maintenance costs. Operating and maintenance costs are related to, employees' wages, transport, and other costs to keep the system in the best condition. This criterion is measured in million dollars per year.

C10. Rate of return: Rate of return is a benefit on an investiture over a period of time, expressed as a proportion of the original investiture. In this study Discounted Cash Flow Rate of Return method has been used for calculating the rate of return for each alternative.

In Figure 4. Structure of fuzzy TOPSIS for CO2 utilization is shown.

4.2. The Evaluation Matrix

For all the alternatives, the technical, economic, and environmental criteria are shown in Table2.

Table 2 shows the values extracted for the different options for each of the criteria. In this matrix, some cells have quantitative values and some cells have qualitative value, which will be quantitatively measured using fuzzy numbers.

Most of the information that has been used in this study take over mostly from the IGCC reports, others adopted by experts in the relevant sector. Decision-maker designates a weight to the criteria by using the lingual variable. It expresses the importance of each criterion.

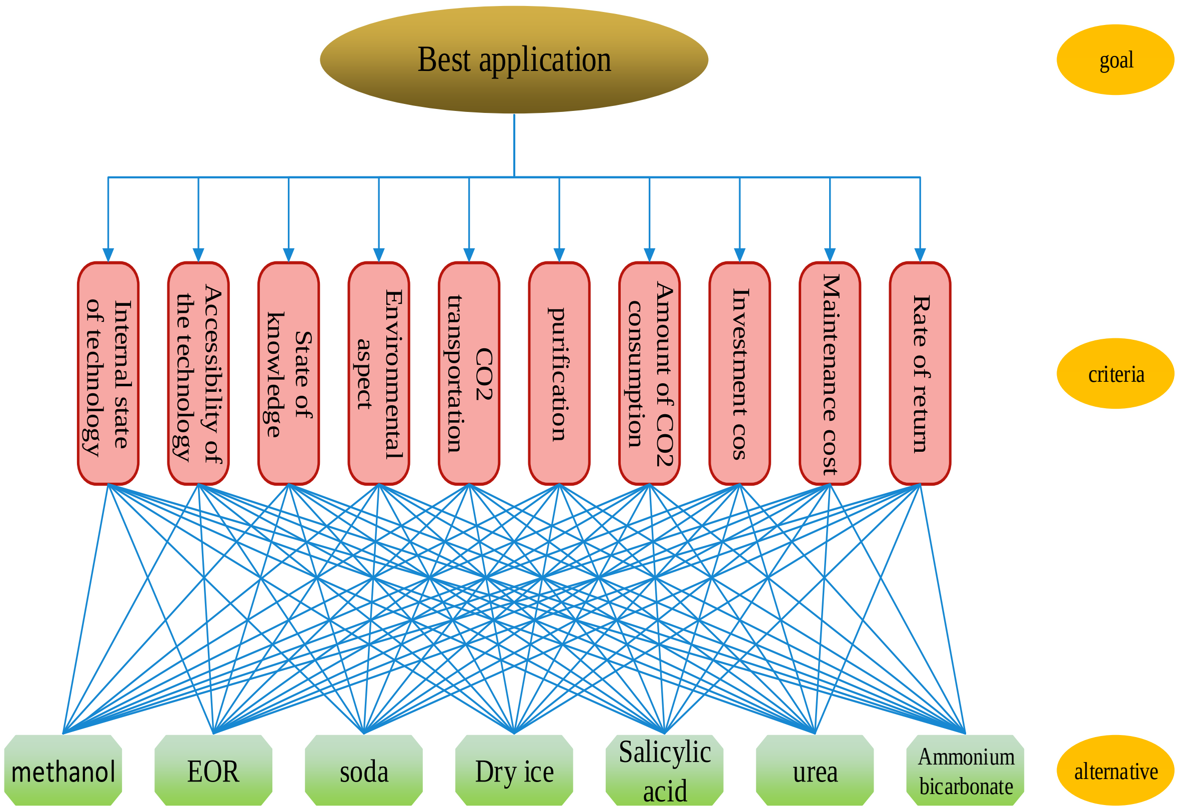

Figure 4. Structure of fuzzy TOPSIS for CO_2 utilization

Table 2. Performance data of seven alternatives

criteria	methanol	EOR	soda	dry ice	salicylic acid	urea	ammonium bicarbonate
C1	VG	VP	G	VG	VP	VG	VG
C2	VG	G	G	VG	M	VG	VG
C3	P	G	G	G	G	P	G
C4	M	G	M	G	P	M	P
C5	VG	P	P	VP	M	VG	P
C6	G	VG	P	P	P	M	VP
C7	86000	86400	155	8622	356	5040	557
C8	56.8	19.9	73.5	18.6	17.3	93.3	15.2

C9	31.6	17.3	30.2	5.2	7	155.5	2.2
C10	0.44	0.34	0.28	0.55	0.21	0.26	0

Then set the fuzzy choice matrix should be normalized then the normalized fuzzy choice matrix should be weighted. In Table 3 weighted fuzzy choice matrix is shown. The next step is calculating the distance of each alternative from FPIS and FNIS. Finally, by using equation (14) CC_i will be calculated to define the rank of each alternative respectively. The rank matrix has been shown in Table 4. Table 4 shows the final values of the positive and negative views of the Topsis method. The second column indicates the ranking in the shortest distance from the positive ideal state and the third column indicates the distance from the negative ideal. Which is obtained from the calculations? In this table, the fourth column indicates the final value for the decision, and the higher the value, the more appropriate the option.

The level of uncertainty for criteria C1- C6 is higher than others because they are qualitative. Four criteria including Rate of return, Operating and maintenance costs, Investment costs, and amount of CO_2 consumption, have been expressed for each alternative in its optimal production.

4.3. Final Ranking

After calculating CC_i and determining the rank for each criterion, the resultant ranking is as follows: producing methanol > EOR> urea > dry ice > soda > ammonium bicarbonate > salicylic acid. As can be seen in table4 the best alternative, which has the highest CC_i, is methanol. The technology of producing methanol is available in the country. Some companies produce it in the country; appropriate shopping market and high rate of return are important features that set methanol as the first rank.

Table 3. the fuzzy weighted normalized choice matrix

	weight	methanol	EOR	soda	dry ice	salicylic acid	urea	ammonium bicarbonate
C1	M	(0.27, 0.5, 0.7)	(0, 0, 0.07)	(0.21, 0.45, 0.7)	(0.27, 0.5, 0.7)	(0, 0, 0.07)	(0.27, 0.5, 0.7)	(0.27, 0.5, 0.7)
C2	VH	(0.81, 1, 1)	(0.63, 0.9, 1)	(0.63, 0.9, 1)	(0.81, 1, 1)	(0.27, 0.5, 0.7)	(0.81, 1, 1)	(0.81, 1, 1)
C3	M	(0, 0.05, 0.21)	(0.21, 0.45, 0.7)	(0.21, 0.45, 0.7)	(0.21, 0.45, 0.7)	(0.21, 0.45, 0.7)	(0, 0.05, 0.21)	(0.21, 0.45, 0.7)
C4	H	(0.21, 0.45, 0.7)	(0.49, 0.81, 1)	(0.21, 0.45, 0.7)	(0.49, 0.81, 1)	(0, 0.09, 0.3)	(0.21, 0.45, 0.7)	(0, 0.9, 0.3)
C5	H	(0.63, 0.9, 1)	(0.21,0.45,0.7)	(0, 0.09, 0.3)	(0, 0, 0.1)	(0.21, 0.45, 0.7)	(0.63, 0.9, 1)	(0, 0.09, 0.3)
C6	H	(0.49, 0.81, 1)	(0.63, 0.9, 1)	(0, 0.09, 0.3)	(0, 0.09, 0.3)	(0, 0.09, 0.3)	(0.21, 0.45, 0.7)	(0, 0, 0.1)
C7	VH	(0, 0, 0.995)	(0, 0, 0.1)	(0, 0, 0.0001)	(0, 0, 0.001)	(0, 0, 0.004)	(0, 0, 0.058)	(0, 0, 0.006)
C8	MH	(0.030, 0, 0)	(0.010, 0, 0)	(0.039, 0, 0)	(0.01, 0, 0)	(0.009, 0, 0)	(0.05, 0, 0)	(0.008, 0, 0)
C9	H	(0.014, 0, 0)	(0.008, 0, 0)	(0.013, 0, 0)	(0.002, 0, 0)	(0.003, 0, 0)	(0.07, 0, 0)	(0.001, 0, 0)
C10	VH	(0, 0, 0.8)	(0, 0, 0.618)	(0, 0, 0.509)	(0, 0, 0.1)	(0, 0, 0.382)	(0, 0, 0.473)	(0, 0, 0)

Table 4. closeness coefficients and ranking of alternatives

	d_i^+	d_i^-	CC_i	Rank
Methanol	0.985	1.535	0.609	1
EOR	1.053	1.489	0.585	2
Soda	1.467	1.075	0.423	5
dry ice	1.418	1.280	0.474	4
salicylic acid	1.659	0.798	0.325	7
Urea	1.103	1.403	0.559	3
ammonium bicarbonate	1.640	1.018	0.383	6

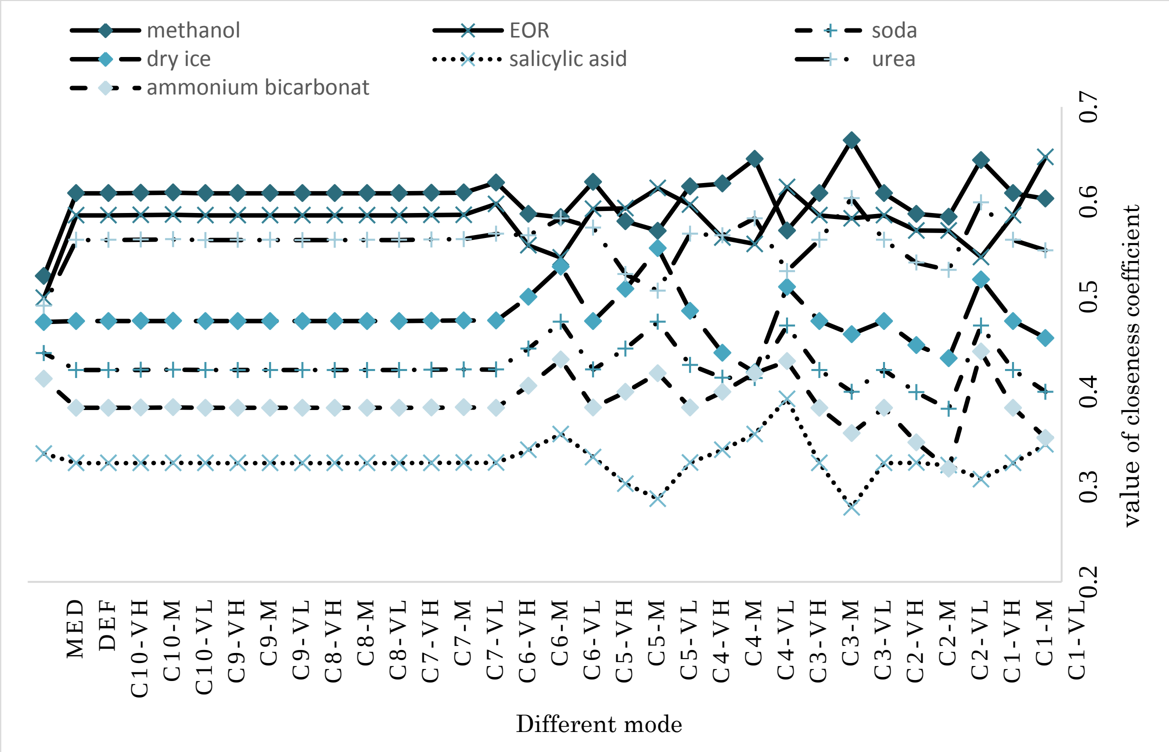

Figure 5. Prioritized options (32 Modes with different coefficients)

4.4. Sensitivity Analysis

Considering the study conducted and obtaining the main priorities of the problem, then in order to investigate the sensitivity of the options to the weighting coefficients of the criteria, different modes are considered for each coefficient. each of the criteria weighting coefficients (Table 3) is considered in the three values of VL, M, VH compared to the original results (in total 30 modes for 10 criteria), an average condition with M taking into account the value of all weighting coefficients for All criteria, also one other case, is the same results as the main reference of all comparisons.

A total of 32 modes have been created and reviewed. In this study, it has been shown that, despite varying coefficients and sensitivities, methanol production is the priority and salicylic acid production is the last priority (Fig 5).

As can be seen from Figure 5, the choice of options does not have much sensitivity to changes in weight coefficients, carbon dioxide consumption criteria, costs, and rate of return, and has not changed the priority of the options or even the difference in their differences. By changing the weight coefficients, the mentioned criteria, the main priority remains the same.

5. Conclusion

This study considers the use of a fuzzy TOPSIS decision-making method to find the best application of CO_2 emitted from ethane treatment units of the Asalouyeh gas processing plant. Selecting the best application is a controversial issue because of the variety and numerousness of the applications. In the technologies investigated for CO_2 utilization and considering different sensitivities to different options (weighting coefficients), methanol production was considered of the 32 modes with 28 being the top priority.

Methanol production is always one of the best options because of its low sensitivity and very good conditions compared to other options. It should be noted that EOR has a second priority because of its high sensitivity to criteria, CO_2 transfer, and level of knowledge and this sensitivity has made it, in four cases, even better than methanol production.

In this study, the conditions and criteria have been considered to be close to the existing reality, indicating that methanol production and harvesting should always be considered as one of the preferred options in the use of carbon dioxide in gas refinery units. also, This study shows that the MCDM method is a suitable method for finding the best application.

For further investigation, more specific criteria, options, and conditions can be considered in the future, such as product demand status, product value-added, etc. It can also be checked for other similar gas units with different carbon dioxide conditions and levels.

References

Ahmadi, Mohammad Ali, Behzad Pouladi, and Tohid Barghi. 2016. "Numerical Modeling of CO_2 Injection Scenarios in Petroleum Reservoirs: Application to CO_2 Sequestration and EOR." *Journal of Natural Gas Science and Engineering* 30: 38–49.

Aresta, Michele, Angela Dibenedetto, and Antonella Angelini. 2013. "The Changing Paradigm in CO_2 Utilization." *Journal of CO_2 Utilization* 3: 65–73.

Barzagli, Francesco, Fabrizio Mani, and Maurizio Peruzzini. 2016. "Carbon Dioxide Uptake as Ammonia and Amine Carbamates and Their Efficient Conversion into Urea and 1, 3-Disubstituted Ureas." *Journal of CO_2 Utilization* 13: 81–89.

Cavallaro, Fausto. 2010. "Fuzzy TOPSIS Approach for Assessing Thermal-Energy Storage in Concentrated Solar Power (CSP) Systems." *Applied Energy* 87 (2): 496–503.

Chen, Chen-Tung. 2000. "Extensions of the TOPSIS for Group Decision-Making under Fuzzy Environment." *Fuzzy Sets and Systems* 114 (1): 1–9.

Cuéllar-Franca, Rosa M, and Adisa Azapagic. 2015. "Carbon Capture, Storage and Utilisation Technologies: A Critical Analysis and Comparison of Their Life Cycle Environmental Impacts." *Journal of CO2 Utilization* 9: 82–102.

Deveci, Muhammet, Nihan Çetin Demirel, Robert John, and Ender Özcan. 2015. "Fuzzy Multi-Criteria Decision Making for Carbon Dioxide Geological Storage in Turkey." *Journal of Natural Gas Science and Engineering* 27: 692–705.

Eshraghi, S Ehsan, M Reza Rasaei, and Sohrab Zendehboudi. 2016. "Optimization of Miscible CO_2 EOR and Storage Using Heuristic Methods Combined with Capacitance/ Resistance and Gentil Fractional Flow Models." *Journal of Natural Gas Science and Engineering* 32: 304–18.

Ganesh, Ibram. 2014. "Conversion of Carbon Dioxide into Methanol–a Potential Liquid Fuel: Fundamental Challenges and Opportunities (a Review)." *Renewable and Sustainable Energy Reviews* 31: 221–57.

Gardarsdottir, Stefania Osk, Edoardo De Lena, Matteo Romano, Simon Roussanaly, Mari Voldsund, José-Francisco Pérez-Calvo, David Berstad, Chao Fu, Rahul Anantharaman, and Daniel Sutter. 2019. "Comparison of Technologies for CO2 Capture from Cement Production—Part 2: Cost Analysis." *Energies* 12 (3): 542.

Ghorbani, Bahram, Mehdi Mehrpooya, and Erfan Omid. 2020. "Hybrid Solar Liquefied Natural Gas, Post Combustion Carbon Dioxide Capture and Liquefaction." *Energy Conversion and Management* 207: 112512.

Ghorbani, Bahram, Reza Shirmohammadi, Mehdi Mehrpooya, and Mohammad-Hossein Hamedi. 2018. "Structural, Operational and Economic Optimization of Cryogenic Natural Gas Plant Using NSGAII Two-Objective Genetic Algorithm." *Energy* 159: 410–28.

Kaufmann, Arnold, and Madan M Gupta. 1991. "Introduction to Fuzzy Arithmetic: Theory and Applications. 1991." *VanNostrand Reinhold, New York*.

McCoy, Sean. 2014. "Carbon Capture and Storage: Legal and Regulatory Review." *IEA, Paris*.

Mehrpooya, Mehdi, and Bahram Ghorbani. 2018. "Introducing a Hybrid Oxy-Fuel Power Generation and Natural Gas/Carbon Dioxide Liquefaction Process with Thermodynamic and Economic Analysis." *Journal of Cleaner Production* 204: 1016–33.

Miguel, Carlos V, Miguel A Soria, Adélio Mendes, and Luis M Madeira. 2015. "Direct CO_2 Hydrogenation to Methane or Methanol from Post-Combustion Exhaust Streams–A Thermodynamic Study." *Journal of Natural Gas Science and Engineering* 22: 1–8.

Olivier, Jos G I, Jeroen A H W Peters, and Greet Janssens-Maenhout. 2012.

"Trends in Global CO_2 Emissions 2012 Report."

Patricio, Joao, Athanasios Angelis-Dimakis, Arturo Castillo-Castillo, Yuliya Kalmykova, and Leonardo Rosado. 2017. "Region Prioritization for the Development of Carbon Capture and Utilization Technologies." *Journal of CO_2 Utilization* 17: 50–59.

Rubin, Edward S, John E Davison, and Howard J Herzog. 2015. "The Cost of CO_2 Capture and Storage." *International Journal of Greenhouse Gas Control* 40: 378–400.

Shirmohammadi, Reza, Mohammad Soltanieh, and Luis M Romeo. 2018. "Thermoeconomic Analysis and Optimization of Post-combustion CO_2 Recovery Unit Utilizing Absorption Refrigeration System for a Natural-gas-fired Power Plant." *Environmental Progress & Sustainable Energy* 37 (3): 1075–84.

Styring, Peter, Elsje Alessandra Quadrelli, and Katy Armstrong. 2014. *Carbon Dioxide Utilisation: Closing the Carbon Cycle*. Elsevier.

Tzeng, Gwo-Hshiung, and Jih-Jeng Huang. 2011. *Multiple Attribute Decision Making: Methods and Applications*. CRC press.

Voldsund, Mari, Stefania Osk Gardarsdottir, Edoardo De Lena, José-Francisco Pérez-Calvo, Armin Jamali, David Berstad, Chao Fu, Matteo Romano, Simon Roussanaly, and Rahul Anantharaman. 2019. "Comparison of Technologies for CO_2 Capture from Cement Production—Part 1: Technical Evaluation." *Energies* 12 (3): 559.

Zadeh, Lotfi A. 1965. "Fuzzy Sets." *Information and Control* 8 (3): 338–53.

Zimmermann, Arno W, Johannes Wunderlich, Leonard Müller, Georg A Buchner, Annika Marxen, Stavros Michailos, Katy Armstrong, Henriette Naims, Stephen McCord, and Peter Styring. 2020. "Techno-Economic Assessment Guidelines for CO_2 Utilization." *Frontiers in Energy Research* 8.

Zimmermann, Hans-Jürgen. 2011. *Fuzzy Set Theory—and Its Applications*. Springer Science & Business Media.