



Development of Sustainable assessment Model of solar hydrogen production techniques: An integrated MCDM approach

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Abstract

Energy has a critical role in human survival and societal progress. Hydrogen is a possible energy carrier for long-term power generation. Known as both an environmental nuisance and an essential hydrogen source, Hydrogen Sulfide (H₂S) may be found in large quantities in the waters of the Black Sea. The primary goal of this research is to determine which breakdown processes, such as thermal, thermochemical, electrochemical, plasma, photochemical and thermal suit sustainability requirements better than others. The most acceptable hydrogen generation technique is chosen based on characteristics such as financial viability, environmental viability, effectiveness, simplicity of the process, energy consumption, safety and dependability, application and operational adaptability, and technological maturity. This paper proposes innovative additions to the CoCoSo approach. The COCOSO method is used to compute the weights of criteria and rank the alternatives. This paper proposed 8 criteria and 5 alternatives.

Keywords: MCDM; COCOSO; Hydrogen production; Sustainability

1. Introduction

Energy demand has skyrocketed due to an increase in population and technological advancements [1]. For the most part, it is made from a variety of different types of energy sources including natural gas, coal, and uranium as well as oil and biomass. Several renewable energy sources may be utilized to create electricity and mechanical energy by converting these sources to electrical and motive forces, such as windy, biofuel, hydraulic, and geothermal energy energies[2], [3]. Of these sources of energy, hydrogen is the most straightforward and eco-friendly, and it will play an important part in clean energy transportation and sustainability in the future[4]. Fusion reactors and storage systems make use of hydrogen energy for transport, dispersed heat and power generation, and other applications. As a result, it does not have a significant influence on the local or global environment[5], [6]. It is thus preferable to manufacture hydrogen from a variety of renewable and nonrenewable energy sources due to its high efficiency and low pollution [7]. Water, fossil fuels, biomass, and geothermal all provide hydrogen when chemical processes are used.

Black Sea deep strata contain large amounts of hydrogen sulfide (H₂S), a significant hydrogen generation resource[8]. Eastern Europe and Western Asia are encircled by the Black Sea, an epeiric sea. Romania, Turkey, Bulgaria, Russia, Georgia, and Ukraine are six of the nations that have a Black Sea port of call. The H₂S in the Black Sea, as in other bodies of water, contributes to pollution and adversely affects human health and the ecosystem. H₂S, on the other hand, has an advantage for hydrogen generation as a potential future energy source since hydrogen plays a key role in practically all kinds of energy systems with expanding economies including energy, distributed thermal power generation, and transportation[9]. Diverse approaches [10] with various economic, environmental, and societal implications are provided for the production of hydrogen from H₂S. To utilize H₂S as a source of renewable energy, a variety of breakdown processes, including thermal, thermochemical, electrochemical, photochemical, and plasma, have been developed. It's not possible to make money with any of them. Experts have come up with five distinct ways to reduce environmental pollution, reduce waste, and use resources more effectively in a

sustainable manner in this research. There are various conflicting numerical and qualitative criteria that must be taken into account when evaluating sustainable hydrogen generation technologies in the Black Sea, hence an MCDM approach is presented that takes these factors into account.

Methods for determining the most acceptable choice from the predefined options, taking into consideration numerous competing criteria, are utilized in the MCDM approach. Even though fuzzy set and their modifications are often employed by decision-makers or specialists in the area to manage the subjectivity and uncertainty of their decisions, Approaches for site selection, appraisal of energy resources, system design, energy investment, and policy choices [11] are largely employed in the literature using MCDM methods. Thus, MCDM approaches may be used in renewable energy management [12]–[15] in a broad range of contexts. Fuzzy modifications in the MCDM technique for hydrogen energy sustainability are also widely used in the literature.

A hybrid MCDM model was used to establish an optimal energy assessment approach for hydrogen energy systems [4]. Hydrogen energy systems are evaluated using FAHP, and DEA approaches [16]. assessed hydrogen energy systems by taking economic potential, capacity, and technological aspects into account. Based on this, they ranked hydrogen alternative energy roadmap (ETRM) weights based on the FAHP [17]. hydrogen generation from six renewable sources was shown. Consequently, Fuzzy Delphi, FAHP, and DEA are used to assess six different renewable energy sources[18]. Evaluation of conventional hydrogen power and environmental energy systems was carried out using an MCDM technique[19]. Analysis of nine natural gas or hydrogen-powered electrical generation technologies was done using the AHP technique[20]. To identify the best renewable energy technology, a group decision-making process was proposed. When they applied the strategy described above to the evaluation of 12 hydrogen production technologies, they found that electrolysis in water was the best choice[21]. The optimal Hydrogen Energy Storages (HES) type was determined by combining an MCDM technique utilizing FAHP and a linear normalizing method based on GRA [22].

Assessment of hydrogen generating systems using a Fuzzy Delphi (FD) methodology. Fuzzy MCDM was proposed as a tool for evaluating hydrogen fuel cell devices [23]. To evaluate hydrogen fuel cell concepts, and FD approach was developed [24], [25]. Using a variety of MCDM approaches, including VIKOR, TOPSIS, ELECTRE, SAW, and Fuzzy TOPSIS, we evaluated the generation of renewable hydrogen in 25 Iranian areas. Hydrogen generation in the southern area of Iran was investigated[26]. categorized and prioritized hydrogen supply chain sustainability using AHP[27]. VIKOR was used to evaluate hydropower's viability. Hydrogen may be generated from a variety of sources and via a variety of methods. Choosing the best environmentally friendly hydrogen generation technology requires a strategic approach. Hydrogen generation is a major challenge in renewable energy management, and this research tries to solve this issue by methodically addressing the inescapable sustainable standards. Consequently, when it comes to hydrogen power generation, numerous sustainability-based factors are determined and tried to apply to choose the method of hydrogen energy production. These criteria include financial viability, environmental viability; effectiveness; simplicity of procedure; energy content; reliability and quality; relevance and operational suitability; and technical maturity. Therefore, the model's outputs are useful to energy planners.

Using several aggregation methodologies, [28] developed a combination compromise decision-making system. They put the strategy to use by selecting logistics service providers. The CoCoSo-Grey approach proposed by [28] was used to identify suppliers in construction management. An evaluation of OPEC nations' long-term viability was carried out utilizing CoCoSo by researchers[29]. A Pythagorean fuzzy environment built on CoCoSo and the Criteria Importance Through Inter-criteria Correlation (CRITIC) was created by[30] for the assessment of the 5G industry. Models from BMW and CoCoSo have been incorporated in the selection of sustainable suppliers by [31]. An integrated fuzzy best-worst method (BMW) and fuzzy CoCoSo with Bonferroni for a sustainable supplier selection issue was suggested by [32] in their paper. For the selection of renewable energy investments, [33]used a hybrid strategy based on CoCoSo and stochastic information. [34] used the integrated BMW and Target-based CoCoSo to offer DM choice in interior construction applications. Logistics hubs in the autonomous communities of Spain are selected using a two-stage decision-making methodology established by [35]. Data envelopment analysis was done in the first step to analyze the criteria. Second, the performance of efficient communities was assessed using rough full consistency (R-FUCOM) and a combined compromise solution (R-CoCoSo). Fuzzy decision-making based on CoCoSo was used by [36]to investigate financial risk assessment. A maximum variation optimization model for cloud provider choice was developed by [37].

The fuzzy-based SWARA and CoCoSo techniques developed by [38]were used to aid in the selection of logistics center locations. It was Peng and Smarandache [39]that proposed CoCoSo, a neutrosophic soft decision-making technique for China's rare earth sector security assessment, to the scientific community.

The following is the remainder of the document. Section 2 defines the proposed methodology. Section 3 defines the case study, criteria, and options. Here, in Section 4, you will find the conclusion.

2. The Proposed MCDM Methodology

The classic CoCoSo technique uses the WSM and the (WPM) to rank options based on the compromise solutions generated by applying these models (WPM). As a result of a compromise technique, the final criteria function was produced and used to rank the options. When the evaluations of the choices in the original decision matrix are uniform, the aggregation of compromise tactics produces objective outcomes. Extreme changes in the WSM and WPM functions occur when extreme values arrive in the initial decision matrix at the location among the most influential criterion. As a result, the criterion's value function for the alternative under consideration rises astronomically even more than it already has. The first choice matrix has extreme values for a variety of reasons, some of which include disproportionate differences between the options evaluated, measurement mistakes, biased expert judgments (either intentionally or unintentionally), and so on. WSM and WPM combination also has the drawback of neglecting the connections and overlaps among the various criteria.

A logical and objective apparatus is required for mathematical models of decision making to provide a realistic perspective of the interaction between both the qualities and eliminate anomalies of this kind. Rather than using the old-fashioned CoCoSo model, these researchers developed a new one. It was not possible to determine the weight coefficients of the criterion in the classic CoCoSo method, which was also omitted in this research. Using the classic CoCoSo paradigm for assessing alternatives, the weighted confidence of the criterion must be calculated using additional mathematical techniques. The framework of this study is in figure 1.

Step 1: Begin by creating a preliminary decision matrix (X).
It is in this first stage that m alternatives and n factors are evaluated.

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

Where $i = 1, 2, \dots, m; j = 1, 2, \dots, n$

Step 2: Normalize the original matrix.

When the original decision matrix R is normalised, the normalised matrix R is discovered.

$$R = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix} \quad (2)$$

The normalized positive and cost criteria are normalized as:

$$r_{ij} = \frac{x_{ij} - x^-_{ij}}{x^+_{ij} - x^-_{ij}} \quad (3)$$

$$r_{ij} = \frac{x^+_{ij} - x_{ij}}{x^+_{ij} - x^-_{ij}} \quad (4)$$

$$x^+_{ij} = \max x_{ij} \quad (5)$$

$$x^-_{ij} = \min x_{ij} \quad (6)$$

Step 3: Compute the value of S_i and P_i

The S_i value is generated using the grey relational generation process, whereas the P_i value is derived using the WASPAS multiplicative feature.

$$S_i = \sum_{j=1}^n (r_{ij} w_j) \quad (7)$$

$$P_i = \sum_{j=1}^n (r_{ij})^{w_j} \quad (8)$$

Step 4: Calculate the best tactics for achieving a high evaluation score.
A variety of aggregation methods are used to calculate the relative weights of every choice.

$$Y_{ia} = \frac{S_i + P_i}{\sum_{i=1}^m (S_i + P_i)} \quad (9)$$

$$Y_{ib} = \frac{S_i}{\min S_i} + \frac{P_i}{\min P_i} \quad (10)$$

$$Y_{ic} = \frac{\lambda(S_i) + (1 - \lambda)P_i}{(\lambda \max S_i + (1 - \lambda) \max P_i)}; \quad 0 \leq \lambda \leq 1 \quad (11)$$

$$\lambda = 0.5$$

Step 5: Calculate the alternative's performance score.
Options are ranked based on how well they perform.

$$Y_i = (Y_{ia} \cdot Y_{ib} \cdot Y_{ic})^{\frac{1}{3}} + \frac{1}{3}(Y_{ia} + Y_{ib} + Y_{ic}) \quad (12)$$

Step 6: To put it another way, the alternatives are rated according to how well they perform. The best possible rating is desired.

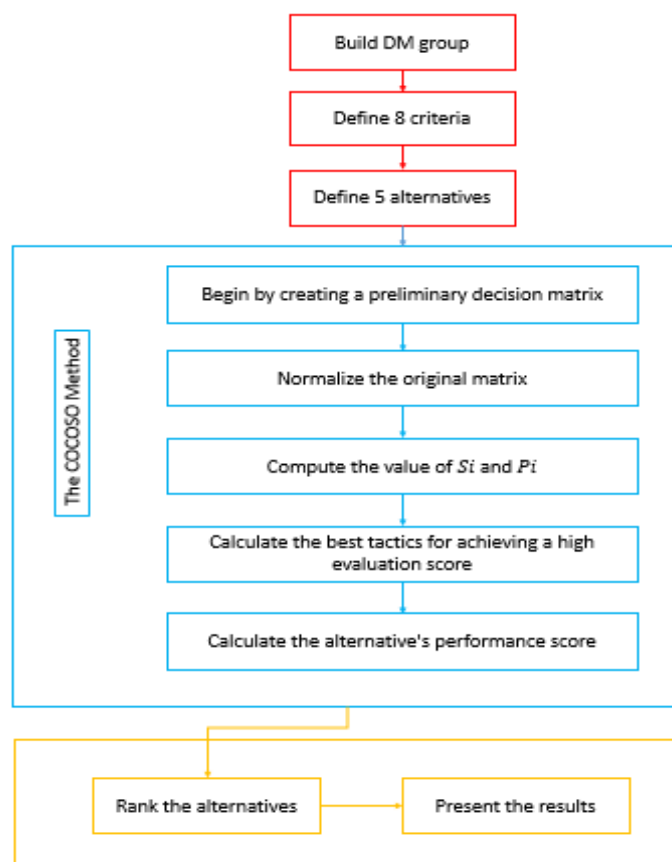


Figure 1. The framework of this study.

3. Experiment Results

Breakdown methods for separating H₂S into its elements at the bottom of a Black Sea are discussed in this research. The options and criteria for evaluating them are derived from thorough literature research and consultations with experts. Experts examined and analyzed the region's hydrogen power generation and efficiency circumstances via a series of interviews. The research is also thoroughly examined both during and before interviews. Both alternative energy production techniques and assessment criteria were developed and reviewed with the help of specialists throughout the procedure. Some academics have also worked in the sector, and they were chosen to serve as advisors to the government on hydrogen energy policy and strategy. This means that to maximize the effectiveness of hydrogen production methods and to identify and investigate any potential negative effects on the environment and the environment's sustainability, it is necessary to focus on several key performance criteria, such as financial viability, environmental viability, effectiveness, process simplicity, energy consumption, safety and reliability, applicability, and operational suitability, all of which have a direct impact on hydrogen production's performance.

Due to the created technique taking into account almost all of the factors usually used to assess hydrogen production methods, the eight criteria considered in this study are recognized as adequate by experts for rating various hydrogen production methods correctly. Thermochemical, Electrochemical, Thermal, Photochemical, Plasma, and Thermal breakdown techniques have been identified. The six-step CoCoSo model was used for the assessment of options.

Step 1: Three experts participated in the research and assessed potential alternatives. The alternatives were assessed based on 8 criteria that had been disregarded in the previous section of the research. It was possible to create one matrix for each of the three experts in the study (see Table 1).

As shown in Table 1, the estimations were combined to provide the initial matrices. Expressions were used to combine the estimations of the experts. The second step is as follows: Table 2 shows the results of normalizing the matrix's decision-making components.

Table 1: The aggregated decision matrix

	H	H	H	H	H	H	H	H
	P C1	P C2	P C3	P C4	P C5	P C6	P C7	P C8
P A 1	6 .6 66 66 7	5 .6 66 66 7	5 .3 33 33 3	4 .6 66 66 7	5 .6 66 66 7	5 .6 66 66 7	3 .6 66 66 7	5 .6 66 66 7
P A 2	5 .6 66 66 7	6 .6 66 66 7	8 .3 33 33 3	7 .6 66 66 7	3 .6 66 66 7	7 .6 66 66 7	5 .6 66 66 7	8 .6 66 66 7
P A 3	4 .3 33 33 3	6 .3 33 33 3	6 .3 33 33 3	8 .3 33 33 3	4 .3 33 33 3	5 .3 33 33 3	3 .6 66 66 7	7 .3 33 33 3
P A 4	4 .3 33 33 3	2 .3 33 33 3	5 .6 66 66 7	4 .3 33 33 3	4 .6 66 66 7	4 .6 66 66 7	4 .3 33 33 3	6 .3 33 33 3
P A 5	4 .3 33 33 3	7 .3 33 33 3	7 .6 66 66 7	4 .6 66 66 7	6 .6 66 66 7	6 .6 66 66 7	5 .6 66 66 7	7 .3 33 33 3

Table 2: The normalized decision matrix.

	H PC 1	H PC 2	H PC 3	H PC 4	H PC 5	H PC 6	H PC 7	H PC 8
P A 1	1	0 .66 66 67	0	0 .15 38 46	0 .66 66 67	0 .33 33 33	0	0
P A 2	0 .57 14 29	0 .86 66 67	1	0 .69 23 08	0	1	1	1
P A 3	0	0 .73 33 33	0 .33 33 33	1	0 .22 22 22	0 .22 22 22	0 .2 5	0 .71 42 86
P A 4	0	0	0 .11 11 11	0 .07 69 23	0 .33 33 33	0	0 .5	0 .28 57 14
P A 5	0	1	0 .77 77 78	0	1	0 .66 66 67	1	0 .71 42 86

The values of the weight coefficients of the criterion are determined in the next step. Three experts evaluated the criteria. The weights of the criteria are obtained as shown in figure 2.

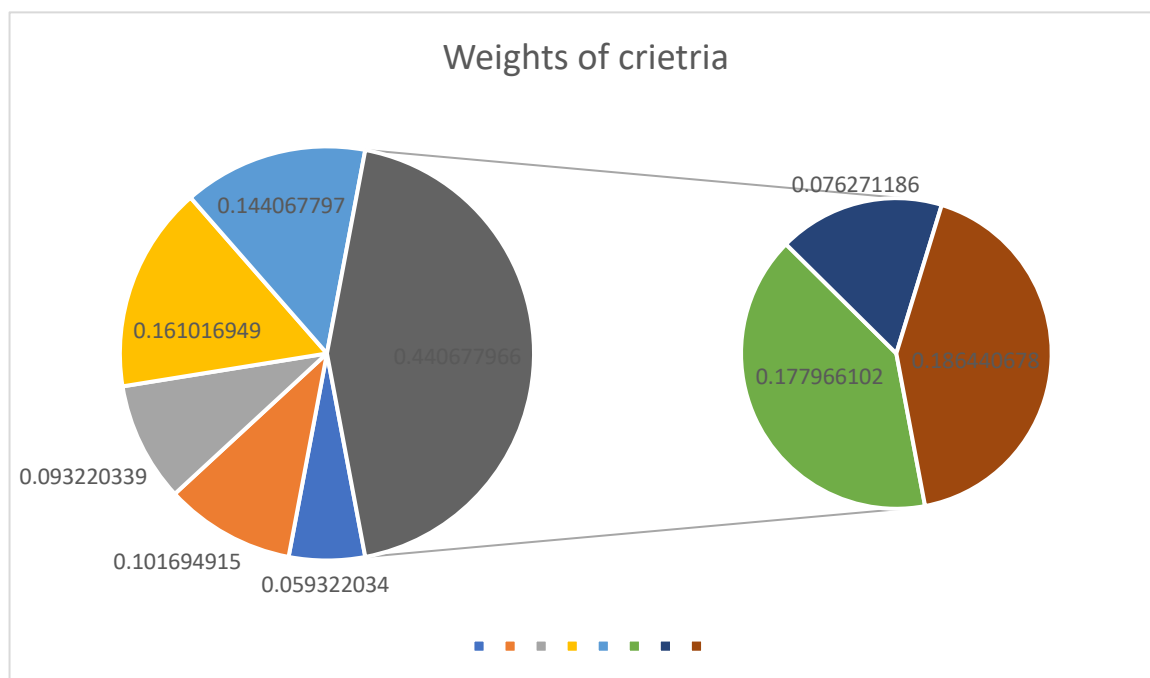


Figure 2. The weights of criteria.

Step 3: Compute the value of S_i and P_i by using Eqs. (7,8) and the weights of criteria in tables 3,4.

Table 3: The value of S_i

	H	H	H	H	H	H	H	H
	P C1	P C2	P C3	P C4	P C5	P C6	P C7	P C8
P A 1	0 .0 59 32 2	0 .0 67 79 7	0 .0 24 77 2	0 .0 96 04 5	0 .0 59 32 2	0 .0 24 77 2	0 .0 96 04 5	0 .0 59 32 2
P A 2	0 .0 33 89 8	0 .0 88 13 6	0 .0 93 22	0 .1 11 47 3	0 .1 77 96 6	0 .0 76 27 1	0 .1 86 44 1	0 .1 86 44 1
P A 3	0 .0 74 57 6	0 .0 31 07 3	0 .1 61 01 7	0 .0 32 01 5	0 .0 39 54 8	0 .0 19 06 8	0 .1 33 17 2	0 .1 33 17 2
P A 4	0 .0 10 35 8	0 .0 12 38 6	0 .0 48 02 3	0 .0 38 13 6	0 .0 38 13 6	0 .0 38 13 6	0 .0 53 26 9	0 .0 53 26 9
P A 5	0 .1 01 69 5	0 .0 72 50 5	0 .0 44 06 8	0 .1 18 64 4	0 .0 76 27 1	0 .1 33 17 2	0 .1 33 17 2	

Table 4: The values of S_i

	H	H	H	H	H	H	H	H
	P C1	P C2	P C3	P C4	P C5	P C6	P C7	P C8
P A 1	1 .9 59 60 5	0 .9 85 55 3	0 .7 39 78 8	0 .9 43 25 9	0 .8 22 41	0 .8 22 41	0 .8 22 41	0 .8 22 41
P A 2	0 .9 67 34 7	0 .9 85 55 3	1 .9 42 50 9	0 .9 42 50 9	0 .9 42 50 9	1 .9 42 50 9	1 .9 42 50 9	1 .9 42 50 9
P A 3	0 .9 68 95 1	0 .9 02 65 7	0 .8 14 78 9	1 .6 61 66 2	0 .8 53 61 5	0 .7 65 15 7	0 .8 99 66 4	0 .9 39 19 5
P A 4	0 .8 14 78 9	0 .6 61 66 2	0 .8 53 61 5	0 .7 65 15 7	0 .8 99 66 4	0 .9 39 19 5	0 .9 39 19 5	0 .9 39 19 5
P A 5	0 .9 76 84 5	1 .9 76 84 5	0 .9 76 84 5	0 .9 76 84 5	1 .9 76 84 5	0 .9 76 84 5	1 .9 76 84 5	0 .9 76 84 5

For the aggregation techniques, the relative importance of options may be determined by using Eqs. (9,10,11). The coefficient was set at 0.5 for determining the relative importance of the various choices in the third aggregation approach. As well as its final rating, Table 5 shows the true significance of the options inside the compromise methods. Using expression, we can figure out the final importance of various options (12). Options are ordered according to Y_i , with the greater the k , the more desirable the option. The rank of alternatives is shown in figure 3. From figure 3. The best alternative is HPA2 and the worst alternative is HPA4.

Table 5: Shows the true significance of the options inside the compromise methods.

	Y_{ia}	Y_{ib}	Y_{ic}	Y_i
HPA 1	0.1594 41	2.99164 8	0.62278 9	1.92520 2
HPA 2	0.2560 11	6.42617 3	1 1	3.74123 9
HPA 3	0.2262 25	4.56749 2	0.88365 3	2.86259 4
HPA 4	0.1414 04	2 2	0.55233 6	1.43647
HPA 5	0.2169 2	5.42201 3	0.84731	3.16093 3

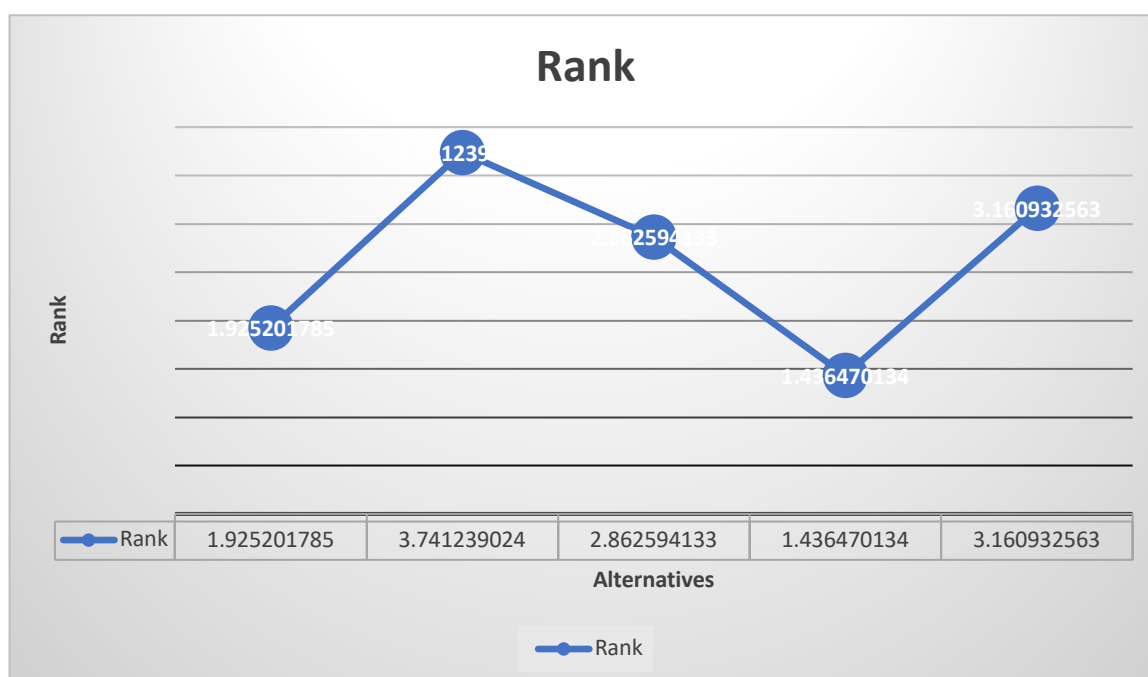


Figure 3. The rank of alternatives.

4. Conclusion

Energy production, storage, and transformation research and development activities are being conducted by industrialized nations to fulfill the increasing need for energy throughout time. Hydrogen is the world's smallest and most plentiful component, making it a vital source of energy. In addition to surface waters, we can also get hydrogen from the ocean's depths. The presence of H_2S in the Black Sea not only causes environmental damage by polluting the air and water, but it also promises a potential source of hydrogen energy. As a result, removing H_2S from the Black Sea's bottom and separating it into its constituent parts might transform the compound into a viable energy resource. Hydrogen generation from H_2S may be performed in both the main and coastal portions of the Black Sea by supporting adequate hydrogen production processes. This paper used three experts to evaluate 8 criteria and 5 alternatives. The COCOSO method is used to compute the weights of criteria and rank the alternatives.

References

- [1]E. Işıklı, N. Aydın, L. Bilgili, and A. Toprak, "Estimating fuel consumption in maritime transport," *Journal of Cleaner Production*, vol. 275, p. 124142, 2020.
- [2]M. Kabak and M. Dağdeviren, "Prioritization of renewable energy sources for Turkey by using a hybrid MCDM methodology," *Energy conversion and management*, vol. 79, pp. 25–33, 2014.
- [3]P. Nikolaidis and A. Poullikkas, "A comparative overview of hydrogen production processes," *Renewable and sustainable energy reviews*, vol. 67, pp. 597–611, 2017.
- [4]B. Yildiz and M. S. Kazimi, "Efficiency of hydrogen production systems using alternative nuclear energy technologies," *International Journal of Hydrogen Energy*, vol. 31, no. 1, pp. 77–92, 2006.
- [5]M. Marzband, E. Yousefnejad, A. Sumper, and J. L. Domínguez-García, "Real time experimental implementation of optimum energy management system in standalone microgrid by using multi-layer ant colony optimization," *International Journal of Electrical Power & Energy Systems*, vol. 75, pp. 265–274, 2016.
- [6]W. E. Piers, A. J. V Marwitz, and L. G. Mercier, "Mechanistic aspects of bond activation with perfluoroarylboranes," *Inorganic Chemistry*, vol. 50, no. 24, pp. 12252–12262, 2011.
- [7]M. Momirlan and T. N. Veziroglu, "Current status of hydrogen energy," *Renewable and sustainable energy reviews*, vol. 6, no. 1–2, pp. 141–179, 2002.
- [8]P. Fragiaco and M. Genovese, "Technical-economic analysis of a hydrogen production facility for power-to-gas and hydrogen mobility under different renewable sources in Southern Italy," *Energy Conversion and Management*, vol. 223, p. 113332, 2020.
- [9]S. Seker and N. Aydın, "Assessment of hydrogen production methods via integrated MCDM approach under uncertainty," *International Journal of Hydrogen Energy*, vol. 47, no. 5, pp. 3171–3184, 2022.
- [10]S. Yu and Y. Zhou, "Photochemical decomposition of hydrogen sulfide," *Adv. Catal. Mater. Photocatal. Other Curr. Trends*, vol. 3, pp. 269–293, 2016.
- [11]I. Kaya, M. Colak, and F. Terzi, "A comprehensive review of fuzzy multi criteria decision making methodologies for energy policy making," *Energy Strategy Reviews*, vol. 24, pp. 207–228, 2019.
- [12]J. R. San Cristóbal, "Multi-criteria decision-making in the selection of a renewable energy project in Spain: The Vikor method," *Renewable energy*, vol. 36, no. 2, pp. 498–502, 2011.
- [13]L. Cradden, C. Kalogeri, I. M. Barrios, G. Galanis, D. Ingram, and G. Kallos, "Multi-criteria site selection for offshore renewable energy platforms," *Renewable energy*, vol. 87, pp. 791–806, 2016.
- [14]A. M. Patel and S. K. Singal, "Optimal component selection of integrated renewable energy system for power generation in stand-alone applications," *Energy*, vol. 175, pp. 481–504, 2019.
- [15]M. Kumar and C. Samuel, "Selection of best renewable energy source by using VIKOR method," *Technology and Economics of Smart Grids and Sustainable Energy*, vol. 2, no. 1, pp. 1–10, 2017.
- [16]S. Lee, G. Mogi, S. Lee, and J. Kim, "Prioritizing the weights of hydrogen energy technologies in the sector of the hydrogen economy by using a fuzzy AHP approach," *International Journal of Hydrogen Energy*, vol. 36, no. 2, pp. 1897–1902, 2011.
- [17]S. A. A. Shah, "Feasibility study of renewable energy sources for developing the hydrogen economy in Pakistan," *International Journal of Hydrogen Energy*, vol. 45, no. 32, pp. 15841–15854, 2020.
- [18]N. H. Afgan, A. Veziroglu, and M. G. Carvalho, "Multi-criteria evaluation of hydrogen system options," *International Journal of Hydrogen Energy*, vol. 32, no. 15, pp. 3183–3193, 2007.
- [19]P. A. Pilavachi, S. D. Stephanidis, V. A. Pappas, and N. H. Afgan, "Multi-criteria evaluation of hydrogen and natural gas fuelled power plant technologies," *Applied Thermal Engineering*, vol. 29, no. 11–12, pp. 2228–2234, 2009.
- [20]A. Manzardo, J. Ren, A. Mazzi, and A. Scipioni, "A grey-based group decision-making methodology for the selection of hydrogen technologies in life cycle sustainability perspective," *International journal of hydrogen energy*, vol. 37, no. 23, pp. 17663–17670, 2012.
- [21]M. Karatas, "Hydrogen energy storage method selection using fuzzy axiomatic design and analytic hierarchy process," *International Journal of Hydrogen Energy*, vol. 45, no. 32, pp. 16227–16238, 2020.
- [22]P.-L. Chang, C.-W. Hsu, and P.-C. Chang, "Fuzzy Delphi method for evaluating hydrogen production technologies," *International journal of hydrogen energy*, vol. 36, no. 21, pp. 14172–14179, 2011.
- [23]P.-L. Chang, C.-W. Hsu, and C.-Y. Lin, "Assessment of hydrogen fuel cell applications using fuzzy multiple-criteria decision making method," *Applied energy*, vol. 100, pp. 93–99, 2012.
- [24]A. Mostafaeipour and E. Jooyandeh, "Prioritizing the locations for hydrogen production using a hybrid wind-solar system: A case study," *Advances in Energy Research*, vol. 5, no. 2, p. 107, 2017.
- [25]O. Alavi, A. Mostafaeipour, and M. Qolipour, "Analysis of hydrogen production from wind energy in the southeast of Iran," *International Journal of Hydrogen Energy*, vol. 41, no. 34, pp. 15158–

15171, 2016.

[26]J. Ren, A. Manzardo, S. Toniolo, and A. Scipioni, “Sustainability of hydrogen supply chain. Part II: Prioritizing and classifying the sustainability of hydrogen supply chains based on the combination of extension theory and AHP,” *International journal of hydrogen energy*, vol. 38, no. 32, pp. 13845–13855, 2013.

[27]B. Vučijak, T. Kupusović, S. Midžić-Kurtagić, and A. Čerić, “Applicability of multicriteria decision aid to sustainable hydropower,” *Applied Energy*, vol. 101, pp. 261–267, 2013.

[28]M. Yazdani, P. Zarate, E. K. Zavadskas, and Z. Turskis, “A Combined Compromise Solution (CoCoSo) method for multi-criteria decision-making problems,” *Management Decision*, 2018.

[29]F. Ecer, D. Pamucar, S. H. Zolfani, and M. K. Eshkalag, “Sustainability assessment of OPEC countries: Application of a multiple attribute decision making tool,” *Journal of Cleaner Production*, vol. 241, p. 118324, 2019.

[30]X. Peng, X. Zhang, and Z. Luo, “Pythagorean fuzzy MCDM method based on CoCoSo and CRITIC with score function for 5G industry evaluation,” *Artificial Intelligence Review*, vol. 53, no. 5, pp. 3813–3847, 2020.

[31]S. H. Zolfani, P. Chatterjee, and M. Yazdani, “A structured framework for sustainable supplier selection using a combined BWM-CoCoSo model,” in *International scientific conference in business, management and economics engineering. Vilnius, Lithuania*, 2019, pp. 797–804.

[32]F. Ecer and D. Pamucar, “Sustainable supplier selection: A novel integrated fuzzy best worst method (F-BWM) and fuzzy CoCoSo with Bonferroni (CoCoSo’B) multi-criteria model,” *Journal of Cleaner Production*, vol. 266, p. 121981, 2020.

[33]X. Mi and H. Liao, “Renewable energy investments by a combined compromise solution method with stochastic information,” *Journal of Cleaner Production*, vol. 276, p. 123351, 2020.

[34]A. I. Maghsoodi, S. Soudian, L. Martínez, E. Herrera-Viedma, and E. K. Zavadskas, “A phase change material selection using the interval-valued target-based BWM-CoCoMULTIMOORA approach: A case-study on interior building applications,” *Applied Soft Computing*, vol. 95, p. 106508, 2020.

[35]M. Yazdani, P. Chatterjee, D. Pamucar, and S. Chakraborty, “Development of an integrated decision making model for location selection of logistics centers in the Spanish autonomous communities,” *Expert Systems with Applications*, vol. 148, p. 113208, 2020.

[36]X. Peng and H. Huang, “Fuzzy decision making method based on CoCoSo with critic for financial risk evaluation,” *Technological and Economic Development of Economy*, vol. 26, no. 4, pp. 695–724, 2020.

[37]H. Lai, H. Liao, Z. Wen, E. K. Zavadskas, and A. Al-Barakati, “An improved CoCoSo method with a maximum variance optimization model for cloud service provider selection,” *Engineering Economics*, vol. 31, no. 4, pp. 411–424, 2020.

[38]A. Ulutaş, C. B. Karakuş, and A. Topal, “Location selection for logistics center with fuzzy SWARA and CoCoSo methods,” *Journal of Intelligent & Fuzzy Systems*, vol. 38, no. 4, pp. 4693–4709, 2020.

[39]X. Peng and F. Smarandache, “A decision-making framework for China’s rare earth industry security evaluation by neutrosophic soft CoCoSo method,” *Journal of Intelligent & Fuzzy Systems*, vol. 39, no. 5, pp. 7571–7585, 2020.