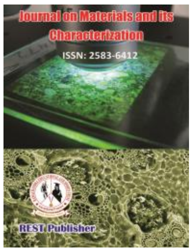
Journal on Materials and its Characterization
Vol: 2(3), September 2023
REST Publisher; ISBN: 2583-6412
Website: http://restpublisher.com/journals/jmc/
DOI: https://doi.org/10.46632/jmc/2/3/5



A Study On Hydrogen Production Methods Using the TOPSIS Method

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Abstract. *For humanity and social health, energy is essential. Hydrogen is one of several potential energy carriers for green technologies. The Black Sea seas are a rich source of "hydrogen Sulphide (H_2S)", which is also a known environmental contaminant. The main drivers of hydrogen technology are global warming and the depletion of fossil fuels. Additionally, the nation's economies that depend on the importation of conventional fuel have been exposed as a result of the rising prices of these fuels due to the rising energy demand. Future renewable technologies need to be carbon-free and renewable to combat climate change on a long-term basis and reduce our reliance on foreign oil. Hydrogen can be produced using a variety of traditional and unconventional sources of energy, including "natural gas, coal, nuclear power, biomass, solar, and wind". The most ecological hydrogen production method using H2S is chosen in this research using the "technique for order of preference by similarity to ideal solution (TOPSIS)", taking into account sustainable factors which are inescapable in energy managerial problems. The "Equal Weights Method (EWM)" allocates weights to many criteria, most notably relevance weights. The rank of alternatives using the TOPSIS method for Thermal is second, Electrochemical is third, Thermochemical is fourth, Photochemical is fifth and Plasma is first. The analysis's findings indicate that plasma is the best and most suitable method for producing hydrogen in terms of delivering high conversion efficiency and environmentally friendly operations, such as handling, shipping, and storing dangerous chemicals.*
Keywords: *Hydrogen production, H_2S, Production methods, ecologically feasibility, efficiency, process simplicity and energy requirement*

1. INTRODUCTION

The continued burning of fossil fuels releases "greenhouse gases (GHG)" into the atmosphere, which constitute a major danger to the environment and subsequent climate change. Additionally, the nation's economy which depends on the import of traditional fuel has been exposed as a result of the rising prices of these fuels due to the rising energy demand. Future power sources must be carbon-free and eco-friendly to address climate change on a long-term basis and reduce our reliance on foreign oil [1]. Renewable energy alternatives can reduce reliance on fossil resources and cut back on emissions that are bad for the environment. Hydrogen has almost no end-use emissions and never runs out of resources, making it a perfect source of sustainable energy. The following are just a few of hydrogen's benefits [2,3]:

(i) great efficiency in the conversion of energy;
(ii) water-based production with zero emissions;
(iii) abundance;
(iv) many types of preservation "(e.g., gaseous, liquid, or in together with metal hydrides)";
(v) protracted travelling;
(vi) the simplicity of conversion to different energy sources;
(vii) greater HHV and LHV compared to the majority of traditional fossil fuels. On the other side, the majority of methods for producing hydrogen are still in their infancy, leading to high manufacturing costs and/or inefficient use of resources.

Throughout these application domains, hydrogen has the potential to offer clean, effective, dependable, and economical solutions with large social advantages. According to the research, hydrogen can facilitate the widespread adoption and commercial penetration of alternative energy sources. To store irregular renewable energy, hydrogen is an essential addition to electricity on the end-user (service) side, which is a significant step towards the greening of the power systems [4,5]. Even though hydrogen has numerous industrial uses, likely, it will soon overtake oil as the primary fuel for transportation. This is brought on by the depletion of crude oil as well as the environmental effects of using gasoline and diesel fuel.

Politicians and the general public are becoming more conscious of how conventional transportation services contribute to environmental damage. Large urban areas are highly affected by exhaust fume emissions, such as "nitrogen and carbon oxides, particulate matter, or hydrocarbons". Along with new approaches to reducing exhaust pollutants following ever stricter rules, innovative technical solutions for road mobility are being researched and put into practice [6,7]. Because it requires a lot of energy, thermal breakdown of H2S to H2 and sulphur has not traditionally been the preferred approach. However, due to how straightforward it is, it might be favoured. According to studies, changing the temperature and pressure significantly affects how the resultant sulphur products' molecules are put together [8]. The Black Sea waters are a rich source of hydrogen sulphide (H2S), which is also a known environmental contaminant. This study's major objective is to assess whether "Thermal, Electrochemical, Thermochemical, Photochemical, and Plasma" are superior breakdown methods to other technologies from a sustainability perspective. The most suitable hydrogen generation technique is chosen based on "economically feasible, ecologically feasible, efficiency, process simplicity, and energy requirement" as sustainable factors.

2. MATERIALS AND METHODS

To evaluate MCDM challenges, the evaluation method "TOPSIS" is frequently employed. It can be applied to a wide range of practical tasks, including assessing an industry's financial sustainability, contrasting economic outcomes, and investing in state-of-the-art manufacturing methods. But there are certain restrictions as well [9]. The "TOPSIS method" does, unfortunately, have some serious problems. One issue with TOPSIS is the potential for "rank reversal" which occurs occasionally. The "order of preference for the alternatives" varies depending on whether a choice is introduced to or withdrawn from the decision-making issue [10]. A "Total rank reversal" occurs when a solution is added to or withdrawn from and the options that were previously considered to be the best are now the worst. A range of possibilities must be looked at and assessed in "MCDM" based on some factors. The goal of MCDM is to give the decision-maker the freedom to choose from a variety of options. As a result, numerous conflicting criteria are usually present in practical circumstances, making it impossible for any one solution to concurrently meet all of the criteria [11,12]. As a result, the choice is a balanced one based on the decision objectives. The optimum outcome will come from the option that is "the Negative Ideal Solution (NIS) and most similar to the Positive Ideal Solution (PIS)".

Step 1: The decision matrix X, which displays "how various options perform concerning certain criteria", is created.

$$x_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

Step 2: Weights for the criteria are expressed as

$$w_j = [w_1 \cdots w_n], \quad where, \sum_{j=1}^{n}(w_1 \cdots w_n) = 1 \quad (2)$$

Step 3: The matrix x_{ij}'s normalized values are computed as

$$n_{ij} = \frac{x_{ij}}{\sqrt[2]{\sum_{i=1}^{m} x_{ij}^2}} \quad (3)$$

"Weighted normalized matrix N_{ij}" is calculated by the following formula

$$N_{ij} = w_j \times n_{ij} \quad (4)$$

Step 4: To begin, let's establish the "ideal best and ideal worst values": Here, we need to decide if the influence is "+" or "-. " If a column has a "+" impact, its greatest value is the "ideal best value for that column," and if it has a "-" influence, its poorest number is the "ideal worst value."

Step 5: Now we need to find "the difference between each response from the ideal best",

$$S_i^+ = \sqrt{\sum_{j=1}^{n}(N_{ij} - A_j^+)^2} \quad for\ i \in [1, m]\ and\ \ j \in [1, n] \quad (5)$$

Step 6: Now we need to find "the difference between each response from the ideal worst",

$$S_i^- = \sqrt{\sum_{j=1}^{n}(N_{ij} - A_j^-)^2} \quad for\ i \in [1, m]\ and\ \ j \in [1, n] \quad (6)$$

Step 7: Now we need to find “the Closeness coefficient of i_{th} alternative”

$$CC_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad where, 0 \leq CC_i \leq 1, i \in [1, m] \qquad (7)$$

The number of "The Closeness Coefficient" shows how much better the options are in relation. A "significantly worse alternative" is indicated by a smaller, CCi. and a "substantially better alternative" by a larger, CCi.

The Black Sea waters are a rich source of hydrogen sulphide (H2S), which is also a known environmental contaminant. This study's major objective is to assess whether "Thermal, Electrochemical, Thermochemical, Photochemical, and Plasma" are superior breakdown methods to other technologies from a sustainability perspective. The most suitable hydrogen generation technique is chosen based on "economically feasible, ecologically feasible, efficiency, process simplicity, and energy requirement" as sustainable factors. **Economically viable:** If hydrogen and sulphur are collected, H2S might be valuable financially. For H2S thermal decomposition, the problem of economic viability is crucial. Utilizing various operational needs, H2 production can be made more economically feasible. [15]. **Ecologically viable:** The H2S decomposition technique chosen must support worldwide goals for reducing environmental damage, waste, and other issues. [16]. **Efficiency:** Productivity is defined as obtaining worthwhile outcomes while utilising inputs. Applying more efficient supporting resources, such as thermal, energy, catalyst, etc., can boost conversion productivity. [17]. **Process simplification:** Operationally simple processes have an advantage in responses. This entails safe processes, a reduction of waste pollutants, and commercialization [18]. **Energy requirement:** Multiphase, energy-intensive processes are needed for the breakdown of H2S. Depending on the process or technology utilised for breakdown, a certain amount of energy is needed to produce one unit of hydrogen. In general, the transformation improves as the additional energy rises [19].

3. Analysis and dissection

TABLE 1. Assessment of H2S Production Methods

	Economically feasible	Ecologically feasible	Efficiency	Process simplicity	Energy requirement
Thermal	4	6	4	4	5
Electrochemical	5	3	5	6	6
Photochemical	3	2	4	5	5
Thermochemical	3	5	4	3	5
Plasma	6	4	4	6	5

Table 1 shows the Assessment of H2S Production Methods according to experts. economically feasibility, ecologically feasibility, efficiency, process simplicity and energy requirement are used to evaluate the H2S Production Methods.

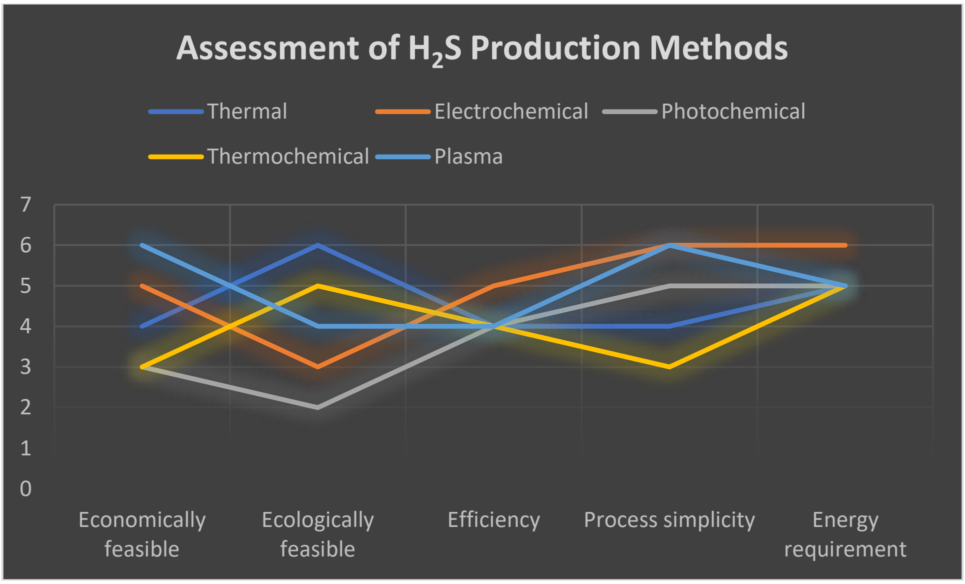

FIGURE 1. Assessment of H2S Production Methods

Figure 1 shows a graphical view of the Assessment of H2S Production Methods according to experts. economically feasibility, ecologically feasibility, efficiency, process simplicity and energy requirement are used to evaluate the H2S Production Methods.

TABLE 2. Normalized Data

0.4104	0.6325	0.4240	0.3621	0.4287
0.5130	0.3162	0.5300	0.5432	0.5145
0.3078	0.2108	0.4240	0.4527	0.4287
0.3078	0.5270	0.4240	0.2716	0.4287
0.6156	0.4216	0.4240	0.5432	0.4287

The normalized matrix of the Ratings of the performance of the selection of the six-sigma project is displayed in Table 2 above. This matrix was produced using equation three.

TABLE 3. Weight

0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2

The preferred weight for the evaluation parameters is shown in Table 3. In this case, weights are equally distributed among " economically feasibility, ecologically feasibility, efficiency, process simplicity and energy requirement ". The sum of weights distributed equals one.

TABLE 4. Weighted normalized decision matrix

0.0821	0.1265	0.0848	0.0724	0.0857
0.1026	0.0632	0.1060	0.1086	0.1029
0.0616	0.0422	0.0848	0.0905	0.0857
0.0616	0.1054	0.0848	0.0543	0.0857
0.1231	0.0843	0.0848	0.1086	0.0857

Table 4 shows the weighted normalized matrix of the decision matrix and it is calculated by table 2 and table 3 using equation 4.

TABLE 5. Positive Matrix

0.1231	0.1265	0.1060	0.1086	0.0857
0.1231	0.1265	0.1060	0.1086	0.0857
0.1231	0.1265	0.1060	0.1086	0.0857
0.1231	0.1265	0.1060	0.1086	0.0857
0.1231	0.1265	0.1060	0.1086	0.0857

Table 5 shows the positive matrix calculated by using table 4. The ideal best for a column is the maximum value of that column in table 4.

TABLE 6. Negative matrix

0.0616	0.0422	0.0848	0.0543	0.1029
0.0616	0.0422	0.0848	0.0543	0.1029
0.0616	0.0422	0.0848	0.0543	0.1029
0.0616	0.0422	0.0848	0.0543	0.1029
0.0616	0.0422	0.0848	0.0543	0.1029

Table 6 shows the negative matrix calculated by using table 4. The Ideal best for a column is the minimum value in that column in table 4.

TABLE 7. SI Plus and Si negative

Methods	Si+	Si-
Thermal	0.0587	0.0903
Electrochemical	0.0687	0.0744
Photochemical	0.1081	0.0401
Thermochemical	0.0874	0.0655
Plasma	0.0472	0.0939

Table 7 shows the "Si plus and Si negative values". The difference between each response from the "ideal best (S_i^+)" is found utilizing equation 5 and the difference between each response from the "ideal worst (S_i^-)" is found utilizing equation 6.

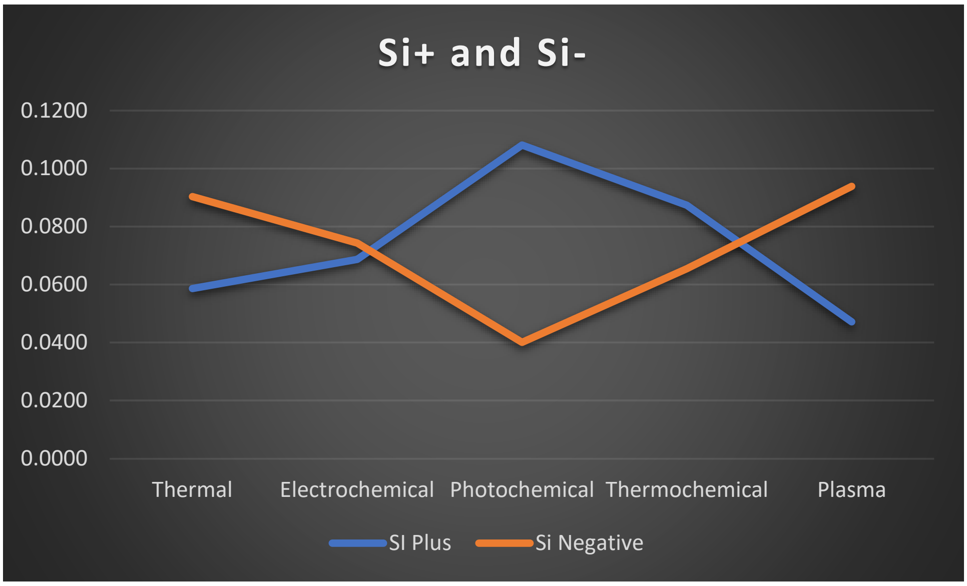

FIGURE 2. SI Plus and Si negative

The figure illustrates the "Si plus and Si negative values" from the analysis. The difference between each response from the "ideal best (S_i^+)" is found utilizing equation 5 and the difference between each response from the "ideal worst (S_i^-)" is found utilizing equation 6.

TABLE 8. Closeness coefficient

Methods	Ci
Thermal	0.6061
Electrochemical	0.5199
Photochemical	0.2705
Thermochemical	0.4286
Plasma	0.6655

Table 8 demonstrates the value of CCi. It is calculated by using equation 7. Here Closeness coefficient value for Thermal is 0.6061, Electrochemical is 0.5199, Thermochemical is 0.4286, Photochemical is 0.2705 and Plasma is 0.6655.

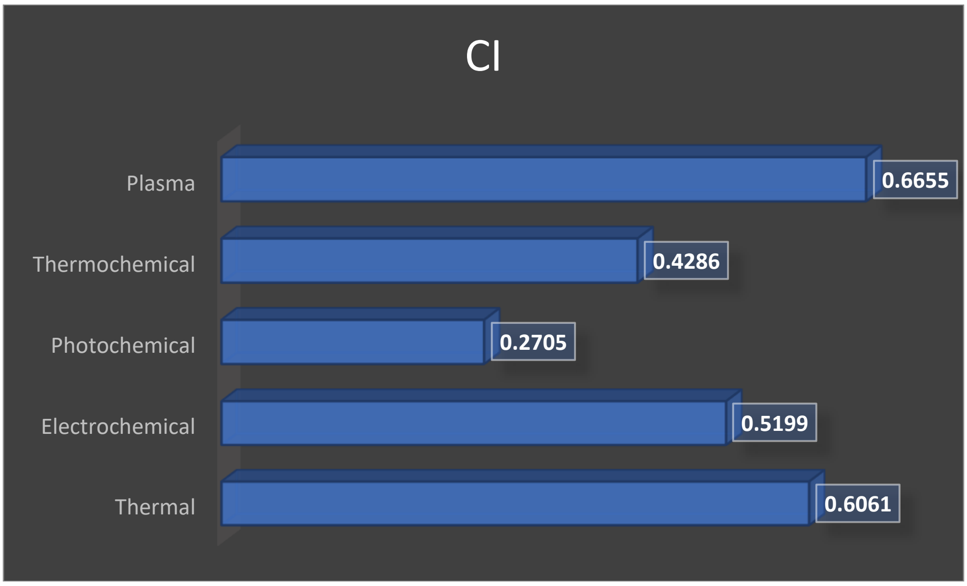

FIGURE 3. Closeness Coefficient (CCi)

Figure 3 illustrates the graphical representation of CCi. It is calculated by using equation 7. Here Closeness coefficient value for Thermal is 0.6061, Electrochemical is 0.5199, Thermochemical is 0.4286, Photochemical is 0.2705 and Plasma is 0.6655.

TABLE 9. Rank

Methods	Rank
Thermal	**2**
Electrochemical	**3**
Photochemical	**5**
Thermochemical	**4**
Plasma	**1**

Table 9 shows the analysis of the Assessment of H2S Production Methods. Here rank of Thermal is second, Electrochemical is third, Thermochemical is fourth, Photochemical is fifth and Plasma is first.

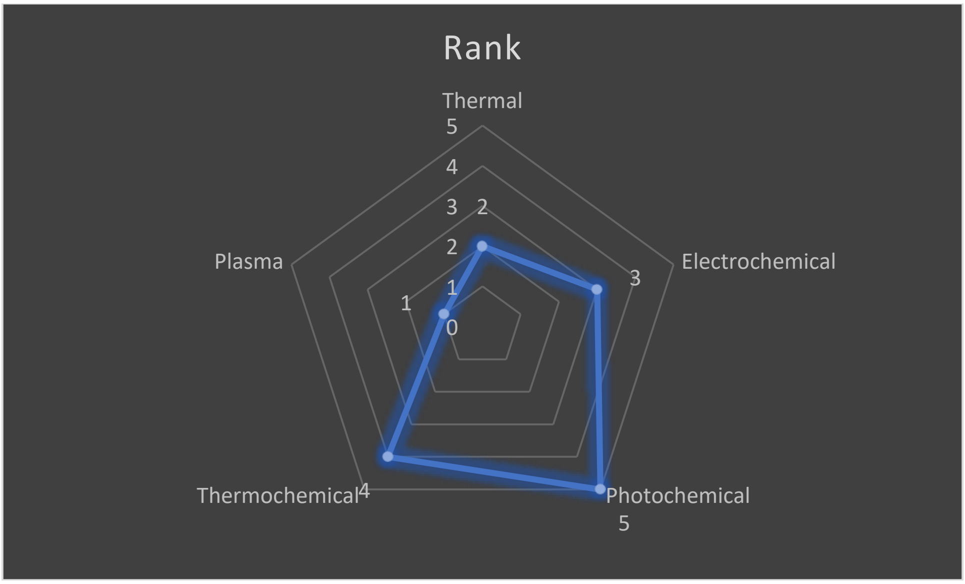

FIGURE 4. Rank

Figure 4 illustrates the ranking of Ui from Table 9. Here rank of alternatives using the TOPSIS method for Thermal is second, Electrochemical is third, Thermochemical is fourth, Photochemical is fifth and Plasma is first. The result of the analysis shows that plasma is selected as the best and most appropriate hydrogen production method in terms of providing high efficiency in conversion and sustainable processes, i.e., handling, transporting and storing harmful chemicals.

4. CONCLUSION

One of the key issues of the twenty-first century is finding environmentally friendly and sustainable power solutions to meet the rising global energy demand. To meet the rising global power demand while reducing reliance on fossil fuels and related environmental harm, clean energy technologies are required. Economic, environmental, and social advantages are the three basic categories into which the advantages of cleaner energy sources can be divided. The ultimate goal is to have clean and efficient energy applications and systems, which are anticipated to offer higher quality and efficiency while lowering costs and environmental effects. To address the demands of the current societies without endangering the future of the following generations, they are also anticipated to give solutions for improved resource management. Both "hydrogen and electricity" should be created utilising energy and resource supplies that are eco-friendly to solve current and potential “environmental, financial, and technical challenges". To guarantee the energy stability of future generations, these alternatives should also be renewable, or at the very least, they shouldn't have a restricted nature like that of fossil fuels. Along with the specifications for the materials and energy sources, both the methods used to produce electricity and hydrogen must be affordable, effective, and have little to no negative effects on the environment and human health. The rank of alternatives using the TOPSIS method for Thermal is second, Electrochemical is third, Thermochemical is fourth, Photochemical is fifth and Plasma is first. According to the analysis's findings, plasma is the most suitable technology for producing hydrogen since it offers high conversion efficiency and environmentally friendly operations, such as safe handling, transportation, and storage of hazardous chemicals.

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