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Multi-Criteria Decision Making Model for Analysis Hydrogen Production for Economic Feasibility and Sustainable Energy

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Abstract

Hydrogen production is pivotal to achieving economic feasibility and sustainable energy systems. This study provides an overview of the criteria for the economic feasibility of hydrogen production and sustainable energy, highlighting the key factors contributing to its viability. Factors such as cost-effectiveness, energy efficiency, carbon emissions, feedstock availability and sustainability, scalability, infrastructure compatibility, water usage, life cycle assessment, technological readiness, and policy support are discussed. By considering these criteria, hydrogen production methods can be evaluated and optimized to ensure economic viability and contribute to the development of sustainable energy systems. We used the multi-criteria decision-making (MCDM) model for various criteria and factors. We used the MULTIMOORA method as an MCDM model to analyse the hydrogen production criteria and select the best alternatives. We compute the weights of criteria using the average method. Then, we used the MULTIMOORA method to rank the other options. The results show that cost-effectiveness has the highest weight, followed by energy efficiency, and the policy criterion has the lowest weight. Then, we used the sensitivity analysis to ensure the stability of the results.

Keywords: Multi-Criteria Decision Making; MULTIMOORA; Economic feasibility; Sustainability.

1 | Introduction

Hydrogen, the most abundant element in the universe, holds tremendous potential as a versatile and clean energy carrier. Its production represents a critical pathway towards achieving economic feasibility and sustainable energy systems [1, 2]. Hydrogen can be used as a transportation fuel, a renewable energy storage medium, and a feedstock for various industrial processes. However, efficient and sustainable hydrogen production methods are essential to fully realizing its benefits [3–6]. The production of hydrogen involves the splitting of water molecules (electrolysis) or the reforming of hydrocarbon-based fuels such as natural gas or biomass. These processes can be energy-intensive and may generate carbon emissions unless appropriate

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measures are taken [2, 7-8]. Therefore, ensuring economic feasibility and sustainability in hydrogen production requires careful consideration of several vital factors [9–11].

This study examines the criteria for hydrogen production, economic feasibility, and sustainable energy. It explores the various aspects contributing to the viability of hydrogen production methods, considering cost-effectiveness, energy efficiency, carbon emissions, feedstock availability and sustainability, scalability, infrastructure compatibility, water usage, life cycle assessment, technological readiness, and policy support [12–14].

By evaluating hydrogen production methods against these criteria, decision-makers can make informed choices to promote economically viable and sustainable hydrogen production. Such decisions can lead to the development of efficient and environmentally friendly processes, ultimately driving the transition towards a cleaner and more sustainable energy future [15–18].

The selection of technique relies on the resources available and the intended use of hydrogen. Each approach has pros and cons of its own. A decision-making approach must be used to examine these elements to assess the benefits and drawbacks of each component. MCDM evaluates and prioritises potential solutions by considering several contradictory factors [19, 20]. MCDM may assess and compare several choices for generating, distributing, and utilising hydrogen as a fuel in hydrogen resource management. Some assessment criteria include economic cost, environmental effect, technological feasibility, and popularity with society [21–23].

MCDM has emerged as a reliable method for delving into complex problems from the standpoint of critically evaluating the alternatives in light of several criteria to choose the most logical options. We used the MULTIMOORA method to analyze the criteria for hydrogen production [24–26].

2 | MULTIMOORA Method

The MULTIMOORA method has three steps: ratio system, reference point, and full multiplicative form. The alternatives are ranked based on three steps, and then the final rank is computed by the dominance theory [27-29]. Figure 1 shows the steps of the MULTIMOORA method.

Figure 1. The steps of the MULTIMOORA method.

Step 1. Building of Decision Making

There are a set of criteria $HPC = (HPC_1, HPC_2, \dots HPC_m); i = 1,2, \dots m$ and a set of alternatives $HPA = (HPA_1, HPA_2, \dots HPA_n); j = 1,2, \dots n$.

Step 2. Normalize the decision making.

$$u_{ij} = \frac{a_{ij}}{\sum_{j=1}^{m} a_{ij}} \quad (1)$$

Step 3. Compute the weight of decision making.

The weights of criteria are computed w_j

Step 4. Compute the ratio system

$$q_i = q_i^+ - q_i^- \quad (2)$$

$$q_i^+ = \sum_{j=1}^{m} w_i u_{ij} \quad (3)$$

$$q_i^- = \sum_{j=1}^{m} w_i u_{ij} \quad (4)$$

Step 5. Compute the reference point

$$g_i^{max} = \max_j \left(w_j \left| u_j^* - u_{ij} \right| \right) \quad (5)$$

$$u_j^* = \begin{cases} \max_i u_{ij} & positive\ criteria \\ \min_i u_{ij} & negative\ criteria \end{cases} \quad (6)$$

Step 6. Compute the full multiplicative form

$$f_i = \frac{s_i}{z_i} \quad (7)$$

$$s_i = \prod_{j=1}^{m} w_i u_{ij}\ positive\ criteria \quad (8)$$

$$z_i = \prod_{j=1}^{m} w_i u_{ij}\ negative\ criteria \quad (9)$$

Step 7. Compute the final rank.

3 | Results

We gathered ten criteria and 15 alternatives in this study to analysis the hydrogen production to achieve sustainability.

Criteria for Hydrogen Production Economic Feasibility and Sustainable Energy:

- Cost-effectiveness: One of the critical criteria for hydrogen production is its economic feasibility. The cost of hydrogen production should be competitive with alternative energy sources to ensure widespread adoption. Factors such as capital investment, operational costs, and the availability and cost of feedstock play a crucial role in determining the economic viability of hydrogen production methods.

- Energy efficiency: The energy efficiency of hydrogen production processes is essential for sustainable energy production. The energy required to produce hydrogen should be minimized to ensure a favourable energy balance. High energy efficiency reduces the environmental impact and improves the sustainability of hydrogen production systems.

- Carbon emissions: hydrogen production methods should aim to minimize or eliminate carbon emissions. Carbon capture and utilization technologies can reduce or capture carbon emissions associated with hydrogen production. Green hydrogen, produced from renewable energy sources without carbon emissions, is desirable for sustainable energy applications.

- Feedstock availability and sustainability: The availability and sustainability of feedstock used for hydrogen production are critical factors. Hydrogen can be produced from diverse sources such as water, natural gas, biomass, or waste materials. Sustainable feedstock options, such as renewable sources or waste materials, should be prioritized to minimize environmental impact and ensure long-term availability.

- Scalability: Scalability is crucial for hydrogen production methods' widespread adoption and commercial viability. The production systems should be able to scale up to meet increasing demand without compromising efficiency or incurring excessive costs. Scalability ensures that hydrogen can be produced sufficiently to support various applications, including transportation, energy storage, and industrial processes.

- Infrastructure compatibility: The existing energy infrastructure plays a significant role in hydrogen production's economic feasibility and sustainability. Compatibility with existing infrastructure, such as pipelines, storage facilities, and distribution networks, can reduce the costs associated with hydrogen transportation and distribution. Adapting or expanding infrastructure to accommodate hydrogen production and utilization is essential for successfully integrating into the energy system.

- Water usage: Hydrogen production methods that require water should consider the availability and sustainable use of water resources. Water scarcity is a global concern, and hydrogen production processes should aim to minimize water consumption or utilize alternative water sources, such as wastewater or seawater, to ensure sustainable water management.

- Life cycle assessment: A comprehensive life cycle assessment (LCA) of hydrogen production methods is crucial for evaluating their environmental impact. LCA considers the entire life cycle of hydrogen production, including feedstock extraction, processing, transportation, and end-use. It assesses factors such as resource depletion, greenhouse gas emissions, and other environmental impacts to ensure the sustainability of hydrogen production methods.

- Technological readiness and innovation: The technological readiness and potential for innovation in hydrogen production methods are crucial for continuous improvement and cost reduction. Research and development efforts should focus on advancing technologies, such as electrolysis, biomass conversion, or photocatalysis, to improve efficiency, reduce costs, and enhance the sustainability of hydrogen production.

- Policy and regulatory support: Government policies and regulations significantly promote economic feasibility and sustainable energy production from hydrogen. Supportive policies, such as financial incentives, carbon pricing, research funding, and regulatory frameworks, can encourage investment, promote innovation, and create a favourable market environment for hydrogen production.

Hydrogen production methods can be evaluated for their economic feasibility and contribution to sustainable energy production by considering these criteria. Balancing cost-effectiveness, energy efficiency, carbon emissions, feedstock sustainability, scalability, infrastructure compatibility, water usage, life cycle assessment, technological readiness, and policy support is essential for realizing the full potential of hydrogen as a sustainable energy carrier.

Step 1. Building of Decision Making between criteria and 15 alternatives by the crisp values between 1 and 9.

Step 2. Normalize the decision making by Eq. (1) as shown in Table 1.

Table 1. The normalization decision matrix.

	HPC_1	HPC_2	HPC_3	HPC_4	HPC_5	HPC_6	HPC_7	HPC_8	HPC_9	HPC_{10}
HPA_1	0.023255814	0.059524	0.092784	0.088889	0.078652	0.045977	0.103448	0.070588	0.088889	0.043011
HPA_2	0.069767442	0.107143	0.051546	0.066667	0.033708	0.022989	0.011494	0.047059	0.055556	0.053763
HPA_3	0.034883721	0.059524	0.092784	0.088889	0.067416	0.091954	0.103448	0.058824	0.066667	0.064516
HPA_4	0.069767442	0.035714	0.092784	0.044444	0.05618	0.068966	0.022989	0.035294	0.1	0.096774
HPA_5	0.023255814	0.071429	0.061856	0.044444	0.05618	0.068966	0.022989	0.105882	0.033333	0.086022
HPA_6	0.058139535	0.02381	0.051546	0.033333	0.089888	0.068966	0.034483	0.070588	0.022222	0.021505
HPA_7	0.046511628	0.059524	0.020619	0.055556	0.044944	0.103448	0.068966	0.023529	0.055556	0.032258
HPA_8	0.081395349	0.095238	0.030928	0.022222	0.078652	0.057471	0.103448	0.058824	0.066667	0.064516
HPA_9	0.093023256	0.107143	0.061856	0.066667	0.101124	0.022989	0.091954	0.094118	0.1	0.053763
HPA_{10}	0.104651163	0.071429	0.092784	0.1	0.067416	0.057471	0.057471	0.035294	0.088889	0.043011
HPA_{11}	0.069767442	0.059524	0.072165	0.088889	0.05618	0.034483	0.08046	0.023529	0.055556	0.086022
HPA_{12}	0.104651163	0.047619	0.082474	0.077778	0.089888	0.103448	0.045977	0.070588	0.088889	0.096774
HPA_{13}	0.093023256	0.083333	0.092784	0.066667	0.05618	0.08046	0.091954	0.105882	0.055556	0.075269
HPA_{14}	0.058139535	0.083333	0.082474	0.1	0.078652	0.091954	0.057471	0.105882	0.044444	0.086022
HPA_{15}	0.069767442	0.035714	0.020619	0.055556	0.044944	0.08046	0.103448	0.094118	0.077778	0.096774

Step 3. Compute the weight of decision making by the average method as shown in Figure 2. Then compute the weighted normalized decision matrix as shown in Table 2. We observed the cost effectiveness criterion is the highest weight and policy criterion is the least weight.

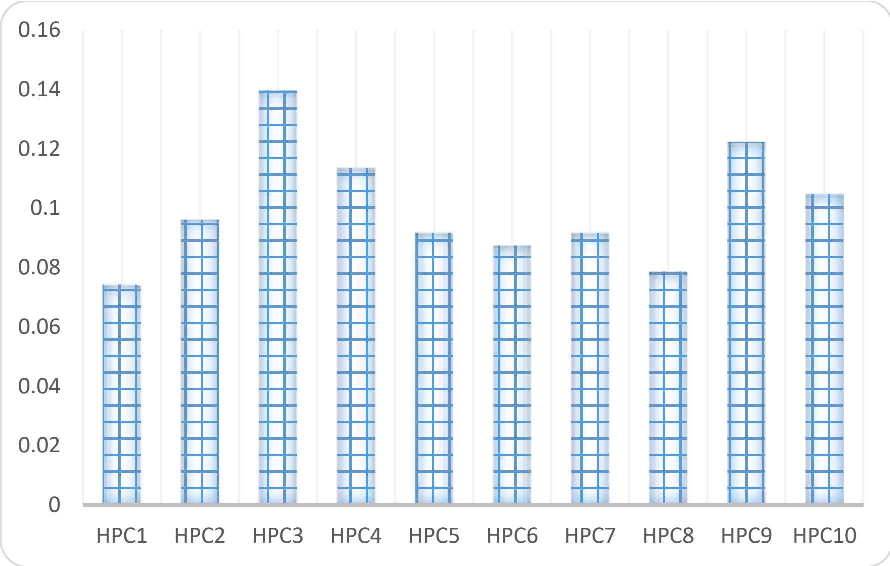

Figure 2. The weights of 15 criteria.

Table 2. The weighted normalized decision matrix.

	HPC_1	HPC_2	HPC_3	HPC_4	HPC_5	HPC_6	HPC_7	HPC_8	HPC_9	HPC_{10}
HPA_1	0.001726414	0.005718	0.012965	0.010092	0.007213	0.004015	0.009487	0.005548	0.010869	0.004508
HPA_2	0.005179242	0.010293	0.007203	0.007569	0.003091	0.002008	0.001054	0.003699	0.006793	0.005635
HPA_3	0.002589621	0.005718	0.012965	0.010092	0.006182	0.008031	0.009487	0.004624	0.008151	0.006762
HPA_4	0.005179242	0.003431	0.012965	0.005046	0.005152	0.006023	0.002108	0.002774	0.012227	0.010142
HPA_5	0.001726414	0.006862	0.008644	0.005046	0.005152	0.006023	0.002108	0.008323	0.004076	0.009015
HPA_6	0.004316035	0.002287	0.007203	0.003785	0.008243	0.006023	0.003162	0.005548	0.002717	0.002254
HPA_7	0.003452828	0.005718	0.002881	0.006308	0.004121	0.009035	0.006324	0.001849	0.006793	0.003381
HPA_8	0.006042449	0.00915	0.004322	0.002523	0.007213	0.005019	0.009487	0.004624	0.008151	0.006762
HPA_9	0.006905657	0.010293	0.008644	0.007569	0.009273	0.002008	0.008432	0.007398	0.012227	0.005635
HPA_{10}	0.007768864	0.006862	0.012965	0.011354	0.006182	0.005019	0.00527	0.002774	0.010869	0.004508
HPA_{11}	0.005179242	0.005718	0.010084	0.010092	0.005152	0.003012	0.007378	0.001849	0.006793	0.009015

HPA12	0.007768864	0.004575	0.011525	0.008831	0.008243	0.009035	0.004216	0.005548	0.010869	0.010142
HPA13	0.006905657	0.008006	0.012965	0.007569	0.005152	0.007027	0.008432	0.008323	0.006793	0.007888
HPA14	0.004316035	0.008006	0.011525	0.011354	0.007213	0.008031	0.00527	0.008323	0.005434	0.009015
HPA15	0.005179242	0.003431	0.002881	0.006308	0.004121	0.007027	0.009487	0.007398	0.00951	0.010142

Step 4. Compute the ratio system by Eqs. (2-4). Then compute the rank of alternatives as shown in Figure 3.

Step 5. Compute the reference point by Eqs. (5-6). Then compute the rank of alternatives as shown in Figure 3.

Step 6. Compute the full multiplicative form by Eqs. (7-9). Then compute the rank of alternatives as shown in Figure 4.

Step 7. Compute the final rank as shown in Figure 3.

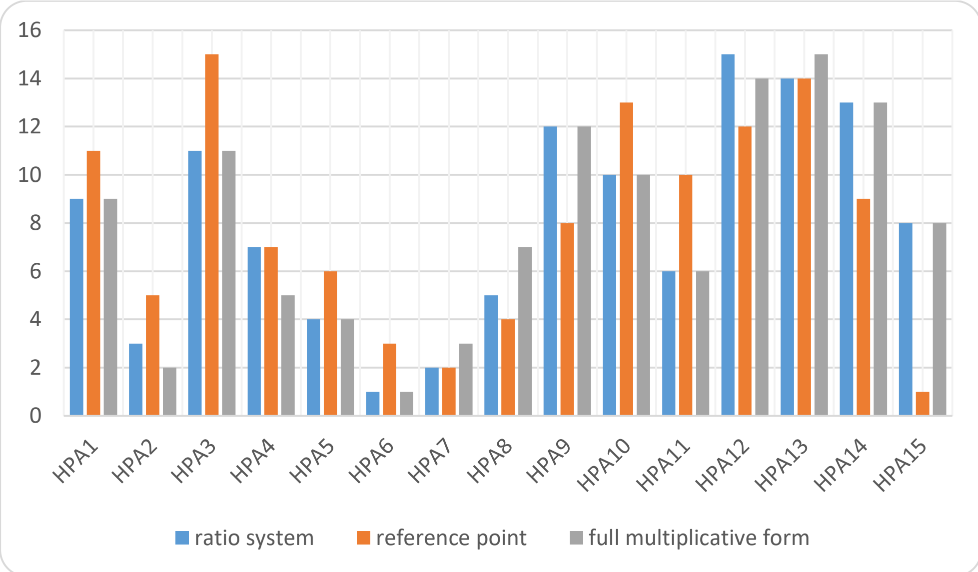

Figure 3. The rank of three steps of MULTIMOORA method.

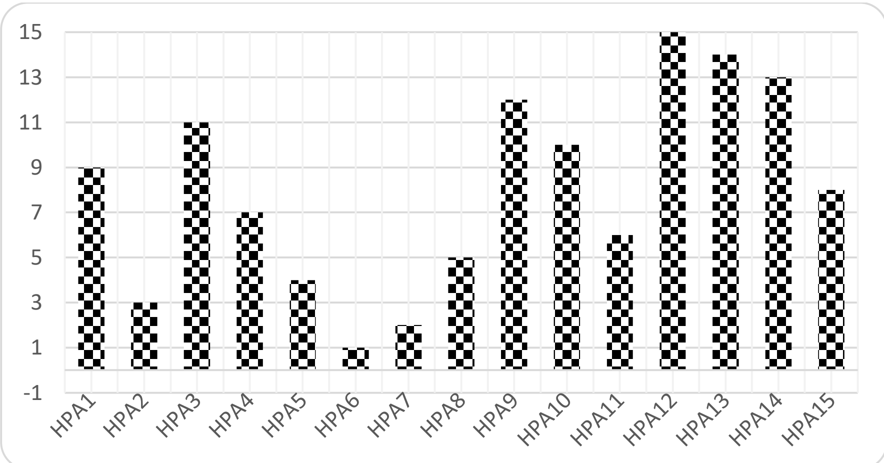

Figure 4. The final rank of MULTIMOORA method.

4 | Discussion

We proposed an MCDM methodology to analyse hydrogen production by collecting some criteria and alternatives. We made this study to achieve economic feasibility and sustainability. We manage ten criteria from the previous studies and 15 alternatives for analysis. We build the decision matrix between criteria and options by the crisp value and evaluate it by the decision-makers and experts. We compute the weights of ten criteria. The results show that cost-effectiveness has the highest weight, followed by the efficiency of energy and the policy factor, which has the least weight.

Then, we used the MULTIMOOR method to rank the alternatives and select the best one. We used the normalization matrix and weighted normalization matrix to compute three stages of MULTIMOORA-named ratio systems: a reference point and a complete multiplicative form. We obtain the rank from each stage and then calculate the final rank using the dominance strategy, as shown in Figure 4.

Then, we conducted a sensitivity analysis between ranks to show the stability of the results. We used ten weights of criteria for sensitivity analysis. We changed the weights of the criteria and then employed these weights in the MULTIMOORA method to show the stability of the results. Figure 5 shows the ten weights for the criteria. We put one factor with 0.12 weight and other factors with equal weight. Then, we compute the weights of the criteria as shown in Figure 6. The ranks show the results are stable.

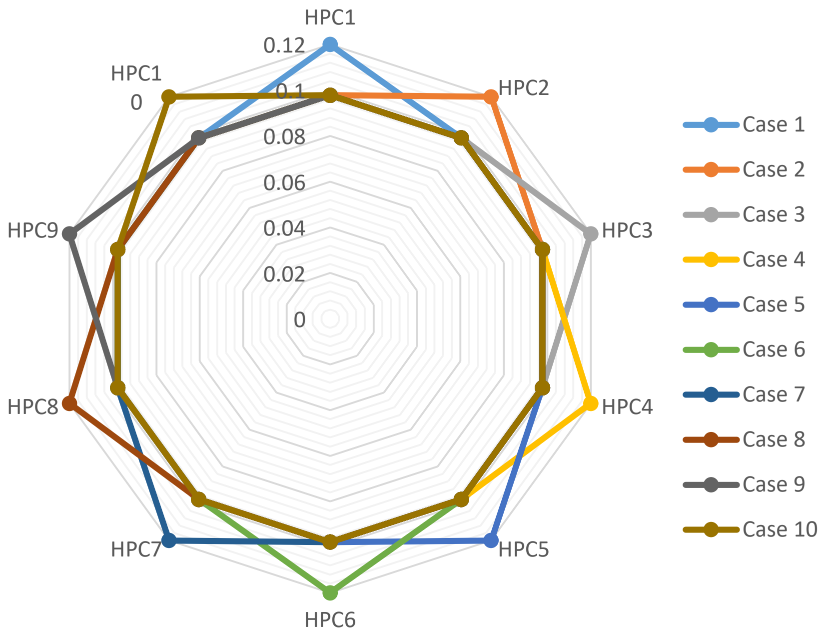

Figure 5. The weights of factors under sensitivity analysis.

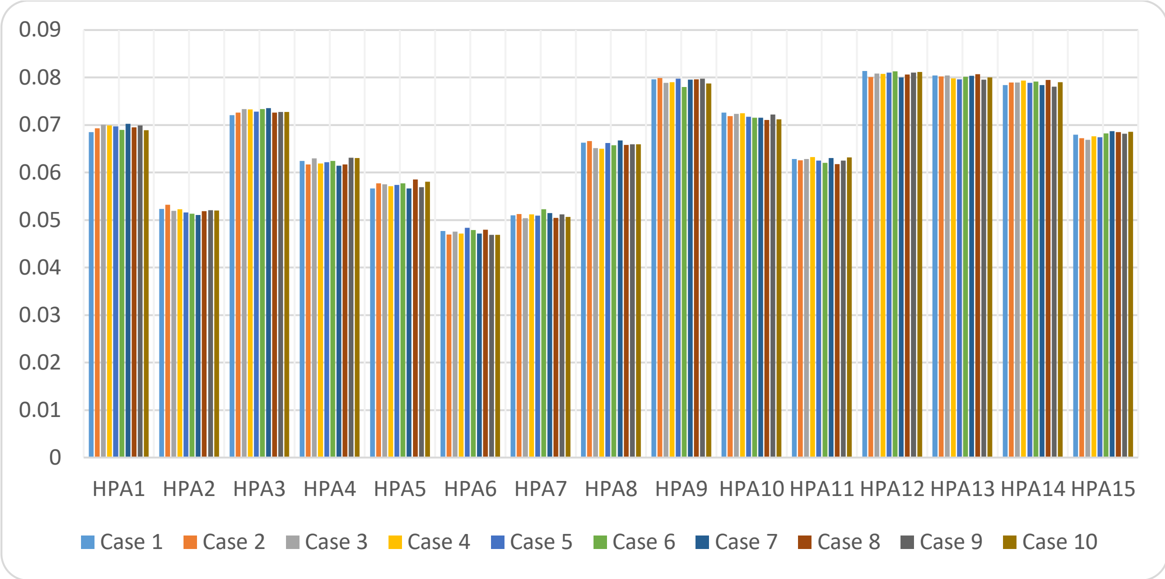

Figure 6. The rank of alternatives under sensitivity analysis.

5 | Conclusions

Hydrogen production holds significant potential for economic feasibility and the advancement of sustainable energy systems. The criteria discussed in this paper provide a comprehensive framework for evaluating hydrogen production methods. Cost-effectiveness is crucial, and efforts should be made to optimize capital investment, operational costs, and feedstock availability. Energy efficiency should be prioritized to minimize energy waste and improve the overall sustainability of hydrogen production. Minimizing carbon emissions through low-carbon or carbon-neutral feedstocks and carbon capture technologies is essential for achieving a decarbonized energy system. Sustainable feedstock sources, scalability, infrastructure compatibility, responsible water usage, life cycle assessment, technological readiness, and supportive policies and regulations are instrumental in ensuring hydrogen production's economic viability and sustainability.

Continued research and development efforts are necessary to fully realize the potential of hydrogen as a sustainable energy carrier. Technological advancements aim to improve efficiency, reduce costs, and enhance environmental performance. Collaborative efforts among industry, governments, and research institutions are crucial for driving innovation, creating supportive policy environments, and fostering the integration of hydrogen into existing energy systems. By addressing the criteria discussed in this paper, hydrogen production can become a key player in achieving economic feasibility and advancing sustainable energy systems, contributing to a cleaner and more sustainable future. We used the MCDM method for the analysis of hydrogen production. We compute the weights of the criteria and rank the alternatives.

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Author Contributaion

All authors contributed equally to this work.

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Data Availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there is no conflict of interest in the research.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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