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A Computational Assessment of Hydrogen Production Methods Using the Weighted Sum Method

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Abstract: *This approach has the benefit of using renewable feedstock's, but it necessitates careful control of the gasification processes and feedstock supply chain. Additionally, photo electrochemical (PEC) or photovoltaic-electrolysis, also known as solar-driven water splitting, uses solar energy to directly create hydrogen from water. Although PEC systems have the potential to utilize a lot of sunlight, research is currently being done on their effectiveness and scalability. Other cutting-edge techniques include biological approaches that use microorganisms or algae to make hydrogen through fermentation or photosynthesis as well as thermo chemical processes like high-temperature electrolysis, where heat from nuclear or solar sources drives the electrolysis reaction. Technical, financial, and environmental factors differ for each technique of producing hydrogen. To choose the best approach for particular applications and realize the vision of a sustainable hydrogen economy, factors including resource availability, efficiency, cost, scalability, and carbon footprint must be carefully assessed. Technology is always evolving, and there is a growing focus on renewable energy sources, which is encouraging the creation of more effective and ecologically friendly hydrogen production techniques. Hydrogen generation is a vital area for research and development because it has great potential as a clean and sustainable energy source. There are several ways to produce hydrogen, each having benefits and drawbacks. This evaluation gives a succinct overview of several hydrogen generation techniques while emphasising their salient characteristics and effects. Steam methane reforming (SMR), a frequently used technique, involves producing hydrogen and carbon dioxide by mixing steam and methane (natural gas). SMR is a well-known and economical technology, however it uses fossil fuels and produces greenhouse emissions. Another technique is electrolysis, which splits water molecules into hydrogen and oxygen using electricity. Electrolysis is an environmentally favourable process since it may be run on renewable energy. It is currently more expensive than traditional procedures nevertheless. Another method is biomass gasification, which involves converting organic materials like wood chips or agricultural waste into hydrogen-rich gas through high-temperature processes. The assessment of hydrogen production methods is of significant research importance due to several key reasons: Energy Transition: A key component in the global energy transition to a low-carbon future is hydrogen, according to several experts. By comparing several production techniques, one may determine the best environmentally friendly and cost-effective ways to produce hydrogen, which can help cut down on emissions of greenhouse gases and reliance on fossil fuels. Environmental Impact: Evaluating hydrogen production methods allows researchers to assess their environmental footprint, including carbon emissions, water usage, and waste generation. This information is vital for making informed decisions regarding the adoption of specific methods and ensuring that hydrogen production aligns with sustainability goals. Technological Advancements: The assessment provides insights into the technical feasibility and efficiency of different production methods. It helps researchers identify areas for improvement, such as enhancing conversion efficiency, reducing costs, and addressing operational challenges, to accelerate the development and deployment of hydrogen technologies. In this Research we will be using Weighted sum method. Alternate Parameters Taken as hydrogen production methods, Thermal Electrochemical Photochemical Thermochemical Plasma. Evaluation Parameters Taken as Economically feasible, Ecologically feasible, Efficiency, Process simplicity, Energy requirement". In this article, we provided a preliminary assessment of the possibility for producing hydrogen using solar energy. First, we gave a quick overview of Morocco's energy situation and potential uses for hydrogen. We thoroughly examined the values before filtering 11 sites for consideration in the study. Then, we ran an uncertainty analysis on the GHI data acquired from the CAMS-Rad spacecraft database to identify their inaccuracy and whether or not they were actually accurate enough for the calculations of hydrogen generation. This was done using a dataset of physical measurements from 11 sites. With a variation of 6.8% resulting from data overestimation from the CAMS-Rad database, the inaccuracy was quite tolerable, especially for the annual averages.*

Keyword: *Production of hydrogen, reforming of natural gas, carbon capture, utilisation, and storage (CCUS), and integrated techno-economic analysis.*

1. INTRODUCTION

Global population growth and rising living standards have caused a steady rise in energy consumption during the twentieth and early twenty-first centuries. illustrates the world's main sources of energy, the amount of power produced, and the related CO2 emission shares. In 2010 [1], the total primary energy supply (TPES) of the world was 12,717MTOE. As seen here, almost 80% of this sum was derived from fossil fuels. The amount of electricity produced globally in the same year was 21,431 TWh [1].Moreover, it demonstrates that 70% of this sum was produced utilizing fossil fuels. 30,326 Mt of CO2 were emitted globally in 2010 [1]. The primary cause of this quantity was the use of fossil fuels. Therefore, switching to a CO2-neutral energy source might significantly lower the emissions caused by CO2. Predictions for the future indicate that the demand for energy will increase going forward. As a result, an increase in energy production capacity will be needed. Finding more dependable, sustainable, and diverse energy sources may be the key to reducing and ultimately eliminating greenhouse gas emissions while meeting all of the world's energy needs. Due to its many advantages over other fuels, hydrogen might be used to reduce pollution and reliance on foreign oil. Hydrogen is the most prevalent, lightest, and simplest crystalline element in the universe. However, it only occurs when it interacts with other elements, particularly oxygen from the air and the carbon, nitrogen, and oxygen found in biological organisms and fossil fuels. Hydrogen is not the main source of energy. But it becomes a desired energy carrier when isolated from these other components by an energy source. Hydrogen emits relatively few emissions when it is used. It combines with oxygen in fuel cells without creating CO2, leaving just water as a byproduct. But it only occurs in mixtures with other substances, principally with oxygen in air and with carbon, nitrogen, and oxygen in biological things and fossil fuels. The primary source of energy is not hydrogen. But when separated from these other components via an energy source, it transforms into a desirable energy carrier. When it comes to emissions at the point of usage, hydrogen is quite clean. In fuel cells, it reacts with oxygen without producing CO2, leaving just water as a byproduct.

With an emphasis on their use in Turkey, this study evaluates the environmental implications of several hydrogen generating processes from renewable and non-renewable sources. The goal is to give the authorities beneficial and useful advise regarding research and development. The environmental impacts, manufacturing costs, energy use, and energy efficiency of eight different approaches are evaluated. In addition to the previously mentioned comparative criteria, the relationship between the capital cost and the ability of the selected techniques to create hydrogen is assessed. The methods that have been chosen include high temperature electrolysis, natural gas steam reforming, coal gasification, solar and water electrolysis, thermochemical water splitting with CueCl and SeI cycles, and natural gas steam reforming. The world's energy consumption is expected to keep increasing in the upcoming decades as a result of rising living standards and an expanding worldwide population. Higher energy generating capacity as well as more dependable and diverse energy sources would be required to meet the rising demand for energy (USDOE, 2009). A sustainable energy source is unquestionably needed due to the finite supply of fossil fuels, environmental harm, climate change, and increased dependency on countries that export fossil resources. Scientists are looking for environmentally benign alternative fuels because fossil fuel combustion and/or reformation have a negative impact on the environment. “According to Romagnoli et al. (2011), these alternative fuels must also be suitable for both mobile and stationary use, emit little to no carbon dioxide (CO2), and fall within a reasonable price range. Hydrogen is one of these possibilities (Cetinkaya et al., 2012). Its use has several benefits including the ability to produce it from renewable energy sources, high fuel cell yields, clean combustion without the release of carbon dioxide (CO2) or nitrogen or sulphur oxides (NOx, SOx), and the ability to store intermittent renewable energy sources indirectly (Balat, 2008; Muradov and Veziroglu, (2008). Similar to electricity, hydrogen is a form of energy conveyance and not a primary energy source. Over 95% of the hydrogen produced worldwide is used in non-energy-related industrial applications. Ammonia manufacturing is the biggest consumer industry, using about 62.4% of total consumption. Energy usage is exceedingly low (Spathand Mann, 2001).”

The European energy landscape is rapidly changing as a result of worries about the safety of the energy supply, growing fuel prices, and the effects of carbon dioxide emissions on climate change. The influence of these variables on the energy industry will be accentuated in the short- and medium-term due to the increasing energy demand (by 14% in 2030 [1]) and continuous reliance on fossil fuels.

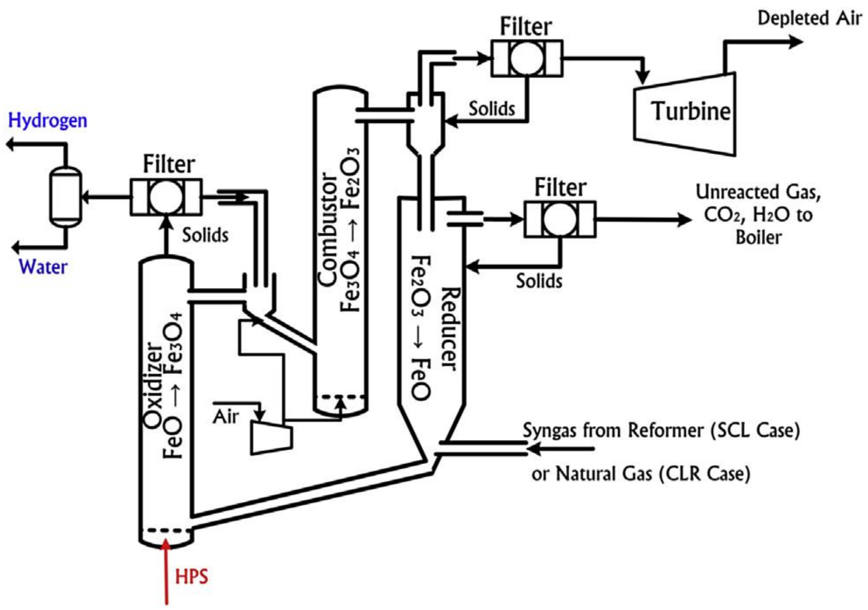

FIGURE 2. Chemical looping unit.

In order to promote the sustainability of the energy system, the European Union (EU), along with other countries around the world, has begun building a hydrogen-inclusive economy that uses hydrogen as an energy carrier in addition to electricity and liquid fuels. The use of hydrogen has a number of advantages.Transportation, homes, businesses, and services are among the nearly all energy-using sectors. In contrast to electricity, it may be stored in small or large quantities for extended periods of time without suffering significant losses. Additionally, since water vapor is the primary result of consuming hydrogen, it generates very little CO2, acid gases, or other pollutants at the place of consumption. Finally, hydrogen can be created from a variety of resources, including renewables, once the commercial viability of the carbon capture and storage technology is established. However, in order to produce hydrogen, carbon capture technologies must be used, and CO2 must be stored safely and for a very long time in appropriate geological formations.The development of a hydrogen-inclusive economy hinges on the efficient, affordable, and environmentally responsible production of hydrogen [2]. Already, there are methods for producing hydrogen for use in the chemical sector, where it is a key ingredient in the production of ethanol, ammonia/urea, and hydrogenation. Numerous resources, including renewable ones, can be used to make hydrogen. It is also used in steel factories and refineries to hydrocrack and hydrodesulfurize oil-based feedstocks. Other small usage include the electrical, metal, glass, and aerospace industries. usage of renewable energy roseRenewable energy will reportedly account for 1%–10% of the world's energy in 15–25 years, which is faster than any other energy source in recorded history. Size and expense are the two main indicators of its rapid rise [17].It contributes for half of the increase in global energy and has the fastest growth rate among renewable energy sources (an average 7.1% per year). "The leveled cost of electricity (LCOE) of solar PV and onshore wind has fallen 77% (13% per year), falling from $0.37/kWh to $0.085/kWh from 2010 to 2018; the LCOE of wind generation has decreased 35%, falling from $0.085/kWh to $0.056/kWh. This trend has been attributed to declining impact costs." Due to the continuously decreasing cost of producing renewable energy, hydrogen produced by steam-methane reforming may now compete with hydrogen produced through water electrolysis. Utility-scale solar photovoltaic projects and onshore wind power, at 77% and 83%, respectively, respectively, respectively, have lower energy costs than the least expensive fossil fuel power output for grid-connected projects in 2020. The price of renewable energy will become more competitive than that of fossil fuels during the next ten years, which is particularly significant given the trend of cost decrease.The development of a distributed energy resource (DER) is swift.The power sector is essential to the conversion of all energy sources to low-carbon energy systems since it is the largest single source of carbon emissions. The power sector, which will use almost half of all primary energy in 2040 and be responsible for more than 3/4 of the increase in primary energy demand, contains a sizable percentage of the lowest-hanging fruit for reducing carbon emissions over the next 20 years [19,20].

2. MATERIALS & METHODS

Making the proper judgments requires taking into account a variety of elements due to the business, engineering, science, and technology environments' increasing complexity. Environmental1, 2, market, 3, 4, and economic5, 6 elements may be included in these deciding criteria. Unfortunately, the majority of these aspects are not adequately denned, which prevents decision-makers from having access to a wide range of methods for addressing complicated, poorly denned issues with a variety of interrelated criteria. Making decisions in the presence of many, typically concluding criteria is referred to as MCDM. Different quality characteristics, units of measurement, and relative weights may apply to each distinct criterion. It's feasible that some criteria can be quantified, while others can only be subjectively defined. Operations research's multiple-criteria decision analysis (MCDA), also known as MCDM, expressly takes into account numerous criteria in decision-making situations. It is crucial to appropriately outline the problem and specifically examine a number of factors when the stakes are high. Making sound judgements requires properly structuring complicated situations and specifically taking into account many factors. Recent years have seen a rise in the importance of the long-term effects of high-quality judgments on overall organizational performance have come to the fore in recent years, drawing more attention to MCDM techniques. A finite collection of criteria is evaluated qualitatively or quantitatively in multi-criteria (or attribute) decisions. By giving preference information in terms of a precise numerical number, the desired alternative may be picked. However, given hazy or inaccurate understanding, preference information in real-world situations can be evaluated qualitatively. This discovery provided researchers with strong impetus to expand MCDM approaches in fuzzy environments. The performance of each alternative in relation to each criterion and the relative weight of the evaluation criteria in relation to the overall objective must frequently be determined using qualitative and/or quantitative assessments provided by the decision makers. The decision makers must frequently use qualitative and/or quantitative assessments to identify the performance of each alternative in respect to each evaluation criterion and the relative weight of the evaluation criteria in relation to the overall aim. MCDM approaches cover a broad range of distinctly unique tactics. MCDM strategies can be loosely classified into two categories: discrete multi-objective decision making (MADM) and continuous multi-objective decision making (MODM) optimization techniques.39–41Many innovative works made great strides during the 1970s. The fundamentals of decision-making with numerous objectives were developed by Keeney et al. According to Hwang et al.45, MODM methodology and applications have advanced quite quickly. Later, Tzeng and Huang46 investigated the MADM approaches, including TOPSIS, the simple additive weighting (SAW), and the linear programming approach for multi-dimensional analysis of preference (LINMAP).downloaded for personal use only on May 13, 2016, from TOPSIS Method Development 647 International Journal of Information Technology December Mak at Nanyang Technological University. Aggregation problems are generally fairly diverse and varied. The wide variety of available methods perplex potential users, who then incorrectly link issues and methods together. Additional connected themes Numerous authors have discussed the subject of aggregating inputs from ordinal scales, sophisticated inputs (such probability distributions), fuzzy sets, etc., including Zadeh,87 Schweizer and Sklar,88 and others. This uncertainty might be reduced by evaluating the appropriateness, usefulness, and validity of various multi-criteria processes in trials with decision makers. Hobbs et al.89 concluded the type-2 fuzzy set and the following fuzzy set.

Hydrogen production methods: The two most common methods for producing hydrogen are steam-methane reforming and electrolysis, which uses energy to split water. Other processes or strategies for producing hydrogen are being investigated by researchers.
Thermal: An adjective that describes heat is thermal. It could particularly refer to an atmospheric convection phenomena called a thermal column (or just "thermal"). Pants designed to retain body heat when it is really chilly. Thermal radiation is the electromagnetic radiation that results from the thermal motion of charged particles in materials.
Electrochemical: Electrochemistry is the study of chemical processes that move electrons. This flow of electrons produces electricity, which may be produced by the transfer of electrons from one element to another in a procedure known as an oxidation-reduction ("redox") reaction.
Photochemical: When Photochemical reactions operate differently from reactions that are governed by temperature. Photochemical routes are able to quickly overcome major activation barriers and permit reactions that would not otherwise be conceivable because they have access to extremely energetic molecules that cannot be created thermally. The chemical breakdown of plastics serves as an example of how damaging photochemistry may also be.
Thermochemical: Gasification and pyrolysis are two thermochemical processes that are used to transform a variety of biomass into liquid fuels, power, and other valuable products.
Plasma: Plasma is the term for blood's liquid portion. About 55% of our blood is plasma, with the remaining 45% being suspended red, white, and platelet blood cells. Water makes up about 92% of plasma.

3. ANALYSIS AND DISCUSSION

TABLE 1. Assessment of hydrogen production methods

Assessment of hydrogen production methods					
hydrogen production methods	Economically feasible	Ecologically feasible	Efficiency	Process simplicity	Energy requirement
Thermal	8	6	8	5	8
Electrochemical	2	3	7	1	5
Photochemical	3	3	2	5	1
Thermochemical	6	7	8	8	5
Plasma	6	3	7	4	9

Table 1 shows "the economically feasible, ecologically feasible, efficiency, Process simplicity and energy requirement. Evaluation parameters – hydrogen production, thermal electrochemical photochemical thermo chemical and plasma" As seeing figure 1.

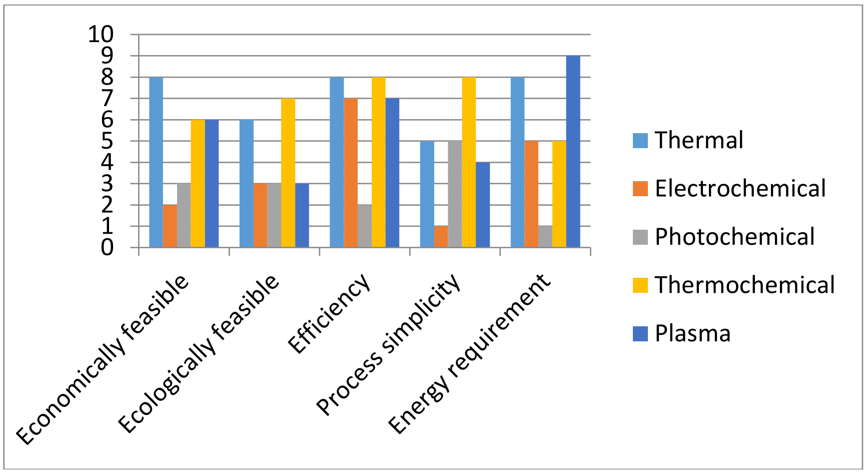

FIGURE 3. Assessment of hydrogen production methods

TABLE 2. Squire Rote of matrix

hydrogen production methods	Economically feasible	Ecologically feasible	Efficiency	Process simplicity	Energy requirement
Thermal	64	36	64	25	64
Electrochemical	4	9	49	1	25
Photochemical	9	9	4	25	1
Thermochemical	36	49	64	64	25
Plasma	36	9	49	16	81

Table 2 shows the Table 2 shows the Squire Rote of matrix value.

TABLE 3. Wireless network system in Normalized Data

hydrogen production methods	Economically feasible	Ecologically feasible	Efficiency	Process simplicity	Energy requirement
Thermal	0.6554	0.5669	0.5275	0.4369	0.5714
Electrochemical	0.1638	0.2835	0.4616	0.0874	0.3571
Photochemical	0.2458	0.2835	0.1319	0.4369	0.0714
Thermo chemical	0.4915	0.6614	0.5275	0.6990	0.3571
Plasma	0.4915	0.2835	0.4616	0.3495	0.6429

Table 3 shows the Table 2 shows Wireless network system in Normalized Data value.

TABLE 3 Weighted

Thermal	0.20	0.20	0.20	0.20	0.20
Electrochemical	0.20	0.20	0.20	0.20	0.20
Photochemical	0.20	0.20	0.20	0.20	0.20
Thermo chemical	0.20	0.20	0.20	0.20	0.20
Plasma	0.20	0.20	0.20	0.20	0.20

The table is organized in rows and columns, where each row corresponds to a specific category (Thermal, Electrochemical, Photochemical, Thermochemical, and Plasma), and each column represents a specific factor within that category (Factor 1, Factor 2, Factor 3, Factor 4, and Factor 5). The numbers in the table, such as 0.20, represent the weights assigned to each factor within its respective category.

TABLE 4 Weighted normalized decision matrix

Thermal	0.1311	0.1134	0.1055	0.0874	0.1143
Electrochemical	0.0328	0.0567	0.0923	0.0175	0.0714
Photochemical	0.0492	0.0567	0.0264	0.0874	0.0143
Thermo chemical	0.0983	0.1323	0.1055	0.1398	0.0714
Plasma	0.0983	0.0567	0.0923	0.0699	0.1286

Table 3 shows Weighted normalized decision matrix the each row corresponds to a specific category (Thermal, Electrochemical, Photochemical, Thermo chemical, and Plasma), and each column represents a specific factor within that category (Factor 1, Factor 2, Factor 3, Factor 4, and Factor 5). The numbers in the table represent the weighted and normalized values assigned to each factor within its respective category. These values are typically obtained through a decision-making process or evaluation method.

TABLE 4. Wireless network system in Si Positive & Si Negative

	SI Plus	Si Negative
Thermal	0.057527	0.176296
Electrochemical	0.183793	0.076462
Photochemical	0.185731	0.064844
Thermo chemical	0.065872	0.180104
Plasma	0.108846	0.13773

Table 4 shows the In the thermal category, the SI Plus value is 0.057527, while the Si Negative value is higher at 0.176296. This suggests that the SI Plus effect is relatively weaker in terms of thermal properties compared to Si Negative. Moving on to the electrochemical category, the SI Plus value is 0.183793, which is significantly higher than the Si Negative value of 0.076462. This indicates that SI Plus has a stronger influence in the realm of electrochemical processes. Similarly, in the photochemical category, SI Plus demonstrates a higher value of 0.185731, while Si Negative lags behind with 0.064844. This implies that SI Plus has a more pronounced impact on photochemical reactions compared to Si Negative. In the thermo chemical category, the SI Plus value is 0.065872, whereas Si Negative shows a higher value of 0.180104. Thus, Si Negative appears to have a greater influence in thermo chemical processes, while SI Plus has a relatively weaker effect. Lastly, in the plasma category, SI Plus and Si Negative values are 0.108846 and 0.13773, respectively. SI Plus is slightly lower than Si Negative, indicating that both have comparable influences in plasma-related phenomena. These comparisons provide an overview of how SI Plus and Si Negative differ in their effects across different categories. However, it's important to note that the specific meaning and implications of these values depend on the context and purpose for which they are being used as seeing figure 4.

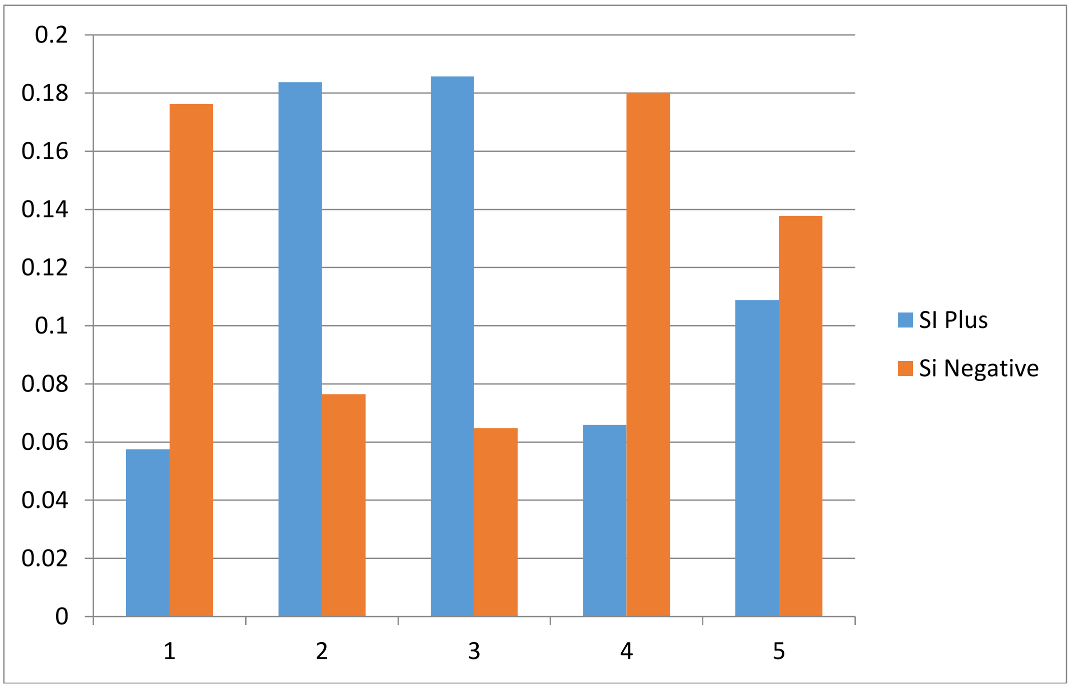

FIGURE 4. Wireless network system in Si Positive & Si Negative & Ci

TABLE 5. Rank

	CI Value	RANK
Thermal	0.753973	1
Electrochemical	0.293796	4
Photochemical	0.25878	5
Thermo chemical	0.732202	2
Plasma	0.55857	3

Table 3 shows provided shows the CI values and rankings for different categories: Thermal, Thermo chemical, Plasma, Electrochemical, and Photochemical. Among these categories, Thermal achieved the highest CI value of 0.753973, securing the top rank of 1. Following closely behind, Thermo chemical obtained a CI value of 0.732202, earning the second rank. Plasma attained a CI value of 0.55857, placing it in the third rank. Electrochemical received a CI value of 0.293796, resulting in the fourth rank. Lastly, Photochemical obtained the lowest CI value of 0.25878, thus being ranked fifth. These rankings indicate the relative performance or significance of each category based on their respective CI values.

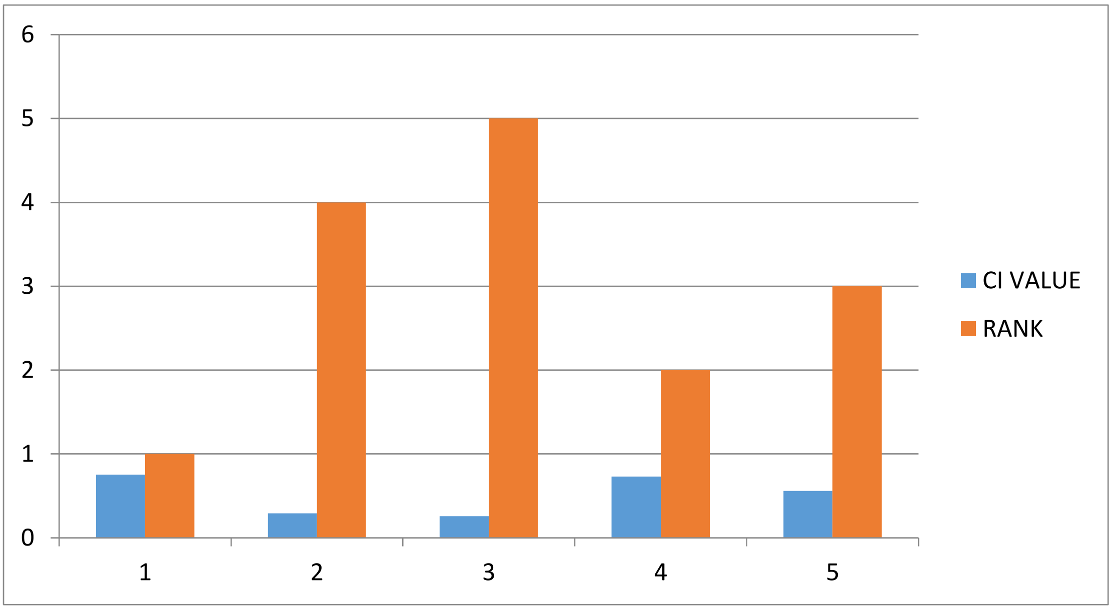

FIGURE 5. Rank

Figure 5 provided shows the CI values and rankings for different categories: Thermal, Thermo chemical, Plasma, Electrochemical, and Photochemical. Among these categories, Thermal achieved the highest CI value of 0.753973, securing the top rank of 1. Following closely behind, Thermo chemical obtained a CI value of 0.732202, earning the second rank. Plasma attained a CI value of 0.55857, placing it in the third rank. Electrochemical received a CI value of 0.293796, resulting in the fourth rank. Lastly, Photochemical obtained the lowest CI value of 0.25878, thus being ranked fifth. These rankings indicate the relative performance or significance of each category based on their respective CI values.

4. CONCLUSION

Potential users are confused by the large range of ways accessible, which leads to an incorrect correlation between methods and issues. Testing the appropriateness, usability, and validity of different multi-criteria procedures in experiments with decision makers might help clear up this uncertainty. This is what Hobbs et al. (1989) concluded. Potential users are perplexed by the vast array of strategies that are accessible, which results in an incorrect correlation between methods and issues. Other authors who have addressed this subject include Zadeh,87 Schweitzer and Sklar,88 and others. Related subjects covered include aggregating infinitely many real inputs, aggregating inputs from ordinal scales, aggregating complicated inputs (such probability distributions), fuzzy sets, etc. Testing the applicability, usability, and validity of methods in experiments where decision-makers utilize many multi-criteria approaches to real-world issues might help clear up this misunderstanding. The following was the finding of Hobbs et al. The average output peaks in the summer at 2364 tons per square kilometer and troughs in the winter at 1289 tons per square kilometer. The daily average hydrogen output ranges from 6.5 to 8.3 tons annually. The price of manufacturing hydrogen is reasonable when compared to other cost estimates in the literature, falling between 4.64 and 5.79 $/Kg. The price of producing hydrogen might decrease much further if the appropriate policies are put in place. In addition, it was found that the nation's north, center, and south could be split for solar hydrogen generation into three key areas.

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