Hydrogen storage for micro-grid application: a framework for ranking fuel cell technologies based on technical parameters

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ABSTRACT

To securely address energy shortage and various environmental issues attributed to fossil fuel, the adoption of renewable energy is growing across the globe. However, wind and solar which form the bulk of the emerging renewable energy for micro-grid applications are intermittent and need energy storage device for backup. Due to its environmentally friendly nature, the use of hydrogen as storage mechanism is now being explored for micro-grid applications. However, due to the various technical criteria attributed to various fuel cell (FC) technologies used for hydrogen production, selecting the most suitable alternative remains a challenge. This study uses evaluation based on distance from average solution, a multicriteria decision making tool to rank FC technologies that can be used to produce of hydrogen energy storage in micro-grid applications. The analysis was based on 4 FC technologies and 6 technical criteria. The results of the study show that the most preferred FC technology for micro-grid application is the polymeric electrolyte membrane while the least preferred is molten carbonate FC. It is expected that future analysis would explore the inclusion of socio-economic criteria in the evaluation of the most preferred FC technology for micro-grid application.

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1. INTRODUCTION

The facilitation of energy transition to securely address energy shortage in a sustainable manner is of growing interest across the globe. Hence, the concerns surrounding sustainability of conventional sources of energy, climate change and environmental pollution has precipitated the development and adoption for alternative sources of energy across the globe. Some of the popular alternative green energy sources include hydro, geothermal, wind and solar. The adoption of solar and wind has increased in recent time; this is attributed to the technological breakthroughs. Energy generated from both wind and solar has been reported to be competitive with conventional sources in terms of the cost of energy. However, due to their intermittent nature, there is need for adequate storage which is environmentally and economically sustainable. Some of the storage devices available to alleviate the intermittent nature of variable renewable energy sources include compressed-air energy storage, flywheels, lead–acid batteries, lithium-ion batteries, pumped hydro, super-capacitors, super-conducting magnetic storage and fuel cell. While some of these storage devices can only store for a short period of time, fuel cell (hydrogen storage) is a medium energy storage device. While it does not require land as compared to pumped hydro storage, hydrogen storage capital cost is lower than that pumped hydro which is a long-term energy storage technology. Battery energy storage, which is the most popular storage device used in micro-grid applications has been reported to have serious environmental concerns after the end of its lifespan; hence, there is need for more research efforts on energy storage device such hydrogen energy storage [1]. Hydrogen energy is an eco-friendly form of renewable energy that could be used to replace fossil fuels. In addition to environmentally friendly features, hydrogen energy allows the generation of mechanical, thermal and electricity. Hydrogen storage is a more promising, clean, pollution-free, effective energy resource with higher calorific value compared to chemical energy.

Of recent, more research efforts have been dedicated to the proliferation of fuel cell as energy storage device. Due to its versatility hydrogen energy has been developed and adopted in the industrial commercial, residential and the transport sector; its viability in the energy sector, especially grid and distributed generation is also being explored. For instance, the application of fuel cell technology is currently being explored in the maritime industry. Using analytic hierarchy process (AHP), Inal and Denzi [2] presented a study that compared and ranked various commercially available fuel cell (FC) technologies that could be used to power merchant ships. Feedback from the study shows that molten carbonate FC technology is the most preferred alternative, while the alkaline fuel cell was inappropriate for the proposed application. Using technique for order preference by similarity to ideal solution (TOPSIS) method, Sadeghzadeh and Salehi [3] presented a framework that could be used in the ranking of strategic fuel cell technologies as converters in the automotive sector. The authors, therefore, presented a multi-criteria decision making (MCDM) method that evaluated the feasibility and significance of the FC as a sub-system for the automotive industry. It is observed that hardware on laboratory scale had the highest score, while professional manpower on industrial and semi-industrial scale had the least score. In another study, nine hydrogen production/fuel cell and natural gas technologies that can be used for electricity generation were presented and ranked using AHP and seven techno-economic and environmental criteria [4].

The technologies considered include natural gas internal combustion engine, hydrogen combustion turbine, the natural gas fueled phosphoric acid fuel cell, the hydrogen internal combustion engine, the natural gas turbine, hydrogen fueled phosphoric acid fuel cell, the natural gas fueled solid oxide fuel cell, and the, the hydrogen fueled solid oxide fuel cell. The results show that the most preferred alternative for the electricity production in the hydrogen turbine technology. Tzeng *et al.* [5] considered fuel cell technologies presented an MCDM methodology for the selection of the most suitable alternative fuel mode in technical development of buses with new alternative fuels sources. Both TOPSIS and meaning multi-criteria optimization and compromise solution or *Vlsekriterijumska Optimizacija I Kompromisno Resenje* (VIKOR) used for the analysis showed that the most suitable alternative for the Taiwan scenario is the hybrid electric bus. Using 5 criteria, Montignac *et al*. [6] also presented the application of measuring attractiveness through a categorical-based evaluation technique (MACBETH) for the comparison and appraisal of three hydrogen storage technologies. The technologies considered include cylindrical steel made liquid hydrogen storage, system IV 70 MPa hydrogen storage system and a solid storage system.

The results of the study manufacturers should strive to reduce system volume and enhance conformability for all the three technologies considered. Using 4 techno-economic and environmental parameters, Üçtuug and Fahriouglu [7] presented a selection framework for the ranking of 5 FC technologies that can be adopted in distributed generation. The authors deployed the efficacy of TOPSIS in the selection process and reported that the most preferred alternative is the solid oxide fuel cells. Khzouz *et al.* [8] investigated a cost estimation tool for life cycle cost analysis based on hydrogen fuel cell vehicles (HFCVs). They considered a centralized and decentralized methodology using economic data for production processes. The research further used a sensitivity analysis framework for the comparison of costing outputs. These outputs cover transportation, production, and final application used to reveal the viability of future hydrogen production through centralized methane reform. Technological tools were used to explore various techniques in the hydrogen production life cycle based on insightful feasibility and proper costing. The proposal in this work can determine which cost is most effective and feasible source of hydrogen as an alternative to conventional energy sources. One of the essential factors for the acceptance of technology under discuss is cost especially when used in cell vehicles; this was revealed from the simulation results and analysis.

Also, some studies have been dedicated to the various processes and technologies that can be used in the conversion of hydrogen into energy [9]–[11]. Some of the fuel cell technologies that have been found to be feasible in the conversion of hydrogen to electricity include, alkaline FCs, direct methanol FCs, molten carbonate FCs, phosphoric acid FCs, polymeric electrolyte membrane FC, solid oxide FCs [10], [12]. These are extensively discussed in section 2. Some studies have proposed the use of these fuel technologies in distributed power systems, grid integration and co-generation power. According to research, molten carbonate FCs, phosphoric acid FCs, polymeric electrolyte membrane FCs, and solid oxide FCs have all found applications in electric utility and large distributed generations [12]. To select the most preferred FC technology for hydrogen storage facilities, engineers usually have to make a comparison of the various technical features of these technologies and make a compromise. Some of the most significant technical characteristics that are usually used during the design and selection stage of these FC technologies include system power output, operational temperature, cell voltage, power density, electrical efficiency, lifespan, and combines heat and power (CHP) efficiency. To make an informed and appropriate choice from these fuel cell technologies based on the mentioned technical parameters may be difficult and would require the application of a decision-making approach. Previous literatures have neglected the application of MCDM approach to the identification of the most preferred FC technology for the production on hydrogen energy considering micro-grid applications; this is the focus of this study.

2. HYDROGEN STORAGE TECHNOLOGIES

The use of renewable energy sources in grids and power systems raises concerns linked to the difficulty of having large-scale energy storage capacity [13]. This is as a result of the intermittent nature of renewable energy sources and its potential to cause grid instability. Hydrogen-based energy storage technologies come into play as a prospective modern option that is able to bridge the gap caused by the intermittency of renewable energy sources [14]. It possesses superior technical advantage in form of enhanced power quality and stability which it provides to the grid during the critical period of imbalance in supply and demand. Hydrogen storage systems are also very affordable to use on a grid. The technology very efficient, reliable and safe for use in power grids ensuring reduced carbon emissions at low costs [15]. Hydrogen fuel cells are power generators that combine hydrogen and oxygen to produce electrical power that is clean and emissions-free [16]. Some of the technical characteristics and applications of the available FC technologies is shown in Figure 1. This section discusses various fuel cells that guarantee environmental-friendly grids.

Metric	AFC	PEMFC	DMFC	PAFC	MCFC	SOFC
Electrolyte	KOH Solution	Proton-conducting polymer membrane	Proton-conducting polymer membrane	Phosphoric acid	Li2CO3; KCO3 melted in LiALO2	ZrO2 and Y2O3
Ions in the electrolyte	OH^-	H^+	H^+	H^+	CO^{2-}_3	O^{2-}
Temperature	60–80°°C	60–100°C	60–100°C	180–220°C	600–660°C	700–1,000°C
Fuel	H_2	H2 (pure or reformed)	Methanol	H2 (pure or reformed)	H2 (pure or reformed)	H2 (pure or reformed)
Application domains	Spatial	Automobile, portable, cogeneration and maritime	Portable	Cogeneration	Cogeneration centralized electricity production, maritime	Cogeneration centralized electricity production, maritime

Figure 1. Comparison of the available FC technologies for hydrogen production (adapted from [9])

2.1. Polymeric electrolyte membrane FCs

First produced in early 1960s, the polymer electrolyte membrane (PEM) technology was powered by hydrogen produced from the mix of water and lithium hydride. The fuel mixture was stored in disposable canisters that could easily be transported to personnel in the field [17]. PEM fuel cells are an electrochemical device that directly and efficiently converts the stored chemical energy present in hydrogen fuel into electrical energy, releasing water as the only available by-product. PEM fuel cells can reduce the emission of pollutants into the environment and also reduce dependence on the use of fossil fuels [18]. The construction of PEM fuel cells involves the use of materials made from platinum (Pt) as catalysts (to speed up reactions) and polymer electrolyte membranes (a popular example being Nafion) as a proton conductor. The polymer electrolyte in PEM fuel cells is in form of a sheet which is thin and permeable. Very important features of PEM include high power density, small size, low operating temperature, light in weight and easy scale-up. Efficiency for a PEM fuel cell is between 40 to 50%. These features make PEM fuel cells very promising for use as efficient power generation sources in grids and power systems [19].

2.2. Solid oxide FCs

Solid oxide fuel cells (SOFC) are fuel cells that generate electricity, water, heat, and little quantity of carbon dioxide with the use of natural gas as fuel. SOFC are solid-state electrochemical devices that convert chemical energy into electrical energy. SOFC through produce electricity by utilizing the movement of electrons through a chain of chemical reactions and not through a combustion process [20]. Hydrogen, and hydrocarbons can be used as fuel by SOFC, while using air (oxygen) as oxidant. SOFC provides the highest efficiency for production of electrical energy when compared to other types of fuel cells, the efficiency of SOFC exceeds 80% when the heat produced due to conversion is used. SOFC is a third-generation fuel cell having a normal temperature for operation between 600 °C to 1000 °C [21]. At high temperatures of 800 °C to 1,000 °C, fuels used in SOFC undergo internal reformation without the need for an external metal catalyst. The benefits of using SOFC include highest efficiency for electricity production, strong internal catalytic activity, high electrical conductivity, and efficient stability in thermal expansion as a result of its modular design. Solid oxide fuel cells (SOFCs) are therefore much more environmentally friendly and efficient when compared to conventional electric power generation processes [22].

2.3. Phosphoric acid FCs

Phosphoric acid fuel cells (PAFCs) are fuel cells that make use of liquid phosphoric acid as an electrolyte to generate electricity. PAFCs operate at temperatures between 160 °C to 200 °C. The acid electrolyte and the high temperature makes PAFCs intolerant of carbon dioxide (CO) and contaminants present in the fuel and the reacting air. The interaction of phosphoric acid with the platinum catalysts, causes PAFCs to have a lower power density compared to polymer electrolyte membrane fuel cells. PAFCs can tolerate the presence of carbon (IV) oxide (CO_2) in air and streams of fuel gas. PAFCs are more tolerant of CO than proton-exchange membrane fuel cells (PEMFCs) when 1% of CO concentration at 200 °C is used [23].

PAFCs are viewed as the first generation of modern fuel cells, as they were the first to be commercialized. They received a lot of investments in terms of research and development from governments and public institutions [24]. PAFCs are thought to be well suited for distributed generation (DG) because electricity can be produced very close to its area of use, this reduces the energy due to electricity transmission and also reduces the cost involved in constructing power grid. PAFCs can generate waste heat of high temperature which can cause the overall efficiency of PAFCs to rise to more than 85% [25].

2.4. Alkaline FCs

The alkaline FCs (AFCs) is a fuel cell that uses an alkaline electrolyte (which could be potassium hydroxide and sodium hydroxide solution) to generate electricity. It operates using pure hydrogen fuel and pure oxygen as the oxidant [26]. According to the operating mechanisms of AFCs, the anode is supplied with hydrogen fuel while the cathode receives transported oxygen. There exists a possible exchange of ion between the cathode and the anode in the alkaline solution which leads to the generation of direct current.

Compared to all other fuel cells, AFC has the highest efficiency when it comes to production of electricity, but typically makes use of pure gases [27]. The operating temperature for AFC exists between ambient temperature and 90 °C, a reason why AFCs are regarded as a low-temperature technology. The AFCs has a low manufacturing cost. Also, the catalyst needed by the AFC electrode is cheaper than the catalysts required in the electrodes of other fuel cell types. AFCs have electricity generation efficiency up to 70% depending on the application and a single AFC can produce up to 0-5 V to 0.9 V voltage depending on the system design. AFC is also reported to have the capability to generate electricity from 5 kW to as high as 150 kW depending on the application.

2.5. Molten carbonate FCs

The molten carbonate fuel cells (MCFCs) are fuel cells that use high-temperature technology and molten carbonate salt as an electrolyte to generate electricity. MCFCs have an operating temperature of between 600 °C to 700 °C, while the operating pressure is between 1-8 atm. MCFCs use carbonated liquid salts like potassium carbonate, lithium carbonate and sodium carbonate. At 650 °C, the salts in MCFCs undergo a melting phase to form carbonated ions. These ions are then transported to the anode from the cathode, a combination reaction between the ions and hydrogen occurs at the anode to form water, CO_2, and electrons. The electrons produced at the anode are then transported to the cathode via an external circuit, an action which produces direct current and heat. CO_2 and oxygen are combined with electrons to produce carbonated ions in order to restore the electrolyte in MCFCs that was used up in the reaction that generated the direct current [28]. MCFCs have an electricity generation efficiency of about 60%, however, in some cases electrical efficiency can be up to 80% if the waste thermal energy is used for purposes of co-generation [29]. The electricity output of MCFC is between 0.3-3 MW thereby being very suitable for small and large electricity generation and distribution systems [30].

2.6. Direct methanol FCs

The direct methanol fuel cells (DMFCs) are fuel cells which use low temperature and methanol as fuel to generate electricity. DMFCs use PEM and the operating temperature of DMFCs is between 60 °C and 130 °C. DMFCs are often regarded as subtypes of PEMFCs because they have similar internal configurations, design, and operating temperature. However, wastes like carbon dioxide (CO) which emanate from the reaction which DMFCs are involved in distinguishes DMFCs from PEMFCs [31]. Although the catalyst used in DMFC is a derivative of PEM, the catalyst extracts hydrogen from liquid methanol at the DMFC anode. With this action, the need for a fuel reformer becomes unnecessary, giving room for the use of pure methanol as fuel. The pure methanol then combines with steam at the anode and this reaction results in the transformation of methanol into CO_2 and hydrogen ions. There is then a flow of electrons via an external circuit (this occurs via the transportation of protons to the cathode through the electrolyte) which produces electricity. The reaction at the cathode between the protons and electrons with oxygen brings about the formation of water [32].

DMFCs are cost-effective. They have very simple structures and designs making them easy to produce. They have low weights making them an alternative for battery technologies for use in portable devices and mobile appliances. DMFCs have the lowest efficiency amongst all fuel cell technologies with an efficiency of less than 40% [33].

3. METHOD

The details of methods employed in this research are provided in this section. In addition, a brief explanation on the multi-criteria framework (evaluation based on distance from average solution [EDAS]) and the weighing method (entropy) used in this study are presented. Elaborate mathematical formulations with respect to decision matrix and the weighing methods are discussed.

3.1. Evaluation based on distance from average solution

EDAS is a MCDM that can be used to select he most preferred alternative by calculating the distance of each alternative from the average solution; its practicality in scenarios with conflicting attributes is one of its strengths. The approach which has been classified as compensatory has found applications in many sectors including information technology [34], environmental management [35], transportation [36], and more recently, energy [37].

Step 1: Evaluate criteria selection

Step 2: Decide matrix formulation (1)

$$\begin{bmatrix} q_{11} & q_{1j} & \cdots & q_{1n} \\ q_{i1} & q_{ij} & \cdots & q_{in} \\ \vdots & \vdots & \vdots & \vdots \\ q_{m1} & q_{mj} & \cdots & q_{mn} \end{bmatrix}_{m\times n} \quad (1)$$

where q_{ij} denotes for the element of the decision matrix for alternative i under criterion j.

Step 3: Compute the average solution of each attribute (2)

$$AV_j = \frac{\sum_{i=1}^{m} q_{ij}}{m}; j = 1, \dots, n \quad (2)$$

Step 4: Compute the positive distance from average (PDA) and negative distance from average (NDA) using (3)-(8)

$$PDA = [PDA_{ij}]_{n\times m} \quad (3)$$

$$NDA = [NDA_{ij}]_{n \times m} \tag{4}$$

Beneficial (B),

$$PDA_{ij} = \frac{\max(0,\ (X_{ij} - AV_j))}{AV_j} \tag{5}$$

$$NDA_{ij} = \frac{\max(0,\ (AV_j - X_{ij}))}{AV_j} \tag{6}$$

Non-beneficial (NB),

$$PDA_{ij} = \frac{max\ (0,\ (AV_j - X_{ij}))}{AV_j} \tag{7}$$

$$NDA_{ij} = \frac{max\ (0,\ (X_{ij} - AV_j))}{AV_j} \tag{8}$$

Step 5: Compute the weighted sum of PDA and NDA

$$SP_i = \sum_{j=1}^{n} w_j PDA_{ij} \tag{9}$$

$$SN_i = \sum_{j=1}^{n} w_j NDA_{ij} \tag{10}$$

where w_j is the weight of the jth criterion. The weight of the criteria in this study is obtained using entropy method.
Step 6: Normalize the SP and SN values

$$NSP_i = \frac{SP_i}{max_i(SP_i)} \tag{11}$$

$$NSN_i = \frac{SN_i}{max_i(SN_i)} \tag{12}$$

Step 7: Determine the alternatives' appraisal score (AS)

$$AS_i = \frac{(\mathrm{NSP}_i + \mathrm{NSN}_i)}{2} \tag{13}$$

where $0 \leq AS_i \leq 1$
Step 8: Rank the alternatives using the values of the appraisal scores; the alternative with the highest score is the most preferred.

3.2. Entropy method

In any MCDM problems one of the most challenging tasks is weight assignment to the identified criteria. It determines the result of the ranking process. Methods such as AHP, criteria importance through inter criteria correlation (CRITIC) and entropy method are usually used to obtain the weights of criteria. The steps involve in the use entropy method for estimating the weight of the criteria is given as:
Step 1: Obtain the decision matrix and proceed to normalize it, calculate it as (14)

$$r_{ij} = \frac{q_{ij}}{\sum_{i=1}^{m} q_{ij}} \tag{14}$$

Step 2: Calculate the entropy using (15)

$$e_j = -\frac{1}{\ln m}\left(\sum_{i=1}^{m} r_{ij} \ln r_{ij}\right) \quad (15)$$

Step 3: Compute the weight vector using (16)

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{n}(1 - e_j)} \quad (16)$$

4. RESULTS AND DISCUSSION

Four of the six hydrogen storage technology alternatives (PEMFC (T_1), SOFCs (T_2), PAFC (T_3), and MCFC (T_4)) discussed in the previous section were explored in this research. These alternatives are carefully selected for micro-grid application. Although they are usually hybridized with various sources such as hydro, natural gas, wind, solar, the FC technologies were considered in isolation. Based on extensive literature search, six important technical parameters were identified and selected for the purpose of MCDM analysis. The criteria energy conversion efficiency, cell voltage (*V*), lifespan (*h*), power density (kW/m^3), combine heat and power efficiency and working temperature. The relationship between the selected technologies and criteria is presented in Table 1, this forms the decision matrix.

Table 1. Decision matrix based on literature search [10], [12]

	System power output	Operational temperature	Cell voltage	Power density	Electrical efficiency	Lifespan	CHP efficiency
(T_1)	250	100	1.1	35	58	20000	90
(T_2)	1000	200	1.1	1.9	40	50000	85
(T_3)	1000	700	1	1.67	47	8000	80
(T_4)	3000	1000	1	19.25	43	10000	90

The first step in the multi-criteria decision process is to obtain the weights of 6 criteria that were selected for the ranking process. The entropy method was used to calculate the weights of the criteria. The results of the weighing method presented in Table 2 shows that systems power output accounted for 21.3%, cell voltage accounted for 0.083%, and operating temperature was 21.5%. Furthermore, the power density is responsible for 36.9% of the total weight, electrical efficiency accounts for 0.75%, lifespan accounted for 19.36% and CHP efficiency was responsible for 0.086%.

Table 2. Weight of criteria obtained through entropy weight method

System power output	Operational temperature	Cell voltage	Power density	Electrical efficiency	Lifespan	CHP efficiency
			e_j			
0.79093	0.99918	0.78919	0.63813	0.99263	0.81011	0.99916
			$1 - e_j$			
0.20907	0.00082	0.21081	0.36187	0.00737	0.18989	0.00084
			w_j			
0.21319	0.00083	0.21496	0.369	0.00752	0.19363	0.00086

After the determination of the weights, the EDAS method was implemented. To implement the EDAS methodology for this case study, the decision matrix as shown in Table 1, was first used to obtain the average solution A_{Vj}; the result of which is presented in Table 3. According to the EDAS algorithm, the next stage is the computation of the positive distance from average and the negative distance from average. However, before this step, the criteria must be categorized as either non-beneficial or beneficial. Apart from the operating temperature, all other criteria used in this analysis were categorized as beneficial.

Table 3. Status and average solution of the criteria

	System power output	Operational temperature	Cell voltage	Power density	Electrical efficiency	Lifespan	CHP efficiency
AV	1312.5	500	1.05	14.455	47	22000	86.25
Status	B	NB	B	B	B	B	B

The information obtained from Table 3 and the decision matrix is used to compute the positive distance and the negative distance from average; the result obtained from this step is presented in Table 4. After this step, the positive distance and the negative distance from average is weighted using the weights obtained by the entropy method as shown in Table 2 and then normalized as shown in Table 5. The alternatives appraisal scores are obtained from the normalized SP and SN, and they are used to rank the FC technologies. The ranking shows that the most preferred alternative for micro-grid application is the PEMFC followed by SOFC, PAFC, and MCFC, respectively. To compare the result obtained through the use of EDAS, additive ratio assessment (ARAS) technique is also implemented for the ranking process. It could be seen that the results obtained from ARAS is the same as that of EDAS as shown in Table 6.

Table 4. NDA and PDA results

		System power output	Operational temperature	Cell voltage	Power density	Electrical efficiency	Lifespan	CHP efficiency
PDA	(T_1)	0.0000	0.0000	0.0000	1.4213	0.2340	0.0000	0.0435
	(T_2)	0.0000	0.0000	0.0000	0.0000	0.0000	1.2727	0.0000
	(T_3)	0.0000	0.4000	0.0476	0.0000	0.0000	0.0000	0.0000
	(T_4)	1.2857	1.0000	0.0476	0.3317	0.0000	0.0000	0.0435
NDA	(T_1)	0.8095	0.8000	0.0476	0.0000	0.0000	0.0909	0.0000
	(T_2)	0.2381	0.6000	0.0476	0.8686	0.1489	0.0000	0.0145
	(T_3)	0.2381	0.0000	0.0000	0.8845	0.0000	0.6364	0.0725
	(T_4)	0.0000	0.0000	0.0000	0.0000	0.0851	0.5455	0.0000

Table 5. Weighted sum results

	SP_i	SN_i	NSP_i	NSN_i	AS_i
(T_1)	0.698272	0.190186	1	0.675693	0.837847
(T_2)	0.375461	0.372392	0.5377	0.364995	0.451347
(T_3)	0	0.58644	0	0	0
(T_4)	0.396545	0.32126	0.567895	0.452185	0.51004

Table 6. Final ranking

FC Alternative	EDAS		ARAS	
	AS_i	rank	Ki	rank
(T_1)	0.837847	1	0.660115	1
(T_2)	0.451347	3	0.449118	3
(T_3)	0	4	0.25756	4
(T_4)	0.51004	2	0.629893	2

5. CONCLUSION

The use of hydrogen technology as an alternative energy storage technology for micro-grid is gradually gaining research and application attention. However, the choice of the best alternative remains a challenge. This study has presented a procedure for the ranking and selection of the most preferable FC technology for hydrogen production meant for micro-grid application. From the literature, 4 FC technologies and 6 criteria were selected for the analysis. Using the EDAS MCDM approach, it was identified that the most suitable FC technology for micro-grid application is the polymeric electrolyte membrane FC while the least preferable is the molten carbonate FCs. Results from ARAS framework also returned the same ranks as proposed by EDAS. In future, a sustainability framework would be used to rank the alternatives. Criteria related to economic, social, legal, and other important sustainability attributes would be included.

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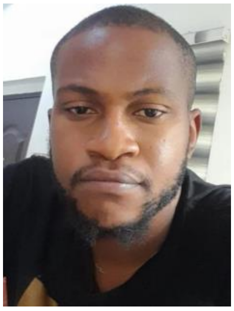

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