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Comparative analysis of various oxygen production techniques using multi-criteria decision-making methods

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ABSTRACT

The current pandemic has adversely affected oxygen production and supply chain, where oxygen treatment is essential for the emergency treatment protocol of patients infected by the virus. This work reports on various techniques of oxygen generation methods, as well as the challenges facing its production, storage, and transportation. Moreover, this study offers a comparative analysis of various oxygen production techniques using Multi-Criteria Decision-Making Methods (MCDM). Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), in addition to the weighting methodologies, Multiplicative Exponential Weighting (MEW) and Simple Additive Weighting (SAW) are chosen as tools to carry out the statistical analysis and rank the oxygen production methods. The ranking criteria includes cost, performance, environmental impact and safety. Moreover, this paper utilizes the Entropy Weight Method (EWM), Criteria Importance Through Inter-criteria Correlation (CRITIC) method, and the Stochastic Dominance (SD) method to distribute the criteria weights. The results show thar oxygen production using membrane technologies is the optimal technique based on all the provided tools and criteria. as it attained the maximum Entropy and Sd values of 0.548 through the TOPSIS method, and the highest CRITIC value through SAW and MEW methods which were 0.260 and 0.236, respectively.

1. Introduction

The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has single-handedly changed the world as we know it. The high global infection rates, limited experience in preventing its spread, and major challenges in finding a cure have strained the research and development efforts. Oxygen therapy is the delivery of medical oxygen as a healthcare intervention, to allow higher oxygen diffusion into the bloodstream to compensate for the reduced efficiency of the respiratory system caused by the disease Oxygen gas is odorless and constitutes 21% of the air in Earth's Atmosphere. Oxygen atoms are very reactive and are incorporated into many common chemical compounds, such as water (H_2O), carbon dioxide (CO_2), carbon monoxide (CO), sulfur oxides (SO_2 and SO_3), and nitrogen oxides (NO and NO_2) [1]. Oxygen possesses exceptional physical and chemical properties and is essential for life on the planet. Its ability to support respiration in humans/animals as well as being essential to combustion reactions that produce energy. So far, this is the main application of oxygen as most of the electricity produced in the world relies on external (or internal) combustion reactions . While most natural applications make use of the availability of oxygen in atmospheric air, some other applications require higher concentrations of the gas. Thus, various methods are available to produce O_2 including natural, laboratory and industrial methods. The tissues and organs' oxygen concentration in human body supports the production of energy through a variety of direct and indirect routes [2]. A recent novel technique used a natural oxygen production system based on genetically modified *Chlorella vulgaris* algae to treat tumor hypoxia by producing O2 in the tumor. To maximize the transport of *C. vulgaris* to tumor tissues,

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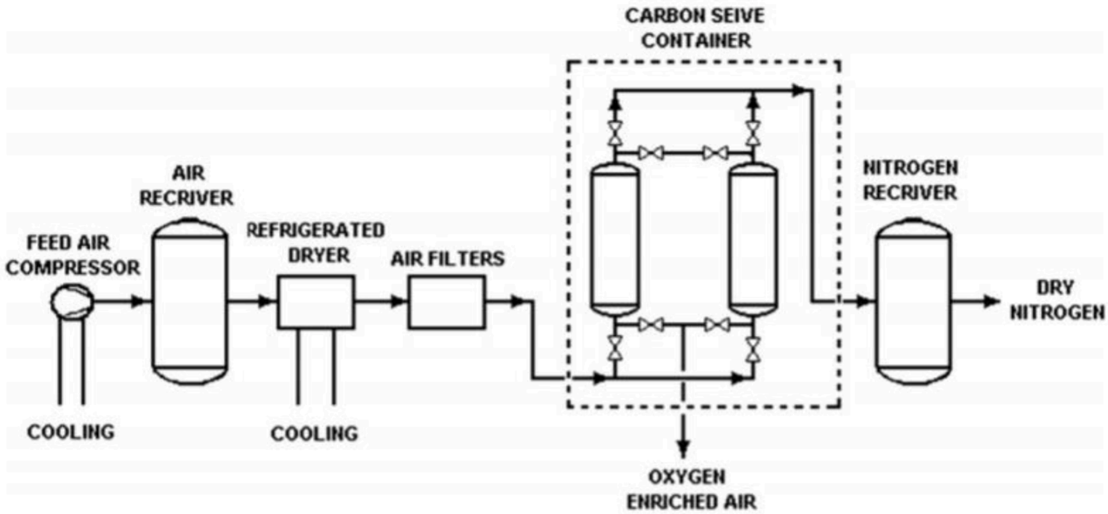


Fig. 1. Schematic of a pressure swing adsorption plant [12].

the red blood cell membrane (RBCM) was first altered, using it as an effective technique to modify the algal surface and decrease macrophage uptake and algae systemic clearance. Then, the RBCM-Algae, effectively provided O2 in situ via red light-induced photosynthesis to tumor tissues to enhance RT and boost tissue oxygenation [3].

An oxygen generation system based on a patient's SpO2 values was created recently by the Defense Research and Development Organization (DRDO), making it a highly effective oxygen conservation device. Patients with mild COVID infection can use it at home and it also provides oxygen at a rate of 2/5/7/10 l/min [4].

Multi-Criteria Decision Making (MCDM) methods are gaining popularity due to their capabilities in solving problems related to alternative selection and decision-making. Normally, these types of decision-making problems are associated with several conflicting criteria and alternatives [5]. Hence, MCDM is an established research field that involves highly computational methods utilized to assess different alternatives depending on a defined set of criteria. MCDM has various methods that are highly capable of carrying out thorough and comprehensive comparisons and then choosing the optimal option. One of these methods is the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Fig. 3 illustrates common MCDM methods.

TOPSIS method is a popular method utilized to evaluate various decision alternatives in different areas. During 1981, Hwang and Yoon developed the TOPSIS method to help ease the decision-making process in selecting the best alternative that enhances the positive outcomes. TOPSIS ranks alternatives by choosing the decision with the lowest distance from the positive ideal solution and the highest distance from the negative ideal solution [6]. Due to the advantages the TOPSIS method provide and to its wide range of applicability in different areas, this paper employs the TOPSIS method to compare between the different O_2 production methods and then rank them from most-favored to least-favored based on a set of defined criteria.

Numerous literatures have been conducted on the various oxygen production techniques and storage methods, especially oxygen for the medical use. Nevertheless, research fails to compare those techniques and provide an optimal method for oxygen production that will meet the increasing demand and optimize the supply chain of oxygen transportation. This work offers a comparative analysis of various oxygen production techniques using Multi-Criteria Decision-Making Methods (MCDM). Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), in addition to the weighting methodologies, Multiplicative Exponential Weighting (MEW) and Simple Additive Weighting (SAW) are chosen as tools to carry out the statistical analysis and rank the oxygen production methods. The ranking criteria includes cost, performance, environmental impact and safety. Moreover, this paper utilizes the Entropy Weight Method (EWM), Criteria Importance Through Inter-criteria Correlation (CRITIC) method, and the Stochastic Dominance (SD) method to distribute the criteria weights. This study provides the first step towards an optimum oxygen production, transportation, and storage techniques that will be able to match the increasing demand in oxygen while maintaining an efficient and frasible distribution network.

2. Oxygen production methods

2.1. Natural oxygen production

Photosynthesis is considered as a natural way in which O_2 is produced in the environment. During photosynthesis, plants take in carbon dioxide (CO_2) and water (H_2O) from the air and soil [7]. Within the plant cell, the water is oxidized, meaning it loses electrons, while the carbon dioxide is reduced, meaning it gains electrons. This transforms the water into oxygen and the carbon dioxide into glucose. The plant then releases the oxygen back into the air, and stores energy within the glucose molecules [4]. The overall reaction behind the photosynthesis process is shown in equation below,

$$CO_2 + 2H_2O \rightarrow (CH_2O) + O_2 + H_2O \tag{1}$$

This released oxygen is used by humans and other animals which need oxygen to live which they breathe in from the air. When we breathe out, human release carbon dioxide into the air which is then used by the plants to make their food and the cycle starts all over again. This continuous cycle is known as the oxygen cycle.

About half of the oxygen produced on the planet comes from algae [8]. Algae are classified into microalgae and macroalgae (seaweed), both are photosynthetic organisms that live in oceans, rivers, and lakes and use the photosynthetic light and dark reactions to convert inorganic compounds and light into organic matter. Like plants, algae produce oxygen through utilizing solar energy to extract protons and electrons from water for CO2 fixation to produce glucose [9]. Algae cultivation in closed systems like *Vertical column photobioreactors* are efficient for the removal of oxygen and CO2 utilization [10].

2.2. Industrial methods for O_2 production

Most of the oxygen generation methods require separating air into its constituents to generate oxygen with different purities, flow rates and pressures. Cryogenic Separation, Pressure Swing Adsorption, and

Table 1
Comparison of different oxygen storage mediums [16].

	Liquid Oxygen	PSA Plant	Concentrator	Cylinders
Description	Liquid oxygen production off-site and stored in large tanks at the medical facility	On-site oxygen generation using PSA technology	A self-contained electrically powered medical device designed for the concentration of oxygen	A refillable cylindrical storage vessel used for the storage and transportation of oxygen
Electricity requirements	No	Yes	Yes	No
Maintenance requirements	Significant	Significant	Moderate	Limited
Distribution mechanism	Central pipeline distribution system	Central pipeline distribution system	Direct to patient areas	Direct to patient areas
Advantages	High oxygen output	Cost effective continuous supply of oxygen	Continuous oxygen supply that can be split among several patients	No power source
Disadvantages	- Requires transport/supply chain - Needs infrastructure - High maintenance for piping - Risk of leakage - Requires cylinders as back up	- High capital investment - Needs infrastructure and uninterrupted power source - High maintenance for piping - Risk of leakage - Requires cylinders as back up	- Low pressure output - Requires uninterrupted power source - Requires cylinders as back up	- Requires transport/supply chain - Highly reliant on supplier - Risk of leakage

Membrane Technology are the common methods for producing O2 [11].

Cryogenic air separation is considered an old but efficient method for the preparation of pure oxygen and nitrogen in gaseous and liquid form at high volumes. The idea behind this air separation unit is different boiling points of the gases present in air. Within the cryogenic air separation unit, the temperature is lowered which results in the separation of nitrogen and oxygen based on their boiling points.

Pressure swing adsorbers (PSA) as compared to cryogenic separators use high pressurized tanks for the production of oxygen. This device takes atmospheric air in the highly pressurized tank, for the separation of the gases present in the atmosphere. The tank consists of zeolites which creates dipoles in which a pressure is applied on them. The dipole created by the selected zeolite in the tank results in the collection of nitrogen gas and separation of oxygen gas. The purification and enrichment of oxygen is carried out in another tank having a minimum pressure of 1.5 atm. The zeolite becomes saturated after a certain time due to maximum adsorption of nitrogen. To regenerate the zeolite, the pressure of the tank is dropped to atmospheric pressure which allows the zeolite to return to its original polarity and nitrogen to be released [9]. Fig. 1 shows the schematic of a pressure swing adsorption plant.

The membrane technology involves moving air through a membrane filter which allows fast gasses to pass while slow gasses remain. In this case, oxygen is the fast gas and nitrogen, and argon are the slow gasses. Varying levels of purity can be achieved by varying the time that the gas spends undergoing filtration [11].

Various processes that require nitrogen gas produces oxygen as a by-product. For example, in food industry, storing food in nitrogen enriched environments reduces respiration rates. Similarly, hydrogen production results in waste oxygen. Hydrogen is produced via electrolysis in which water is broken into hydrogen and oxygen [11].

2.3. Oxygen production from electrolysis

Electrolysis is process of separating water into oxygen and hydrogen by means of electricity. Although electrolysis is mainly utilized for hydrogen generation, oxygen can be produced and collected through the anodic or cathodic reaction occurring at the electrolyzer. Currently, various water electrolysis technologies are available, where some are commercialized, and some are lab-scaled. Alkaline water electrolyzer (AWE), Proton exchange membrane cell (PEM), and solid oxide electrolysis cells (SOEC) are the most commonly utilized water electrolysis systems [13].

AWE and PEM are usually operated at low temperatures up to 90 °C, whereas SOEC are operated at high temperatures between 700-950 °C, yielding a durability in the range of 100,000, 10,000-50,000 and 500-2000 for AWE, PEM, and SOEC, respectively [14]. PEM employs platinum as the cathode catalyst and Iridium/Ruthenium as the anode catalyst, rendering it as the most expensive water electrolysis technology [14]. Nevertheless, PEM is not the most efficient as it yields an efficiency of 80%, while AWE and SOEC show an efficiency of 60% and 100%, respectively. Oxygen generation through electrolysis is a mature technology and is gaining major attraction as research and applications are geared towards the utilization of hydrogen as the fuel of the future.

2.4. Oxygen production and storage for medical use

Oxygen production systems consist of an oxygen source, or an oxygen production system coupled with storage. Some of the common oxygen production sources are: (i) oxygen generating plants, (ii) liquid oxygen in bulk storage tanks, and (iii) oxygen concentrators. Pertaining to the medical field, the most common oxygen storage provision is storage in cylinders. The selection of the suitable oxygen production source and storage method depend on several factors such as cost, required capacity, supply chain of medical oxygen, infrastructure available, and most importantly the amount of oxygen needed at the treatment facility [15]. For example, liquid oxygen plants produce oxygen at an off-site location. The oxygen is then periodically transported via trucks to the large bulk liquid oxygen tank located on the premises of the medical facility. Oxygen reaches the health facility through a central piping system propelled by self-vaporization. Although from an economic perspective, the employment of liquid oxygen depends heavily on the supply chain mechanics and required caution in transportation and storage due to the risks involved with high operational pressures. Pressure Swing Adsorption (PSA) plants solves the issues involved with transportation as they can be located on-site at the target medical facility. Oxygen from the PSA can then be piped directly to units at patient areas or can be used to refill oxygen cylinders for discretized distribution. The PSA, however, requires high capital cost and a reliable source of power. Oxygen may also be produced using a self-contained, electrically powered device that concentrates oxygen from ambient air using PSA technology. These oxygen concentrators are portable, but also can be set up as stationary fixtures in patient areas where they provide oxygen at a flow rate of 5-10 L/min. Concentrators provide a safe and cost-effective source of oxygen but require a reliable source of power and preventative maintenance.

Oxygen can also be compressed and stored at the medical facility by the utilization of cylinders. The cylinders can be filled by the liquid oxygen or by the oxygen produced from the PSA plant. The cylinders can

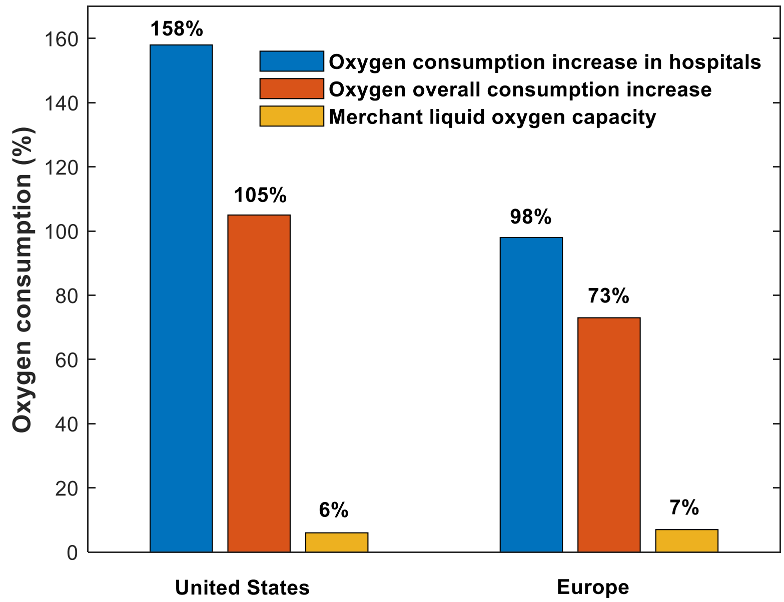


Fig. 2. The increase in oxygen consumption.

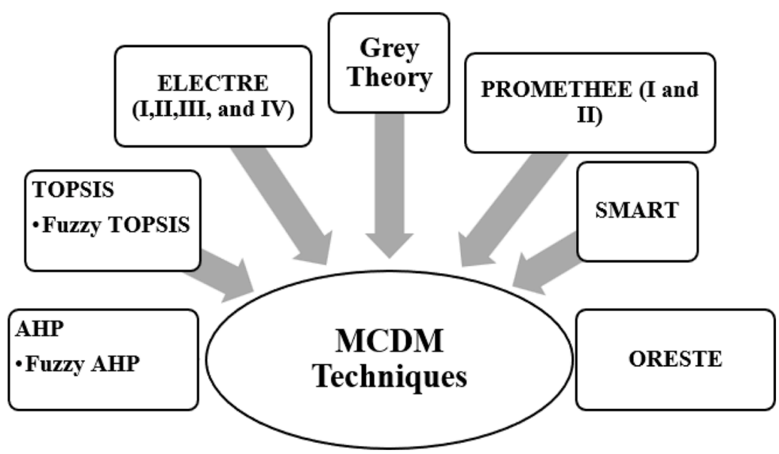


Fig. 3. Types of MCDM methods [6].

Table 2
Multi-Criteria problem expressed in a matrix form.

	C1	C2	…	C*n*
A1	x^k_{11}	x^k_{12}	…	x^k_{1n}
A2	x^k_{21}	x^k_{22}	…	x^k_{2n}
…	…	…	…	…
A*m*	x^k_{m1}	x^k_{m2}	…	x^k_{mn}

also be deployed by installing them in the patient area or by connecting them to a sub-central manifold system at the medical facility. Once the cylinders are filled, they do not require electricity, but they require pressure gauges, regulators, flow meters, and in rare cases humidifiers. Thus, cylinders are the most common method of delivering oxygen in medical facility and they require trained personal to look over the storage and transportation of the medical oxygen and cylinders. Table 1 presents a summary and a comparison of the oxygen storage mediums.

2.5. Global oxygen capacity

Pandemics expose any flaw in global medical systems, especially ones with long and elaborate supply chains. Oxygen production and transportation is currently at the forefront of most prominent medical commodity and providing sufficient amounts of it during the current pandemic has proven to be a significant struggle [17]. The demand on oxygen during this pandemic has increased many folds. Fig. 2 shows that increase in oxygen consumption in the United States and Europe in the year 2020 has seen around 158% increase [18]. Other less developed countries have reported a genuine struggle with insufficient oxygen supplies. For example, a study facilitated by Belle *et al.* [19] was conducted to assess the situational analysis on the capacity of oxygen supply in twelve sub-Saharan African countries. The study showed in that there are several limitations to access oxygen in these countries. The analysis showed that about 56.2% of the heath care facilities had interrupted access to oxygen, and only about 24.6% of the facilities owned a fully operating oxygen concentrator. Therefore, the authors recommended increasing the delivery capacities of oxygen in these countries especially during pandemics.

From the discussions and case-studies above for times of pandemics, it is recommended to utilize oxygen concentrators to cover the oxygen required for patient treatment. This is mainly due to their high efficiencies and relatively low costs. However, oxygen concentrators

Table 3
Ranking O_2 production technologies based on the TOPSIS method.

	Natural Production (Algae)	Cryogenic Separation	Pressure Swing Adsorption	Membrane Technology
Costs	1 [25]	4 [26]	2 [27, 28]	3
Efficiency	4 [29]	3 [30]	1 [31]	2 [32]
Safety	1 [25]	2 [33, 27]	3 [27]	4 [27]
Energy Required	4 [34]	1 [35]	3 [27]	2 [36]
Pollutant Emissions	4 [34]	3 [27]	2 [27]	1 [27]
Market Availability	4 [37]	3 [35]	2 [38]	1 [39]
Oxygen Purity Level	1 [40]	2 [11]	4 [41]	3 [42]

require access to electricity and trained operators for proper activation of the concentrators. These requirements have caused a shortage of oxygen supply during previous pandemics. For example, throughout the influenza pandemic, many low-income countries faced several limitations in acquiring oxygen supply due to the electricity shortages and low budgets. Hence, maintaining oxygen supply devices that are low in costs, have simple maintenance, and are not dependent on electricity is a necessity to reduce the losses associated with such pandemics as much as possible. Moreover, after the influenza pandemic, more attention rose on enhancing the development and distribution processes of oxygen supply devices [19].

2.6. Global oxygen supply chain

The race to combat the ramifications of COVID-19 has led to the adoption of various preventative measures. These measures include lockdowns and travel restrictions adopted by various countries. However, these preventative procedures and protocols have adversely affected global supply chains, which includes medical supplies, medical gases and even vaccines. The longer these lockdowns persist the higher the accumulated and sometimes irrecoverable losses of global supply chains [20]. In a sense the COVID-19 has revealed many vulnerabilities in the global supply chains in general and necessitated devising remedies and alternatives. The supply of medical and health care tools and equipment have not been exempted from such disruptions in procurement, shipment, and mobility of these products. Moreover, the COVID-19-forced lockdowns and travel restrictions has taken place from the origin of the virus which coincidentally is the world largest manufacturer and exporter of almost all goods, China. In addition to the lockdowns, there are other factors that weakened the global supply chain, including the adoption of a linear supply chain, utilized by several countries up till now. Linear supply chains focus on minimizing costs and making quick deliveries, leading to the reduction of buffers and inventories which results in frequent supply shortages. All these factors lead to the deterioration of the global supply chain. However, this deterioration can be stopped by strengthening local markets and enhancing local procurements to lower the interdependency on imports. Additionally, supply chains current deterioration can be lifted by shifting the focus from costs, delivery time, and quality to flexibility, responsiveness, and degree of resilience. Companies can also assist in building a more resilient supply chain by adhering to regulations associated with the diversification of suppliers based on geographical locations. These regulations will lower the risks of supply shortages associated with a specific region. Moreover, companies' focus on building a robust system that prioritizes the alternation between suppliers and the accumulation of buffer, will significantly aid in strengthening supply chains. Additionally, to accommodate the deficiencies of the supply chains, new supply chain technologies are emerging. These technologies, such as digital supply networks, increase supply chain degree of resilience, flexibility, agility, and visibility. These technologies coupled with a framework for risk management will strengthen global supply chains even in the face of future pandemics [21].

3. Theory and model

Fig. 3 shows the various techniques of the MCDM technology. In this section, detailed calculations of the TOPSIS method are presented and applied to find the best oxygen production method concerning different criteria set. The traditional TOPSIS MCDM approach uses numerically calculated weights for criteria and ratings. Linguistic variables could be used to express the criteria and their weights. Creating a decision-making matrix is the first step in solving any multi-criteria problem (individual or group decisions). The values of the criterion for alternatives in such matrices could be real numbers, intervals, fuzzy integers, or qualitative labels.

Alternatives indicated as A_1, A_2, and... A_m and C_1, C_2, C_n denote the criteria used to assess alternative performance. x_{ij}^{k} is a number or interval data representing the decision maker's rating of alternative Ai about criteria C_j. Table 2 illustrates the multi-criteria problem as a matrix in which alternatives are A and criteria are C.

- *Step 1: Assign criterion weights to decision matrixes for k-decision makers.*

$X^{k} = (x_{ij}^{k})$ denotes a decision matrix for k- decision maker or expert.

- *Step 2: Normalize the decision matrix for each decision maker.*

Normalization is required to obtain numerically and comparably comparable input data on a similar scale, as well as to provide a norm or standard to the input data. Each criterion in the decision matrix has a value that increases or decreases monotonically. Any non-numerical consequence should be quantified using the appropriate scaling approach.

$$\text{rkij} = \frac{\text{xkij}}{\sqrt{\sum_{i=1}^{m}(\text{xkij})2}} \tag{2}$$

Eq. (2) provides normalization to the desired decision matrix.

- *Step 3. Determine the ideal positive and ideal negative solutions for each decision maker.*

The optimum positive solution A^{k+} has the form for k-decision maker.

$$A^{k+} = \{r_1^{k+}, r_2^{k+}, \ldots, r_n^{k+}\} = \{(max(r_{ij}^{k})| \; j \in I), (min(r_{ij}^{k})| \; j \in J)\} \tag{3}$$

Table 4
Results of TOPSIS, SAW and MEW.

Alternative Names	Average Rank	TOPSIS CRITIC	Rank	Entropy	Rank	SD	Rank	SAW CRITIC	Rank	Entropy	Rank	SD	Rank	MEW CRITIC	Rank	Entropy	Rank	SD	Rank
Natural Production (Algae)	4	0.519	1	0.464	4	0.464	4	0.245	4	0.229	4	0.229	4	0.195	4	0.181	4	0.181	4
Cryogenic Separation	3	0.493	3	0.483	3	0.483	3	0.245	3	0.243	3	0.243	3	0.226	3	0.225	3	0.225	3
Pressure Swing Adsorption	2	0.483	4	0.517	2	0.517	2	0.250	2	0.257	2	0.257	2	0.230	2	0.238	2	0.238	2
Membrane Technology	1	0.497	2	0.548	1	0.548	1	0.260	1	0.271	1	0.271	1	0.236	1	0.248	1	0.248	1

The negative ideal solution A^{k-} has the form for k-decision maker.

$$A^{k-} = \{r_1^{k-}, r_2^{k-}, \ldots, r_n^{k-}\} = \{(min(r_{ij}^{k})| j \in I), \{(max(r_{ij}^{k})| j \in J)\} \tag{4}$$

- *Step 4. Calculate the separation measures between the positive and negative ideal solutions.*
- *Step 5.1. Determine the separation measures for each decision maker.*

For the positive ideal solution A^{k+} for each k decision maker is given as:

$$d_ik+ = (^{m}\textstyle\sum_{j=1} w_jk(r_{ij}k - r_jk+)p))^{1/p}, \ i = 1,2,\ldots,m. \tag{5}$$

For the negative ideal solution A^{k-} for each k decision maker is given as:

$$d_ik- = (^{m}\textstyle\sum_{j=1} w_jk(r_{ij}k - r_jk-)^{p})^{1/p}, \ i= 1,2,\ldots,m. \tag{6}$$

where $p \geq 1$. For $p = 2$ we use the Euclidean metric.

- *Step 5.2. Calculate the group's separation measure.*

Where di*+ denotes the positive ideal solution's group measure and di*- denotes the negative ideal solution's group measure.

$$d_i^{*+} = \frac{\sum_{k=1}^{K} dik+}{K} \text{ and } d_i^{*-} = \frac{\sum_{k=1}^{K} dik-}{K} \tag{7}$$

- *Step 6. Calculate the relative closeness to the positive ideal solution.*

The relative closeness of the alternative A_i to the positive ideal solution is given as:

$$R_i^* = \frac{di*-}{di*- + \ di*+} \text{for } i = 1, 2, \ldots m. \tag{8}$$

where 0 is $\leq R^*_i \leq 1$ and the greater the index value, the better the evaluation of the alternative.

Alternatives' distances from the positive and negative ideal solutions are distances between matrices. The coefficient of the relative proximity of each option to the positive ideal solution is used to construct a ranking of alternatives, and optimal cleaning techniques can be identified.

- *Step 7. Rank the preferred order or select the alternative closest to 1.*

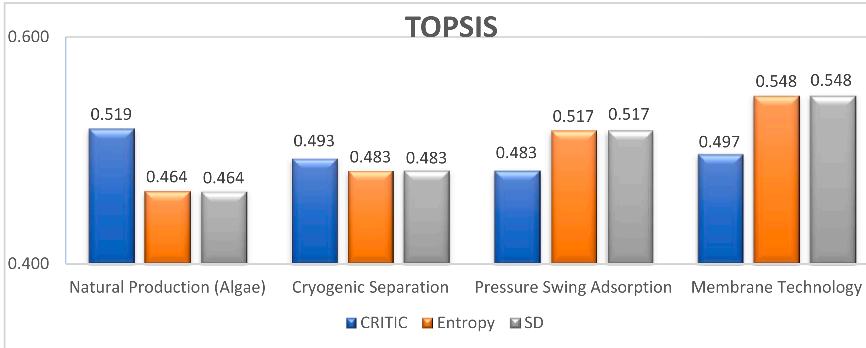
The descending order of the value of R^*_I can now be used to rank the set of alternatives. With these steps provided, we conclude the TOPSIS method. The alternatives are ranked according to their closeness to ideal solutions R^*_I (the higher the value, the better the alternative). The alternative with the highest value is the best option.

Simple Additive Weighting (SAW) is a multi-criteria procedure based on the concept of a weighted summation. The algorithm will attempt a weighted summing of ratings for each option's performance on all alternative criteria. The alternative with the highest score is the best and therefore is recommended. SAW involves a procedure of normalizing the decision matrix (X) to a scale that can be compared to all current alternative ratings. For the benefit criteria, Eq. (9) can be utilized, whereas, for cost criteria, Eq. (10) is used. i corresponds to an alternative, and each j corresponds to an attribute.

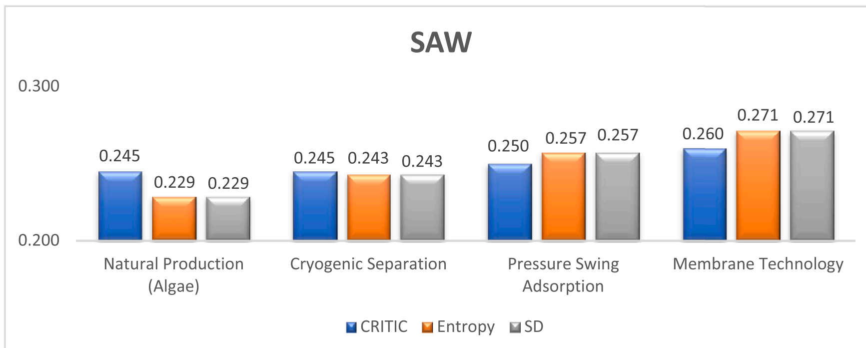
$$r_{ij} = \frac{x_{ij}}{Max(x_{ij})} \tag{9}$$

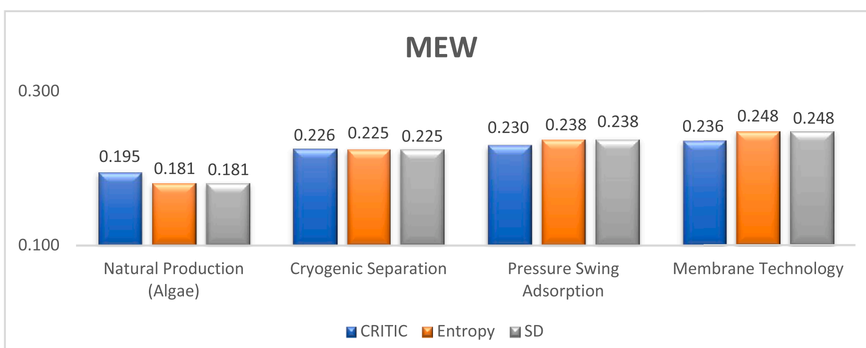
$$r_{ij} = \frac{Min(x_{ij})}{x_{ij}} \tag{10}$$

$$w = \frac{c_1}{c_1 + \ldots + c_n} x100\% \tag{11}$$



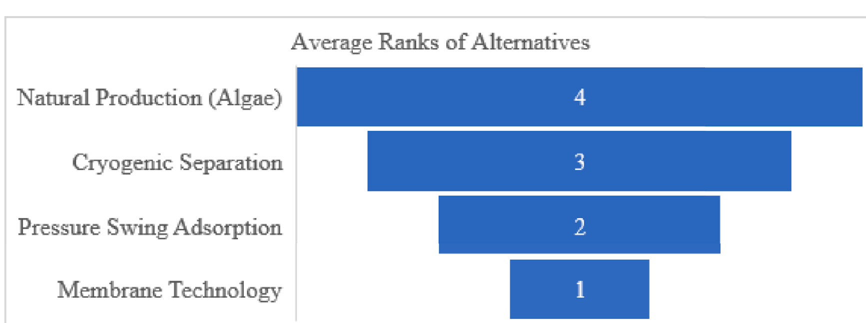
(a)





(b)

(c)



(d)

Fig. 4. (a), (b), (c), and (d): Outcomes of TOPSIS, MEW, SAW methods, and the average rankings, respectively.

$$V_i = \sum_{j}^{n} w_i \, r_{ij} \tag{12}$$

After calculating Vi for the number of alternatives, the successive alternatives can be obtained based on the gained ranking [22].

Multiplicative Exponential Weighting (MEW) is a multi-criteria decision-making scoring method. C stands for criteria, ij are the number of alternatives and criteria, Cj represents the importance of the weight, rij is the rating of the I alternative on the jth criteria; this can be implemented after normalizing all values. Moreover, rij denotes the attribute j of the alternative I, wj denotes the weight of attributed j, and wj =1. Meanwhile, Si represents the alternatives and W is the overall evaluation of weights [23,24].

$$W_i = \frac{S_i}{\sum S_i} \tag{13}$$

$$V_i = \prod_{j=1} r_{ij}^{\,cj} \tag{14}$$

4. Results and discussion

The alternatives were ranked based on the TOPSIS MCDM and the weighting methodologies, MEW and SAW. The alternatives were thoroughly compared to each other based on a set of defined criteria. Table 3 presents a comparison between the O_2 production alternative methods based on the cost, efficiency, safety, energy utilization, pollutant emitted, market availability, and Oxygen purity level.

TOPSIS, SAW, and MEW ranked Membrane technology as the optimal O_2 production method. Pressure Swing Adsorption was ranked as the second-best O_2 production alternative, followed by Cryogenic Separation, and natural production. Membrane technology was ranked as the top O_2 production method due to its high positive and low negative economic, environmental, and social impacts. Membrane technology is perceived as a safe O_2 production method, associated with low costs. Moreover, membrane technology produces Oxygen with high purity levels. Table 4 depicts the average ranks for the O_2 production alternative methods through TOPSIS, MEW, and SAW.

This paper utilizes the Entropy Weight Method (EWM), Criteria Importance Through Inter-criteria Correlation (CRITIC) method, and the Stochastic Dominance (SD) method to distribute the criteria weights. EWM presents a way to evaluate the dispersity through the decision-making process. The value of dispersity increases as the degree of differentiation increases. Consequently, the index is associated with a higher weight. The EWM is utilized in this paper to give weights to the criteria based on the index dispersity. In order to allocate criteria weights via the EWM method it is necessary to first normalize the decision matrix. Eqs. (15) and (16) are utilized to normalize the decision matrix for beneficial and non-beneficial criteria, respectively. Followed by that, the Entropy is calculated for each criteria using Eq. (17). Based on the Entropy values, the Entropy weights are computed for all the criteria through Eq. (18).

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} xij}, \text{ for i } = 1, 2, \ldots.., \text{ n (beneficial criteria)} \tag{15}$$

$$p_{ij} = \frac{1/x_{ij}}{\sum_{i=1}^{n}\left(\frac{1}{x_{ij}}\right)}, \text{ for i } = 1, 2, \ldots.., \text{ n (non} - \text{beneficial criteria)} \tag{16}$$

$$E_j = -\frac{\sum_{i=1}^{n} p_{ij}\ln p_{ij}}{\ln n}, \text{ for j } = 1, 2, \ldots., \text{ m} \tag{17}$$

$$w_j = \frac{1 - E_j}{\sum_{k=1}^{m}(1 - E_k)}, \text{ for j} = 1, 2, \ldots.., \text{ m} \tag{18}$$

The CRITIC method is employed to determine the criteria weights. The appointed weights formulated by the CRITIC method include the intensity of the contrast and the conflict induced from the defined criteria [43]. The CRITIC method allocates the criteria weights based on the standard deviations and correlations of the criteria. Based on the correlation decision matrix, $R = (r_{jk})_{mxm}$, the criteria weights are computed. Eqs. (19) and (20) are employed to find the criteria weights.

$$w_j = \frac{Cj}{\sum_{k=1}^{m} C_k}, \text{ for j } = 1, 2, \ldots., \text{ m} \tag{19}$$

$$C_j = \sigma_j \cdot \sum_{k=1}^{m}\left(1 - r_{jk}\right), \text{ for j } = 1, 2, \ldots., \text{ m} \tag{20}$$

Finally, the SD approach distributes the weights based on the common preferences of the criteria, their results, and likelihood [6]. Furthermore, the SD method allocates the weights based on the standard deviations of the criteria. Eq. (21) is used to compute the criteria weights via the SD method.

$$w_j = \frac{\sigma j}{\sum_{k=1}^{m}\sigma_k}, \text{ for j } = 1, 2, \ldots., \text{ m} \tag{21}$$

Fig. 4 (a), (b), (c), and (d) demonstrate the results of the TOPSIS, SAW, MEW, and their average rankings, respectively. The membrane technology attained the maximum Entropy and SD values through the TOPSIS method, and the highest CRITIC value through SAW and MEW methods.

5. Conclusion

In this paper, the various oxygen production and distribution methods in the shadow of the current pandemic have been presented and discussed. The challenges facing oxygen generation and transportation became of paramount importance during the past two years as the world faced the pandemic and attempted to adapt to it. Oxygen generation methods were discussed and presented, as well as the effect of the pandemic on the global supply chain Moreover, this work facilitates a comparison between the O_2 production alternative methods, namely natural production, Cryogenic Separation, Pressure Swing Adsorption, and membrane technology. The alternatives were compared then ranked via TOPSIS, MEW, and SAW methods. These methods ranked membrane technology as the top O_2 production method based on its positive environmental, social, and environmental impacts. The findings were successful in comparing oxygen production techniques and provided an optimal approach for oxygen production that can be explored more in academia by taking into consideration the cost, performance, environmental impact, and safety.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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