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Holistic Methodology of Hypersoft in Tandem with Uncertainty-based Triangular Neutrosophic for Wave Energy Converter Optimization

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Abstract

Global warming, environmental degradation, and climate change have recently emerged as compelling arguments against the combustion of fossil fuels. As well Eliminating and forgoing the intake of fossil fuels is also encouraged by the Sustainable Development Agenda's goals. The healthy substitute for fossil fuels, renewable energy is one of the main devoid power sources found in our natural surroundings. An effective proposition for harnessing wave energy with an emphasis on increasing energy and efficiency are wave energy converters, or WEnCos. It contributes to producing a clean, limitless energy source that might drastically lessen our need for fossil fuels. Generally speaking, the selecting of the appropriate converter is an important endeavor that this study takes on. The process of selecting the optimal converter has been conducted based on effective benchmarks or criteria and its attributes. Multiple Criteria Decision Making (MCDM) techniques seem to be effective tools when it comes to handling the complex issue of benchmarking WEnCos. These approaches consider a variety of criteria, allowing for a comprehensive and nuanced examination. Each utilized technique plays vital role in our decision problem. Hence, CRiteria Importance Through Inter-criteria Correlation (CRITIC) method—which determines the weights of criteria and its attributes in decision making problems. These weights are utilized in Weighted Sum Product (WISP) method. Totally, these techniques are implemented under uncertainty theory of Neutrosophic which combined with soft sets notion to generate Triangular Neutrosophic HyperSoft (TrNSHSS). Totally, all these techniques are contributed to constructing soft decision-making model for analyzing and recommending optimal WEnCo.

Keywords: Wave Energy Converters; WEnCo; Hypersoft Set; Triangular Neutrosophic Set; CRITIC Method; WISP Method.

1 | Introduction

Fossil fuels are presently the main source of energy utilized in energy production globally [1], owing to the increasing global population. In which [2] anticipated that the global average yearly rise in energy consumption would be around 2%. In the meanwhile, fossil fuels provide around 81% of the world's energy requirements. It has been shown via several studies according to [3] that have detrimental impacts on both the environment and human healing. From an economic sense [4] indicated that the depletion of conventional fossil fuel sources has raised the price of natural gas and oil, and the problem of an energy crisis is made worse

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by the inability to replace fossil fuel supplies. Environmentally speaking [5] referred to 60% of greenhouse gas emissions worldwide are attributable to energy use, which is a major cause of climate change. Socially speaking and humanity, where burning fuel exposes individuals to ailments when they consume it frequently. Thus, it may be claimed that conventional fossil fuels are antagonistic to the objectives of the Sustainable Development Agenda. Aiming for a world without carbon emissions by 2050, the Climate Action Summit as in [6] which has the endorsement of more than 100 nations, has established this goal to address these issues and limit the rise in global temperatures. As well, [7] to create a low-carbon economy and satisfy the growing need for energy sources by nations globally, several have turned their attention to and begun utilizing renewable energy sources in offshore locations. For instance [8] elucidated that Australia is now undergoing a transition from a fossil fuel-based energy system to one that is based mostly on renewable energy sources. Due to [2] where making use of these energy sources also significantly reduces a country's need for imported energy. Long-term social and economic growth depends on using more alternative energy sources such as renewable energy sources. Wherein [6] demonstrated that to mitigate the energy issue and achieve the decarbonization objective, investigating inexpensive, clean, and renewable energy is mandatory. It is essential for sustainable social and economic growth to increase the use of alternative energy sources, particularly renewable energy[2]. Accordingly, Wave energy is becoming more and more popular as a result of the search for clean and renewable energy sources because of its enormous relevance and potential [9]. Due to [1] the potential of wave energy to lessen reliance on fossil fuels as a result of rising interest in renewable, sustainable. Also, wave energy [10] is a reliable, potent source that is yet largely unexplored and has the potential to repeatedly satisfy the world's energy needs. As well, its capacity to lessen carbon footprint and ecological impact makes it a crucial component in the shift to sustainable energy solutions [11]. Compared with other energy sources [12] it has the ability to reduce issues pertaining to natural disasters including tornadoes, floods, and storms. Generally speaking, the process of selecting the suitable wave energy converter is crucial and many prior studies have discussed this topic. Wherein address this matter through leveraging MCDM techniques [13] which have ability to treat with problems characterized by conflict criteria /attributes.[14]. Hence, CRiteria Importance Through Intercriteria Correlation method (CRITIC) is one of the MCDM techniques for determining the objective weights of criteria using weighting it. This approach [15]incorporated the degree of contrast and conflict into the problem structure of the decision-making process. and the generated criteria weights are utilizing in Simple Weighted Sum Product method (WISP) [16] used for determining an alternative's overall utility by integrating four interactions between beneficial and non-beneficial criteria. As well, these techniques are implemented in uncertainty environment without obstacles through leveraging TrNSHSS. All these techniques are integrated for constructing soft decision-making model for evaluating the various converters of wave energy to achieve the objectives of sustainable development agenda. The objectives of this study are achieving via this constructed soft model through deploying the following procedures as in Figure 1:

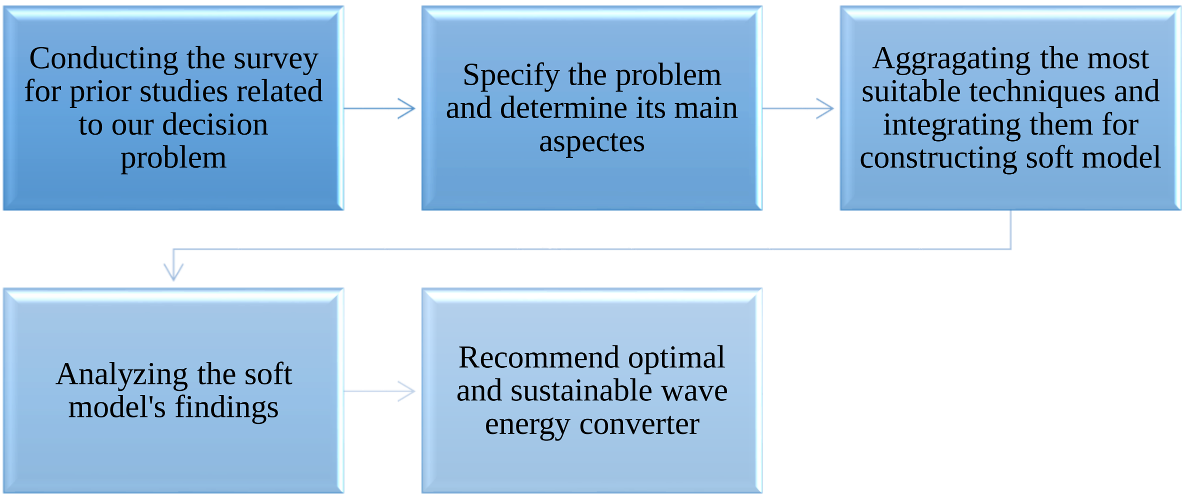

Figure 1. Soft decision-making objectives.

2 | Literature Review

This study offers a useful implementation of earlier research and recommends considering WEnCo for early development by choosing the best station to satisfy wave energy demand [13]. To ensure the sustainable deployment of wave energy technology in low-energy seas, emphasis was given to studies that looked at the viability of WEnCo emplacement, performance, secondary roles, environmental difficulties, and the impact of climate change on wave energy [17]. The adaption of WEnCo technology for low-medium wave power zones has been a study focus in the current hunt for sustainable energy resources [18]. Large centers of consumption may not be able to receive electricity from these places, but perhaps local needs could be satisfied by wave energy harvesting [18]. In the past, wave energy has been evaluated for offshore deep ocean wave data but more recently, coastal regions have been studied to identify hotspots [19]. Most of the hotspots in the research that was reported were chosen using standards that were meant to take into account the sustainability and long-term sustainability of the energy and resources that were accessible [20]. Also, Strong winds and consequently big waves can result from the area's cold fronts, which can cause sudden temperature fluctuations of up to 20°C a day and 200 mm of rain per day [21]. The cold front season typically lasts from October through April, with December through March being the most intense period [22]. There are, on average, 44 cold fronts per season, based on meteorological data from 1981 to 2010 [23]. [24] used 15-year hindcast data to examine the Black Sea's wave-energy potential. The shores in the southwest were found to be the ideal locations for wave farm installations. [25] estimated the Aegean Sea's wave-energy potential using 35 years of data. [26] provided an overview of wave energy economics. The cost of WEnCos was shown to be a highly substantial component of a wave farm's total cost. [26] reevaluated the price of wave energy by taking several factors into account. It was determined that a wave farm's overall investment included a significant amount for the cost of WEnCo s. It was also mentioned that maintenance and operation expenditures were essential. The richest wave power zones at the oceanic globe scale are found in both hemispheres between 40° and 60° latitude [19]. In terms of Europe, earlier research demonstrated that 70 kW/m of maximum annual mean wave energy is attained on the western coasts of Scotland and Ireland [19]. The highest points in North America are found in Alaska, British Columbia, and Oregon, where the values vary from 40 to 60 kW/m [19]. Notably, the Southern interannual volatility is significantly lower despite the same wave power values in the Northern and Southern Hemispheres, which may encourage the utilization of the wave energy resource [19]. A group of six companies released a wave power atlas [27] in 2004 that showed offshore wave potentials ranging from 0.75 kW/m in the northern Adriatic Sea to 14.75 kW/m in the western Sardinia and Corsica islands. This atlas had a spatial resolution of roughly 50 km. This led to an increase in interest in the Mediterranean Sea [28]. Using wave data from the Italian wave buoys network, [29] found yearly mean values in the middle Adriatic Sea that were less than 2 kW/m. At the Alghero wave buoy, which is located on a 100 m water depth in the northwest offshore facing Sardinia Island, the values were equal to 9.1 kW/m. The wave power for the entire Mediterranean Sea for the period 2001–2010 was evaluated by [30] using numerical simulation hindcasting. Their findings indicate that the most energetic region is in the Western Mediterranean, between the Balearic Islands and the western coast of Sardinia, where it reaches values above 15 kW/m. In [31] discovered that the yearly mean wave power in the Mediterranean Sea at Menorca Island was around 8.9 kW/m. [32] continued the line that [30] had started, but they did so by increasing the atmospheric forcing resolution from 1◦/4◦ to 1◦/10◦, extending the numerical simulation's range from 10 to 35 years (from 1 January 1979 to 31 December 2013), and reducing the time step for recording wave characteristics (1 h as opposed to 3 h). To sum up, the research conducted in the past indicates that the average energy flux offshore in the Mediterranean Sea varies between 1 and 2 kW/m in the northern and central Adriatic Sea regions, and between 10 and 20 kW/m in the western Sardinia and Corsica Islands offshore regions [19]. The best place to extract wave energy and the best kind of wave energy converter are determined by several elements and criteria. Nevertheless, additional factors considered in the study's recommended approach have not yet been considered, and the efficacy of WEnCo has not yet been thoroughly assessed For instance, fall in the Caspian Sea experiences a significant amount of tidal weather, but the Persian Gulf experiences winter and summertime with northwesterly Shamal winds [33]. Numerous wave energy changes produced by shallow water have been described by this [17]. Assessments of the marine and oceanic distribution of tidal energy resources are being conducted on the Australian southeast shelf [34]. WEnCo examined where to locate wave farm installations while considering various adjacent waveform kinds, and it identified several hotspots for device deployment. A performance assessment was conducted on the ability of different devices, including terminators, attenuators, and point absorbers, to capture wave energy [35]. The problem is to evaluate the performance of these neutrosophic sets in the MCDM method. To improve test quality by making the procedure transparent, logical, and efficient, MCDM is a widely used procedure in research, engineering, and business.

3 | Methodology: Soft Decision-Making Model Procedures

This section illustrates the techniques that are utilized and implemented for serving and achieving the study's objectives. Wherein, the first subsection exhibits the philosophy of utilized techniques. Also, the amalgamation of the explained techniques is exhibited in sub-section two.

3.1 | Preliminaries and Definitions

In this part, a set of definitions and preliminaries related to HyperSoft is presented.

The soft set can be defined as [36]:

Let μ be a universe of discourse, (μ) the power set of μ, and A a set of attributes. Then, the pair (F, μ), F: A → (μ) is called a Soft Set over μ

The HyperSoft can be defined as [36]:

Let μ be a universe of discourse, (μ) the power set of μ. $Let\ a1, a2, \ldots an\ for\ n \geq 1$, be n distinct attributes, whose corresponding attributes are respectively the set $A1$, $A2$, $\ldots$ $An\ with\ Ai \cap Aj = \emptyset, for\ i \neq j, and$ $i,j \in \{1,2, \ldots n\}$.

Then the pair (F: $A1 \times A2 \times \ldots An$ → (μ)) is called a HyperSoft over μ.

3.2 | Methodology: Soft Decision-Making Model

In this sub-section, the steps of the proposed approach to select optimal wave energy converters are presented. The proposed approach consists of two MCDM methods, the CRITIC method and the WISP method. The proposed approach is implemented using a Triangular neutrosophic scale.

3.2.1 | Building Aggregate Matrix

Step 1: the main aspects of the decision problem where alternatives of WEnCo and criteria and its attributes have been determined.

Step 2: An expert panel is formed to rate and evaluate the alternatives of WEnCo based on criteria and its attributes.

Step 3: decision matrices for members of the panel have been constructed. Their evaluations have been conducted by utilizing the scale mentioned in Table 1.

Step 4: Use the de-eutrophication Eq. (1) to transform the Triangular neutrosophic number to the crisp value.

$$\text{Score}(Qij) = \frac{lij+mij+uij}{9} * (2 + T - I - F) \quad (1)$$

Where: i=1,2,3,…m; n=1,2,3,….. j; l, m, u refer to the lover, middle, and upper values and T, I, F refer to truth, indeterminacy and false respectively.

Step 5: Eq. (2) is employed in crisp matrices to aggregate it into a single decision matrix.

$$x_{t_{ij}} = \frac{\sum_{j=1}^{N}(Qij)}{N} \quad (2)$$

Where: (Qij) refers to the value of criterion in the matrix, N refers to the number of decision makers

Table 1. The linguistic scale is based on the Triangular Neutrosophic number[37].

Scale	Explanation	Neutrosophic Triangular Scale
1	Equally significant	1 = << 1,1,1>;0.50;0.50;0.50>
3	Slightly significant	3 = << 2,3,4>;0.30;0.75;0.70>
5	Strongly significant	5 = << 4,5,6>;0.80;0.15;0.20>
7	very strongly significant	7 = << 6,7,8>;0.90;0.10;0.10>
9	Absolutely significant	9 = << 9,9,0 >;1.00;0.00;0.00>
2	Sporadic values between two close scales	2 = << 1,2,3>;0.40;0.60;0.65>
4		4 = << 3,4,5>;0.35;0.60;0.40>
6		6 = << 5,6,7>;0.70;0.25;0.30>
8		8 = << 7,8,9>;0.85;0.10;0.15>

3.2.2 | CRITIC Method

$$R_{ij} = \begin{cases} \frac{x_{ij}-\min(x_{ij})}{\max(x_{ij})-\min(x_{ij})} & for\ benefit\ criteria \\ \frac{\max(x_{ij})-x_{ij}}{\max(x_{ij})-\min(x_{ij})} & for\ cost\ criteria \end{cases} \quad (3)$$

Step 7: The standard deviations of all criteria (σ_j) are calculated with Eq. (4).

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{m}(R_{ij}-\bar{R}_j)}{m}} \ , \quad \bar{R}_j = \frac{1}{m}\sum_{i=1}^{m} R_{ij} \quad (4)$$

Step 8: The correlation coefficients (ρ_{jk}) are calculated with Eq. (5).

$$\rho_{jk} = \frac{\sum_{i=1}^{m}[\,(R_{ij}-\bar{R}_j)(R_{ik}-\bar{R}_k)}{\sqrt{\sum_{i=1}^{m}[\,(R_{ij}-\bar{R}_j)^2 \sum_{i=1}^{m}(R_{ik}-\bar{R}_k)^2}} \quad (5)$$

Step 9: The information measure of each criterion (U_j) is calculated with Eq. (6).

$$U_j = \sigma_j \sum_{l=1}^{m}(1 - \rho_{jk}) \ , j, l = 1, 2, \cdots, \mathrm{n} \quad (6)$$

Step 10: The weights (w_j) are calculated with Eq. (7).

$$w_j = \frac{U_j}{\sum_{j=1}^{n} U_j} \quad (7)$$

3.2.3 | WISP Method

Step 1: Construct a normalized decision-making matrix calculated by implementing Eq. (8) in the aggregated matrix.

$$r_{ij} = \frac{x_{ij}}{\max(x_{ij})} \quad (8)$$

Step 2: Calculate the values of utility measures, as follows:

$$U_i^{\mathrm{sd}} = \sum_{j\in\ \Omega_{max}} r_{ij}w_j - \sum_{j\in\ \Omega_{min}} r_{ij}w_j \quad (9)$$

$$U_i^{\mathrm{pd}} = \prod_{j\in\ \Omega_{max}} r_{ij}w_j - \prod_{j\in\ \Omega_{min}} r_{ij}w_j \quad (10)$$

$$U_i^{\mathrm{sr}} = \frac{\sum_{j\in \Omega_{max}} r_{ij}w_j}{\sum_{j\in \Omega_{min}} r_{ij}w_j} \tag{11}$$

$$U_i^{\mathrm{pr}} = \frac{\prod_{j\in \Omega_{max}} r_{ij}w_j}{\prod_{j\in \Omega_{min}} r_{ij}w_j} \tag{12}$$

where U_i^{sd} and U_i^{pd} denote differences between the weighted sum and weighted product of normalized ratings of alternative i, respectively, and Ω_{max} and Ω_{min} denote sets of maximization and minimization criteria, respectively. Similar to the previous one, U_i^{sr} and U_i^{pr} espectively

Step 3: Recalculate the values of utility measures:

$$\bar{U}_i^{\mathrm{sd}} = \frac{1+ U_i^{\mathrm{sd}}}{1 + \max U_i^{\mathrm{sd}}} \tag{13}$$

$$\bar{U}_i^{\mathrm{pd}} = \frac{1+ U_i^{\mathrm{pd}}}{1 + \max U_i^{\mathrm{pd}}} \tag{14}$$

$$\bar{U}_i^{\mathrm{sr}} = \frac{1+ U_i^{\mathrm{sr}}}{1 + \max U_i^{\mathrm{sr}}} \tag{15}$$

$$\bar{U}_i^{\mathrm{pr}} = \frac{1+ U_i^{\mathrm{pr}}}{1 + \max U_i^{\mathrm{pr}}} \tag{16}$$

where $\bar{U}_i^{\mathrm{sd}}$, $\bar{U}_i^{\mathrm{pd}}$, $\bar{U}_i^{\mathrm{sr}}$ and $\bar{U}_i^{\mathrm{pr}}$ denote recalculated values of U_i^{sd} , U_i^{pd} , U_i^{sr} and U_i^{pr}

Step 4. Determine the overall utility U_i of the considered alternatives as follows:

$$U_i = \frac{1}{4}(\bar{U}_i^{\mathrm{sd}} + \bar{U}_i^{\mathrm{pd}} + \bar{U}_i^{\mathrm{sr}} + \bar{U}_i^{\mathrm{pr}}) \tag{17}$$

Step 5. Rank the alternatives and select the most optimal one.

4 | Real Case Study

This section introduces the results of the CRITIC-WISP methods for evaluating and selecting optimal wave energy converters.

4.1 | Comprehensive Overview

This section illustrates the techniques that are utilized and implemented for serving and achieving the study's objectives. We are implementing the constructed soft model in a real case study to validate the efficacy of the soft model. Table 2 represents the WenCo alternatives as volunteers in the decision process while implementing the constructed soft model.

Table 2. Alternatives of wave energy converters.

Converters	Rated Power (kW)	Classification	Ref
Pelamis	750	Attenuator	[38]
Wave Dragon	7000	Terminator	[39]
Aquabuoy	250	Point absorber	[40]
OEbuoy	2880	Oscillating Water Column	[41]
Langlee	1665	Oscillating wave surge converter	[41]
Archimedes Wave Swing (AWS)	2000	Submerged Pressure Differential	[42]

4.2 | Identify a Set of Criteria and Alternatives

Selection of the most suitable WEnCo type and site for wave energy extraction is influenced by several factors and criteria. We identified 8 criteria and 6 alternatives in this study based on the opinions of experts and decision-makers. Then we used 22 attribute values for all criteria.

The criteria for the evaluation of wave energy converters and their values are:

C1 = Energy Capture Efficiency → Benefit

C2 = Power Output → Benefit

C3 = Survivability → Benefit

C4 = Interoperability → Benefit

C5 = Environmental Impact → Non-Benefit

C6 = Capital Costs → Non-Benefit

C7 = Operation and Maintenance costs (O&M) → Non-Benefit

C8 = Levelized Cost of Energy (LCOE) → Non-Benefit

The attributes values are:

A1 = {>50%, 30-50%, <30%}

A2 = {<1 KW, 1-10 KW**, >10 KW**}

A3 = {>50 years, <50 years}

A4 = {High, Moderate, Poor}

A5 = {Minimal, Moderate, Significant}

A6 = {<$1 million/MW, $1-3 million/MW, >$3 million/MW}

A7 = {$100,000/year, $500,000/year}

A8 = {<$0.05/kWh, $0.05-$0.10/kWh, >$0.10/kWh}

4.3 | Valuating Criteria and Attributes Values: CRITIC-HPPS-TrNSs

4.3.1 | Valuating Criteria

Table 3. Aggregate de-neutrosophic matrix of criteria.

	C1 (+)	C2 (+)	C3 (+)	C4 (+)	C5 (-)	C6 (-)	C7 (-)	C8 (-)
WEnCo1	2.9300	2.5267	2.2367	2.4133	3.2933	1.5300	2.2900	3.5300
WEnCo2	1.4267	3.2600	6.0500	3.6500	6.2800	6.1100	5.0200	4.4233
WEnCo3	3.9367	4.1667	3.8600	4.2967	3.3600	4.6200	4.5767	4.4333
WEnCo4	2.1000	4.4167	2.4833	2.2633	3.7200	4.2200	2.6733	3.7200
WEnCo5	0.6767	1.9100	3.0300	3.2533	1.7233	1.7400	2.7700	0.6933
WEnCo6	4.6233	2.3067	1.6967	2.5733	1.6267	2.0933	2.3333	1.3333
max	3.9367	4.4167	6.0500	4.2967	6.2800	6.1100	5.0200	4.4333
min	0.6767	1.9100	2.2367	2.2633	1.7233	1.5300	2.2900	0.6933

Table 4. Normalize aggregate de-neutrosophic matrix of criteria.

	C1 (+)	C2 (+)	C3 (+)	C4 (+)	C5 (-)	C6 (-)	C7 (-)	C8 (-)
WEnCo1	0.6912	0.2460	0.0000	0.0738	0.6554	1.0000	1.0000	0.2415
WEnCo2	0.2301	0.5386	1.0000	0.6820	0.0000	0.0000	0.0000	0.0027
WEnCo3	1.0000	0.9003	0.4257	1.0000	0.6408	0.3253	0.1624	0.0000
WEnCo4	0.4366	1.0000	0.0647	0.0000	0.5618	0.4127	0.8596	0.1907
WEnCo5	0.0000	0.0000	0.2080	0.4869	1.0000	0.9541	0.8242	1.0000
WEnCo6	1.2106	0.1582	-0.1416	0.1525	1.0212	0.8770	0.9841	0.8289
σj	0.4614	0.4096	0.4110	0.3936	0.3717	0.4081	0.4400	0.4307

Table 5. Correlation coefficient values of the criteria.

	C1 (+)	C2 (+)	C3 (+)	C4 (+)	C5 (-)	C6 (-)	C7 (-)	C8 (-)
C1	1.0000	0.1391	-0.4359	-0.0353	0.3129	0.1441	0.1401	-0.0927
C2	0.1391	1.0000	0.2689	0.2170	-0.4948	-0.7190	-0.4522	-0.7821
C3	-0.4359	0.2689	1.0000	0.6995	-0.8300	-0.8187	-0.9257	-0.5442
C4	-0.0353	0.2170	0.6995	1.0000	-0.2964	-0.5321	-0.8563	-0.3194
C5	0.3129	-0.4948	-0.8300	-0.2964	1.0000	0.8413	0.7280	0.8099
C6	0.1441	-0.7190	-0.8187	-0.5321	0.8413	1.0000	0.8673	0.7450
C7	0.1401	-0.4522	-0.9257	-0.8563	0.7280	0.8673	1.0000	0.6334
C8	-0.0927	-0.7821	-0.5442	-0.3194	0.8099	0.7450	0.6334	1.0000

Table 6. Conflict degree (rij).

	C1 (+)	C2 (+)	C3 (+)	C4 (+)	C5 (-)	C6 (-)	C7 (-)	C8 (-)
C1	0.0000	0.8609	1.4359	1.0353	0.6871	0.8559	0.8599	1.0927
C2	0.8609	0.0000	0.7311	0.7830	1.4948	1.7190	1.4522	1.7821
C3	1.4359	0.7311	0.0000	0.3005	1.8300	1.8187	1.9257	1.5442
C4	1.0353	0.7830	0.3005	0.0000	1.2964	1.5321	1.8563	1.3194
C5	0.6871	1.4948	1.8300	1.2964	0.0000	0.1587	0.2720	0.1901
C6	0.8559	1.7190	1.8187	1.5321	0.1587	0.0000	0.1327	0.2550
C7	0.8599	1.4522	1.9257	1.8563	0.2720	0.1327	0.0000	0.3666
C8	1.0927	1.7821	1.5442	1.3194	0.1901	0.2550	0.3666	0.0000

Table 7. Final weights of main criteria.

Criteria	σj	rij	Cj	Wj	Wj %
C1	0.4614	6.8276	3.1504	0.1281	12.81%
C2	0.4096	8.8231	3.6140	0.1470	14.70%
C3	0.4110	9.5860	3.9403	0.1602	16.02%
C4	0.3936	8.1230	3.1975	0.1300	13.00%
C5	0.3717	5.9292	2.2036	0.0896	8.96%
C6	0.4081	6.4722	2.6410	0.1074	10.74%
C7	0.4400	6.8653	3.0205	0.1228	12.28%
C8	0.4307	6.5500	2.8213	0.1147	11.47%
SUM			24.5886	1.0000	100%

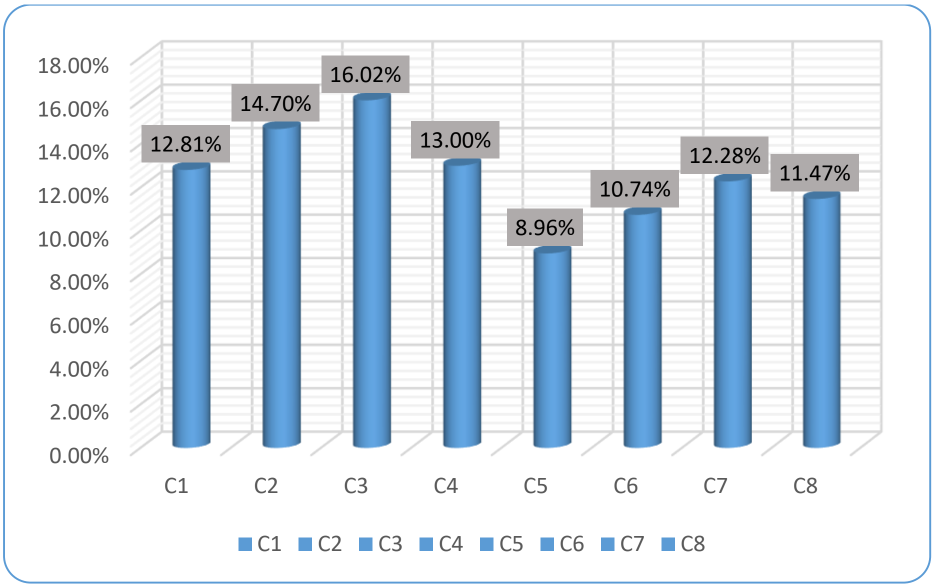

Figure 2. Weights of main criteria-based CRITIC.

4.4 | Ranking Alternatives using the WISP-HSS-TrNSs Method

Let C = C1 × C2 × C3 × C4 × C5 × C6 × C7 × C8 and the attribute values are (A1, A2, …. ,22). We choose the 8 attributes values as A = A1 × A6 × A7 × A10 × A13 × A15 × A18 × A20

Table 8. Aggregate de-neutrosophic matrix.

	A1 (+)	A6 (+)	A7 (+)	A10 (+)	A13 (-)	A15 (-)	A18(+)	A20 (-)
WEnCo1	3.5467	1.8500	4.1933	3.3500	1.4267	1.6167	5.0900	1.5833
WEnCo2	4.8667	5.4633	4.9933	2.6167	5.2667	4.2333	3.1800	4.9500
WEnCo3	3.9333	2.4467	4.3900	3.2867	3.2833	3.0933	3.1000	4.4333
WEnCo4	3.3800	2.0733	3.7200	2.7633	5.1667	4.9333	1.7800	3.4600
WEnCo5	1.9800	4.0567	0.6933	2.8767	3.1967	1.7767	2.0333	1.7400
WEnCo6	1.0733	3.5667	1.1267	2.2367	1.5300	3.0067	1.0200	1.8333
weight	0.0503	0.0385	0.0792	0.0451	0.0251	0.0279	0.0532	0.0412
max	4.8667	5.4633	4.9933	3.3500	5.2667	4.9333	5.0900	4.9500

Table 9. Normalized decision matrix.

	A1 (+)	A6 (+)	A7 (+)	A10 (+)	A13 (-)	A15 (-)	A18(+)	A20 (-)
WEnCo1	0.7288	0.3386	0.8398	1.0000	0.2709	0.3277	1.0000	0.3199
WEnCo2	1.0000	1.0000	1.0000	0.7811	1.0000	0.8581	0.6248	1.0000
WEnCo3	0.8082	0.4478	0.8792	0.9811	0.6234	0.6270	0.6090	0.8956
WEnCo4	0.6945	0.3795	0.7450	0.8249	0.9810	1.0000	0.3497	0.6990
WEnCo5	0.4068	0.7425	0.1389	0.8587	0.6070	0.3601	0.3995	0.3515
WEnCo6	0.2205	0.6528	0.2256	0.6677	0.2905	0.6095	0.2004	0.3704

Table 10. Weight sum normalized.

	A1 (+)	A6 (+)	A7 (+)	A10 (+)	A13 (-)	A15 (-)	A18(+)	A20 (-)
WEnCo1	0.0367	0.0130	0.0665	0.0451	0.0068	0.0092	0.0532	0.0132
WEnCo2	0.0503	0.0385	0.0792	0.0352	0.0251	0.0240	0.0332	0.0412
WEnCo3	0.0407	0.0173	0.0696	0.0442	0.0156	0.0175	0.0324	0.0369
WEnCo4	0.0350	0.0146	0.0590	0.0372	0.0246	0.0279	0.0186	0.0288
WEnCo5	0.0205	0.0286	0.0110	0.0387	0.0152	0.0101	0.0212	0.0145
WEnCo6	0.0111	0.0252	0.0179	0.0301	0.0073	0.0170	0.0107	0.0153

Table 11. Weight product normalized.

	A1 (+)	A6 (+)	A7 (+)	A10 (+)	A13 (-)	A15 (-)	A18(+)	A20 (-)
WEnCo1	0.9842	0.9591	0.9863	1.0000	0.9678	0.9693	1.0000	0.9541
WEnCo2	1.0000	1.0000	1.0000	0.9889	1.0000	0.9957	0.9753	1.0000
WEnCo3	0.9893	0.9695	0.9899	0.9991	0.9882	0.9870	0.9740	0.9955
WEnCo4	0.9818	0.9634	0.9770	0.9914	0.9995	1.0000	0.9457	0.9853
WEnCo5	0.9557	0.9886	0.8552	0.9932	0.9876	0.9719	0.9524	0.9578
WEnCo6	0.9267	0.9837	0.8887	0.9820	0.9695	0.9863	0.9181	0.9599

Table 12. Ranking alternatives.

	U_i^{sd}	U_i^{pd}	U_i^{sr}	U_i^{pr}	$\overline{U}_i^{sd}$	$\overline{U}_i^{pd}$	$\overline{U}_i^{sr}$	$\overline{U}_i^{pr}$	U_i	Rank
WEnCo1	0.1854	2.0384	7.3615	1.7050	1.0000	1.0000	1.0000	1.0000	1.0000	1
WEnCo2	0.1462	1.9685	2.6195	1.6571	0.9670	0.9770	0.4329	0.9823	0.8398	3
WEnCo3	0.1341	1.9511	2.9135	1.6568	0.9568	0.9713	0.4680	0.9822	0.8446	2
WEnCo4	0.0830	1.8743	2.0203	1.6279	0.9137	0.9460	0.3612	0.9715	0.7981	5
WEnCo5	0.0803	1.8279	3.0176	1.6266	0.9113	0.9307	0.4805	0.9710	0.8234	4
WEnCo6	0.0553	1.7836	2.3970	1.6117	0.8903	0.9161	0.4063	0.9655	0.7945	6
Max	0.1854	2.0384	7.3615	1.7050						

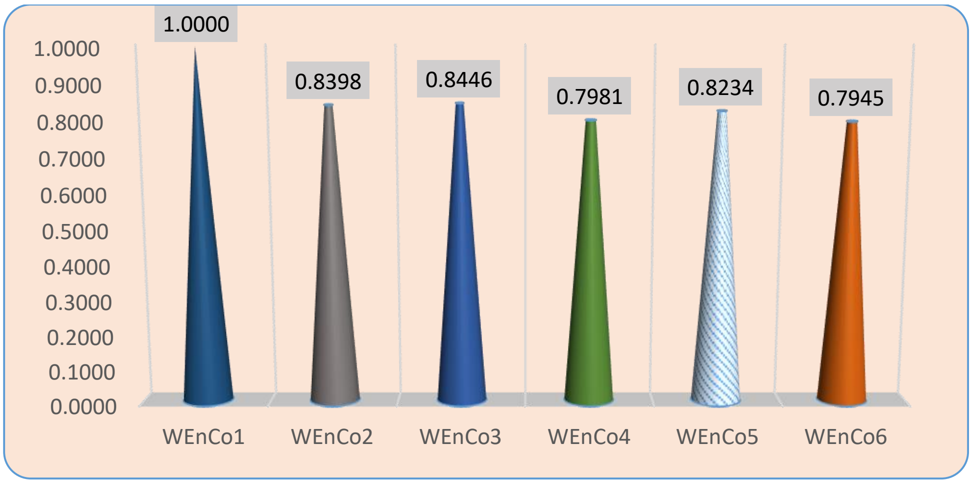

Figure 3. Ranking of optimal wave energy converters.

5 | Discussion

This section introduces the results of the CRITIC-WISP methods for evaluating and selecting optimal wave energy converters.

5.1 | Sensitivity Analysis

In this section, we are applying the various scenarios of changing criteria weight by conducting a sensitivity analysis method to determine how the decision for final rank is affected by changing criteria. Hence, a sensitivity analysis model is presented by changing the weights of factors to show the rank of strategies under different cases in weights. Herein, we implemented the five scenarios of changing the weights of criteria as shown in Table 13. In the first case, the weights of the criteria are equal. In other cases, we change the weight of two criteria and make other criteria similar. According to Figure 4, all scenarios agree that WEnCo1 is the optimal whilst WEnCo4 is the worst as well as the findings of the proposed decision-making model.

Table 13. Five cases in the change of weights of criteria.

	Case1	Case2	Case3	Case4	Case5
C1	0.125	0.2	0.1	0.1	0.1
C2	0.125	0.2	0.1	0.1	0.1
C3	0.125	0.1	0.2	0.1	0.1
C4	0.125	0.1	0.2	0.1	0.1
C5	0.125	0.1	0.1	0.2	0.1
C6	0.125	0.1	0.1	0.2	0.1
C7	0.125	0.1	0.1	0.1	0.2
C8	0.125	0.1	0.1	0.1	0.2

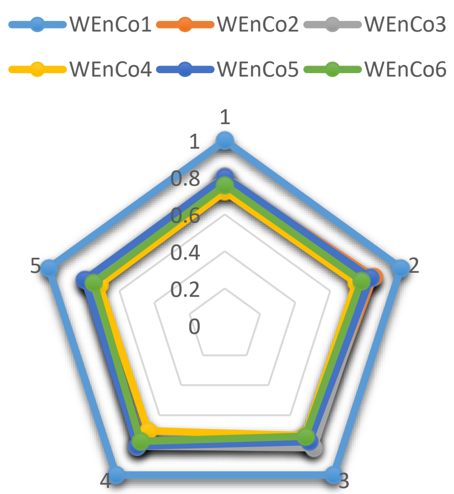

Figure 4. The rank of alternatives after changing weights of criteria.

5.2 | Comparative Analysis

A comparative analysis is shown to demonstrate the suggested method's applicability. In this section, we compare the results of the WISP method in this research with other MCDM methods to better understand the advantages of the used methodology. More comprehensive comparisons were conducted with other MCDM methods such as ARAS, MABAC, CoCoSo, MACROS, and RAM as shown in Figure 5. We used the same weight. Table 14 shows in detail the rank of comparative methods. We find all methods accepted. In this context, the WEnCo1 was again identified as the best converter and WEnCo6 was identified as the worst convertor in all methods.

Table 14. Rank of comparative methods.

Ranking Methods	WEnCo1	WEnCo2	WEnCo3	WEnCo4	WEnCo5	WEnCo6
ARAS	1	2	3	4	5	6
MABAC	1	2	3	5	4	6
CoCoSo	1	3	2	5	4	6
MACROS	1	2	3	4	5	6
RAM	1	2	3	4	5	6

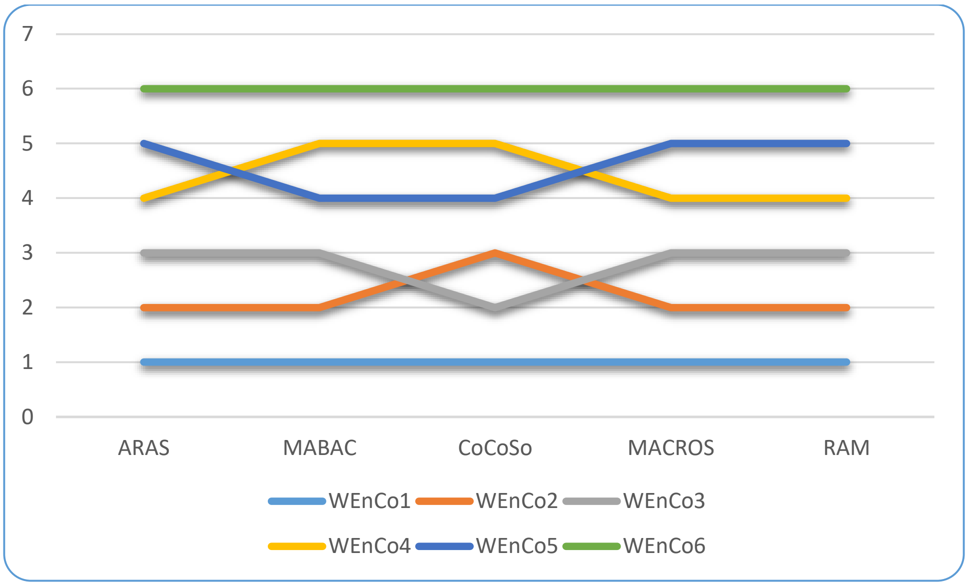

Figure 5. Rank of alternatives by using different MCDM methods.

6 | Conclusions

This paper has tracked the power performance of different types of wave energy converters over the years. We present a methodology for the selection of the most suitable WEnCo type and site for wave energy extraction is influenced by several factors and criteria. The main criteria of these WEnCos: Energy Capture Efficiency (C1), Power Output (C2), Survivability (C3), Interoperability (C4), Environmental Impact (C5), Capital Costs (C6), Operation and Maintenance costs (O&M) (C7), Levelized Cost of Energy (LCOE) (C8). Six different WEnCos were selected for this work: Pelamis Wave Dragon, Aquabuoy, OEbuoy, and Langlee. The proposed MCDM framework under TrNs-HSS is a valuable tool for the Selection of the most suitable WENCO type. We used 8 criteria and 22 attribute values based on 6 alternatives. Also, this study combines the benefit of the CRITIC Method—which determines the weights of criteria in MCDM problems—with WISP to evaluate and rank wave energy converter alternatives. Also, some analysis was performed to show the impact of the attribute of each criterion in choosing the best convertor that shows how effective is the presence or absence of each of the criteria. All performed sensitivity analyses are used as the guide for the managers to analyze all statuses in calculating the scores of the strategies. The results show that the criteria weights and scores of the sustainable strategies are more reliable than results obtained from the same methods.

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Author Contributions

All authors contributed equally to this work.

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Data Availability

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

Conflicts of Interest

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

Ethical Approval

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

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