



Ranking Sustainable Technologies in Wave Energy: Multi-Criteria Decision-Making Approach under Neutrosophic Sets

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Abstract

While it is still in its infancy in comparison to other forms of renewable technology, there is a growing amount of interest and backing for wave energy as a potentially useful renewable resource that could replace a portion of the existing energy supply. In the context of sustainable development, the choice of technology represents a multi-criterion decision-making (MCDM) challenge that may affect the competitive advantages enjoyed by an organization or a nation. The purpose of this study is to evaluate the many wave energy technologies that are now in use as possible choices for green and sustainable technologies that may be used in the seas and oceans. However, requirements like ecological, financial, and technological factors that are based on the fundamental idea of sustainability calls for unclear or unreliable expert assessments that can be solved using single-valued neutrosophic sets (SVNSs). Because of this, the selection of sustainable wave energy technology requires the creation of a one-of-a-kind framework that can analyze both clear and ambiguous data simultaneously without sacrificing any of the information in either category. This study developed a framework that uses measurement alternatives and ranking based on compromise solution (MARCOS) within the context of SVNSs to assist decision-makers in the process of resolving real-time energy problems. An application of the process of selecting the wave energy technology is taken into consideration here as a means of illustrating how applicable the suggested framework is.

Keywords: Single-Valued Neutrosophic Sets; MCDM; Renewable Energy; Wave Energy Technology.

1. Introduction

In today's world, there is an ever-increasing need for various forms of energy, since both human civilization and the economy are through a period of fast expansion. However, the excessive consumption of traditional fossil fuels that we engage in results in severe pollution of the environment and a significant increase in the pressure of an impending energy crisis. To achieve sustainable development, a growing number of nations are beginning to shift their attention from conventional energy sources to renewable sources of energy. Ocean energy has a massive amount of untapped potential in comparison to other forms of renewable energy[1]–[3].

There has been a sustained uptick in the development of ocean energy technologies over the last several decades. Particularly, tidal stream and wave energy have been recognized as technologies that have a chance to offer significant benefits for the majority of countries that have ocean resources in the medium to long term. This potential was discovered by researchers at the Massachusetts Institute of Technology[4]–[6].

Selection of suitable wave energy technology concerning various criteria this a multi-criteria decision-making (MCDM)[7]–[9]. It can be challenging for specialists to satisfy the needs of experts when confronting challenging and ambiguous choice-making issues by expressing the choices of experts via precise values in the analysis of real-world decision issues. This is because it is hard for specialists to deal with complicated decision-making difficulties[10], [11]. A new mathematical tool named fuzzy set is proposed to use membership degree to express uncertain information[12], [13]. This is done in response to the restrictions imposed by the intended difficulty of decision-making issues as well as the constraints imposed by the subjective comprehension of decision-makers [14]–[16].

Based on the fuzzy set, the intuitionistic fuzzy set (IFS) theory was established to more appropriately represent unreliable data. This was accomplished by adding non-membership and hesitation operations to the fuzzy set. This restriction was brought about by the fact that fuzzy sets can only employ the membership function to express fuzzy information. The study that was done on intuitionistic fuzziness has yielded excellent findings in recent years and has seen widespread application. Although IFSs have been the subject of extensive research and have provided solutions to a large number of uncertain decision and evaluation issues, they are unable to represent indefinite or inconsistent information[17], [18].

Smarandache devised a brand-new uncertain model from the point of view of philosophy that he dubbed the neutrosophic set (NS) to represent how individuals evaluate real information. This was done so that he could overcome this flaw. The truth-membership, indeterminacy-membership, and falsity-membership functions are what make up NS. Even though NS further popularises fuzzy sets and IFS, it is difficult to apply them directly to real-world issues because membership functions have a wide range of possibilities[19]–[21]. Therefore, Wang et al. came up with the idea to develop the single-valued neutrosophic (SVN) set as an initial step towards further enriching the applications of neutrosophic theory in real-world problems. Investigations on SVNS are receiving an increasing amount of interest in both the creation of fundamental theory and the expansion of application in practice. This is due to the superiority of SVNS in presenting ambiguous information[22], [23].

The main contribution of this paper:

- A. The goal of this study is to identify and rank the most promising methods for harnessing the energy contained in waves so that it may be converted into electricity.
- B. The single-valued neutrosophic sets are used to solve the uncertainty and vague information.
- C. The various criteria of positive and negative criteria are used.
- D. The integration of single-valued neutrosophic sets (SVNSs) with the MARCOS method to rank the technology of wave energy.

The following is a list of what falls within the purview of this work: The steps of the single-valued neutrosophic sets with the MARCOS method are investigated in Section 2. In section 3 the results of the applying steps of the MARCOS method are obtained and discussed. The conclusions are the last section of this paper.

2. Neutrosophic MARCOS

An innovative framework that combines neutrosophic sets and MARCOS is offered as a means of assisting decision-makers in the selection of suitable wave energy technology in the face of competing requirements within an SVN setting[24]. The SVN -MARCOS methodology provides the designers with the freedom to concurrently analyze specified information in the form of crisp values and ambiguous data. This is made possible by the modular nature of the methodology. The following outlines the methodical process that should be followed to implement the suggested SVN-MARCOS methodology. Figure 1 shows the steps of the proposed methodology.



Figure 1: The steps of the neutrosophic MARCOS method.

Step 1: Build the SVN decision matrix

This step provides a decision matrix between the set of criteria and alternatives. The sets of alternatives can be presented as $i = (WETA_1, WETA_2, \dots, WETA_i)$ and the set of criteria can be presented as: $j = (WETC_1, WETC_2, \dots, WETC_j)$. This matrix is built by the linguistic term by the SVN, then replaces these terms with the single-valued neutrosophic numbers[24].

Step 2: Compute the weights of the criteria

The weights of the criteria can be computed by the average method.

Step 3: Employ the ideal and non-ideal in the decision matrix

The decision matrix is extended by the ideal and non-ideal solutions:

$$ID = \begin{cases} \max R_{ij} & \text{positive criteria} \\ \min R_{ij} & \text{negative criteria} \end{cases} \tag{1}$$

$$NID = \begin{cases} \min R_{ij} & \text{positive criteria} \\ \max R_{ij} & \text{negative criteria} \end{cases} \tag{2}$$

The *ID* and *NID* refers to the ideal and non-ideal solutions, R_{ij} refers to the element in the decision matrix.

Step 4: Normalize the decision matrix

The previous decision matrix is extended as:

$$O_{ij} = \begin{cases} \frac{R_{ij}}{ID} & \text{positive criteria} \\ \frac{ID}{R_{ij}} & \text{negative criteria} \end{cases} \tag{3}$$

Step 5: Compute the weighted normalized decision matrix

The weighted normalized decision matrix is obtained by multiplying the weights of criteria by the normalization extended matrix as:

$$WO_{ij} = O_{ij} \times w_j \tag{4}$$

Where the O_{ij} refers to the normalization decision matrix and w_j refers to the weights of the criteria.

Step 6: Compute the sum of the weighted normalized decision matrix

This step obtains the sum of the weighted normalized decision matrix (WO_{ij}) as

$$Sum_i = \sum_{j=1}^m WO_{ij} \tag{5}$$

Step 7: Compute the degree of utility as:

This step computes the degree of utility to an alternative under the ideal and non-ideal solution as:

$$U_i^+ = \frac{sum_i}{sum_{ID}} \tag{6}$$

$$U_i^- = \frac{sum_i}{sum_{NID}} \tag{7}$$

Where Sum_{ID} and Sum_{NID} refer to the sum weighted to ideal and non-ideal solutions

Step 8: Compute the function of the utility

The utility function is used to rank the alternatives as:

$$f(U_i) = \frac{u_i^+ + u_i^-}{1 + \frac{1-f(u_i^+)}{f(u_i^+)} + \frac{1-f(u_i^-)}{f(u_i^-)}} \tag{8}$$

$$f(U_i^+) = \frac{u_i^-}{u_i^- + u_i^+} \tag{9}$$

$$f(U_i^-) = \frac{u_i^+}{u_i^- + u_i^+} \tag{10}$$

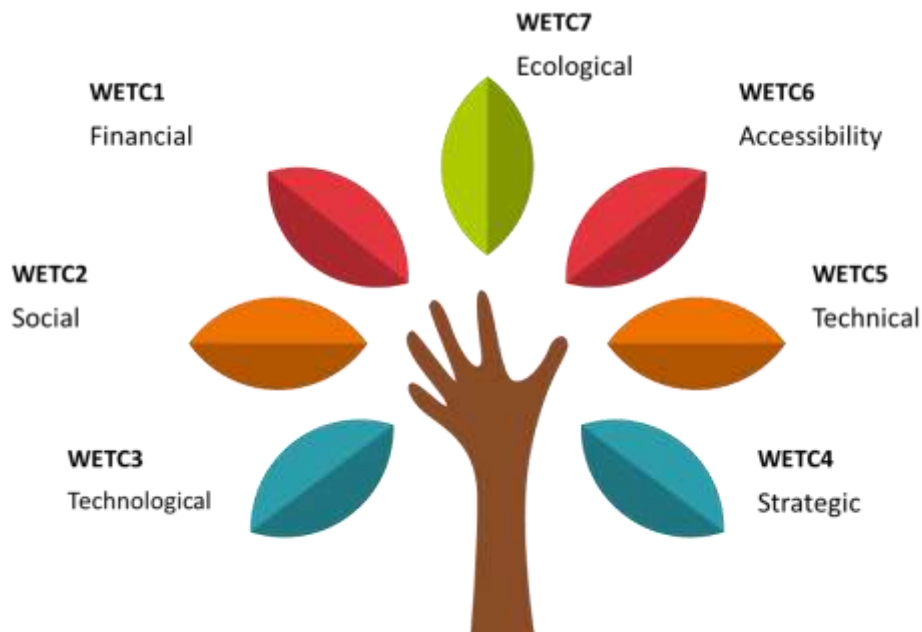


Figure 2: List of seven wave energy criteria

3. Results

In this section, we apply the steps of the SVN-MARCOS method to select the best wave energy technology to achieve sustainable development. The data are collected from previous research and questionnaires. There are seven criteria and ten alternatives collected from previous works are shown in Figure 2. The results of the literature review make this very clear. To assess wave energy throughout a region, this study has been carried out, and in it, complete and multilateral criteria that take into account the sustainability of the economy, the environment, and society have been developed. In this study, seven significant and all-encompassing criteria have been taken into consideration to choose the most suitable wave energy technology. These criteria include geopolitical aspects/reliability, accessibility, technical expertise, technological expertise, financial expertise, social understanding, and environmental information. Research conducted in the fields of technology assessment, technological selection, and particularly the use of renewable energy technologies concerning sustainability was used to compile the data that led to the development of these criteria. The experts and decision-makers who evaluated the criteria and alternatives to build the decision matrix have experience in renewable energy and wave energy. The experts and decision-makers have had expertise in this field for more than ten years.

The experts evaluated the criteria and alternatives to build the decision matrix as shown in Table 1. Then compute the weights of criteria by the average method. The weights of the seven criteria are shown in Figure 3.

Table 1: The decision matrix between criteria and alternatives.

	WETC ₁	WETC ₂	WETC ₃	WETC ₄	WETC ₅	WETC ₆	WETC ₇
WETA ₁	(0.90, 0.10, 0.10)	(0.40, 0.55, 0.55)	(0.80, 0.25, 0.20)	(0.60, 0.35, 0.40)	(0.60, 0.35, 0.40)	(0.80, 0.25, 0.20)	(0.90, 0.10, 0.10)
WETA ₂	(0.60, 0.35, 0.40)	(0.20, 0.75, 0.80)	(0.40, 0.55, 0.55)	(0.40, 0.55, 0.55)	(0.90, 0.10, 0.10)	(0.20, 0.75, 0.80)	(0.40, 0.55, 0.55)
WETA ₃	(0.80, 0.25, 0.20)	(0.80, 0.25, 0.20)	(0.60, 0.35, 0.40)	(0.90, 0.10, 0.10)	(0.20, 0.75, 0.80)	(0.90, 0.10, 0.10)	(0.80, 0.25, 0.20)
WETA ₄	(0.60, 0.35, 0.40)	(0.40, 0.55, 0.55)	(0.90, 0.10, 0.10)	(0.60, 0.35, 0.40)	(0.90, 0.10, 0.10)	(0.20, 0.75, 0.80)	(0.90, 0.10, 0.10)
WETA ₅	(0.90, 0.10, 0.10)	(0.90, 0.10, 0.10)	(0.20, 0.75, 0.80)	(0.20, 0.75, 0.80)	(0.60, 0.35, 0.40)	(0.80, 0.25, 0.20)	(0.60, 0.35, 0.40)
WETA ₆	(0.80, 0.25, 0.20)	(0.60, 0.35, 0.40)	(0.60, 0.35, 0.40)	(0.80, 0.25, 0.20)	(0.20, 0.75, 0.80)	(0.90, 0.10, 0.10)	(0.60, 0.35, 0.40)
WETA ₇	(0.40, 0.55, 0.55)	(0.20, 0.75, 0.80)	(0.90, 0.10, 0.10)	(0.40, 0.55, 0.55)	(0.40, 0.55, 0.55)	(0.20, 0.75, 0.80)	(0.40, 0.55, 0.55)
WETA ₈	(0.60, 0.35, 0.40)	(0.80, 0.25, 0.20)	(0.90, 0.10, 0.10)	(0.40, 0.55, 0.55)	(0.80, 0.25, 0.20)	(0.20, 0.75, 0.80)	(0.90, 0.10, 0.10)
WETA ₉	(0.40, 0.55, 0.55)	(0.20, 0.75, 0.80)	(0.60, 0.35, 0.40)	(0.20, 0.75, 0.80)	(0.20, 0.75, 0.80)	(0.40, 0.55, 0.55)	(0.60, 0.35, 0.40)
WETA ₁₀	(0.90, 0.10, 0.10)	(0.80, 0.25, 0.20)	(0.40, 0.55, 0.55)	(0.90, 0.10, 0.10)	(0.60, 0.35, 0.40)	(0.80, 0.25, 0.20)	(0.90, 0.10, 0.10)

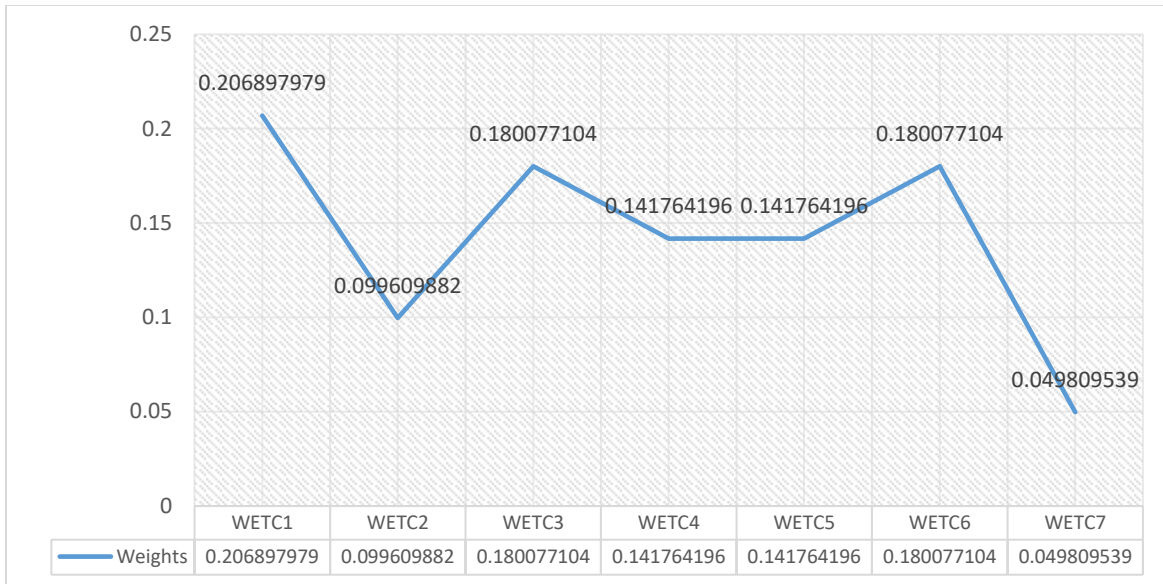


Figure 3: The weights of seven factors.

Then compute the ideal and no-ideal solutions to extend the decision matrix by using Eqs. (1,2). Then compute the normalization decision matrix by using Eq. (3). The normalization decision matrix is shown in Table 2. Then multiply the weights of criteria by the normalization decision matrix to compute the weighted normalized decision matrix by using Eq. (4) as shown in Table 3.

Table 2: The normalization decision matrix.

	WETC ₁	WETC ₂	WETC ₃	WETC ₄	WETC ₅	WETC ₆	WETC ₇
WETA ₁	2.077083	0.481444	0.870367	0.685189	0.685189	0.870367	1
WETA ₂	1.423194	0.240744	0.481444	0.481444	1	0.240744	0.481444
WETA ₃	1.807824	0.870367	0.685189	1	0.240744	1	0.870367
WETA ₄	1.423194	0.481444	1	0.685189	1	0.240744	1
WETA ₅	2.077083	1	0.240744	0.240744	0.685189	0.870367	0.685189
WETA ₆	1.807824	0.685189	0.685189	0.870367	0.240744	1	0.685189
WETA ₇	1	0.240744	1	0.481444	0.481444	0.240744	0.481444
WETA ₈	1.423194	0.870367	1	0.481444	0.870367	0.240744	1
WETA ₉	1	0.240744	0.685189	0.240744	0.240744	0.481444	0.685189
WETA ₁₀	2.077083	0.870367	0.481444	1	0.685189	0.870367	1

Table 3: The weighted normalization decision matrix.

	WETC ₁	WETC ₂	WETC ₃	WETC ₄	WETC ₅	WETC ₆	WETC ₇
WETA ₁	0.429744	0.047957	0.156733	0.097135	0.097135	0.156733	0.04981
WETA ₂	0.294456	0.023981	0.086697	0.068252	0.141764	0.043353	0.023981
WETA ₃	0.374035	0.086697	0.123387	0.141764	0.034129	0.180077	0.043353
WETA ₄	0.294456	0.047957	0.180077	0.097135	0.141764	0.043353	0.04981
WETA ₅	0.429744	0.09961	0.043353	0.034129	0.097135	0.156733	0.034129
WETA ₆	0.374035	0.068252	0.123387	0.123387	0.034129	0.180077	0.034129
WETA ₇	0.206898	0.023981	0.180077	0.068252	0.068252	0.043353	0.023981
WETA ₈	0.294456	0.086697	0.180077	0.068252	0.123387	0.043353	0.04981
WETA ₉	0.206898	0.023981	0.123387	0.034129	0.034129	0.086697	0.034129
WETA ₁₀	0.429744	0.086697	0.086697	0.141764	0.097135	0.156733	0.04981

Then compute the sum of the weighted normalized decision matrix by using Eq. (5). Then compute the utility degree of ideal and non-ideal solutions concerning alternatives by using Eqs. (6,7). Then compute the function of utility by using Eqs. (8,9,10). Then rank the alternatives according to the highest value of $f(U_i)$ as shown in Figure 4. Alternative 10 is the best and alternative 2 is the worst.

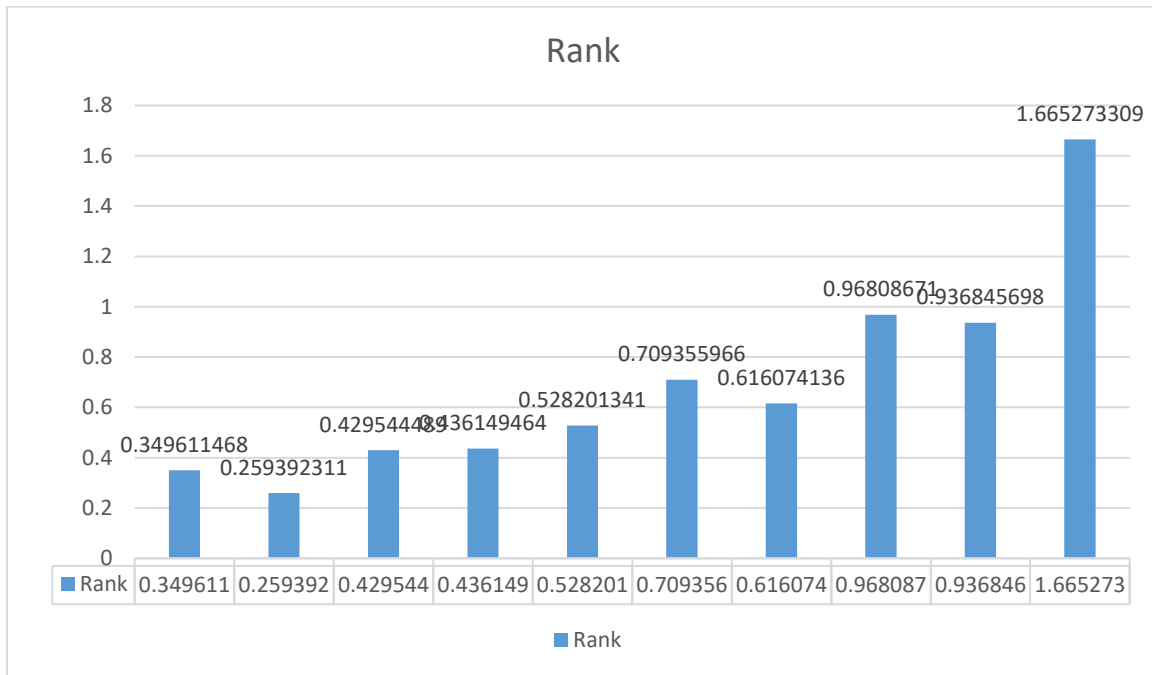


Figure 4: The rank of wave energy technology alternatives.

4. Conclusions

Oceans and oceans are rich sources of renewable energy that have the potential to provide a portion of the energy that the world requires while simultaneously reducing the usage of fuels that are not renewable or fossil-based. Wave energy is considered to be one of the cleanest and most sustainable kinds of renewable energy. Even though wave energy production is still in its early stages, it is worthy of consideration as a potential alternative green energy source. Through an all-encompassing evaluation, the purpose of this research was to develop a template for prioritizing wave energy. To accomplish this goal, the MCDM approach was used. By reading various articles and books, as well as soliciting the feedback of industry professionals, we were able to derive converters as substitutes and evaluation variables as standards. This research used the neutrosophic sets to overcome the vague information. The SVNSs are a type of neutrosophic set used in this paper. The concept of MCDM is used due to various criteria of wave energy. The SVNSs-MARCOS method is used in this paper to rank alternatives.

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