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Toward Energy Transformation: Intelligent Decision-Making Model Based on Uncertainty Neutrosophic Theory

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Abstract: There has been an increasing tendency for the generation of energy from diverse renewable resources because of the application of contemporary pollution mitigation and justification regulations. Precisely a consequence, choosing the best renewable energy source might be considered a challenging issue given the complexity of the future conditions in any society. Environmental, economic, social, and technical aspects are merely some of the factors that are taken into consideration while evaluating renewable energy sources (RnESs). The suitable RES selection problem, which relies on ambiguous and imprecise data, is also influenced by a variety of circumstances. Hence, this study constructs multi-stages intelligent decision-making model (MsIDMM) based on multi-criteria decision making (MCDM) with support with neutrosophic theory especially, interval valued neutrosophic sets to rank the sources of renewable energy. Ultimately, combinative distance-based assessment (CODAS) method under interval-valued neutrosophic sets is used to rank the sources of renewable energy.

Keywords: Renewable Energy; CODAS; MCDM; Interval Valued Neutrosophic Set; Sustainability.

1. Introduction

Given the ongoing rise in energy demand and the potential depletion of fossil fuels, academics and energy producers alike should focus more on the sustainability of renewable energy sources (RnESs) [1]. Arguably based on [2] the most serious issues the world is currently facing are the enormous and rapid growth of the population reaching 9 Billion by 2050, innovation, growth, and cultural advancement, which is related to the enormous demand and excessive consumption patterns of energy, water, and food resources compared to the generation of energy and the limited natural land, water, materials, and fuels resources. Therefore, changes in energy usage have a substantial impact on economic activity and the determination of income [3]. Hence sustainable Energy (SusE) is crucial for a nation's economic and social development as well as for improving people's quality of life [4].

In order to ensure that everyone has access to cheap, dependable, sustainable, and contemporary energy, one of the global goals of the 2030 Agenda for Sustainable Development (SusD) is to promote SE [4]. The goals of SusD are threatened by conventional energy-generating techniques such as those that rely on fossil fuels. According to [5] utilizing fossil fuels not only harms the environment and produces harmful pollutants, not only damage the environment and emit hazardous gases, but also their energy sources are not sustainable. From the researchers' point of view in [6], the problem raised in [5] can be controlled by offering substitute and cleaner sources, and the nation's level of living may raise. The solution of [6] is represented in RnESs which play an essential role in guaranteeing the cleanest possible energy that is sustainable. In a similar vein, [7] emphasized that to fulfill the energy demand, combat climate change, and fulfill the need for clean and sustainable development, the continued growth of RnESs has become a crucial strategy.

Making the best choice for a renewable energy source would benefit sustainability in other aspects as social, and environmental in addition to the economic one. Contrariwise [8], the wrong choice of RnES might have negative effects on aspects of sustainability as the environment and the economy as exhibited in Figure 1.

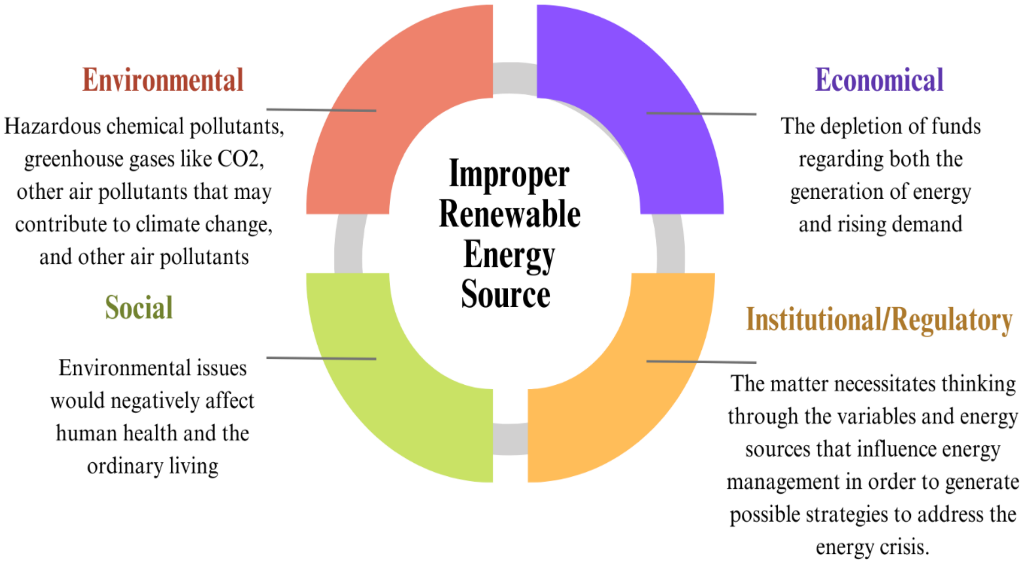

Figure 1. Consequences of adopting an undesirable renewable energy source.

Wherefore, selecting optimal or suitable RnES is a critical process. In order to reduce environmental pollution, usage of traditional resources, and improve economic growth, [6] affirmed that the selection process need to be strategically chosen.

For the purpose of planning for sustainable energy, [9] indicated that there are a number of aspects including environmental, social, economic, technological, and institutional considerations, should be utilized as benchmarks. Consequently [10] contributed multi-criteria decision-making (MCDM) methods in choosing an optimal RnES candidate. Nevertheless, there is a further perspective on the application of these methods. For instance, [6] MCDM methods are insufficient for handling the ambiguous information that frequently arises during energy planning procedures. So, scholars as Zadeh [11] resorted to using Fuzzy Sets (FSs). Its adaptability and efficiency in resolving circumstances where the information at hand is ambiguous or insufficient are remarkable. Ditto the generalization of (FSs) is Intuitionistic fuzzy sets (IFSs) which take into consideration measurements of truth and non-truth otherwise FSs which concerns truth.

Nonetheless, herein the study is followed suit Smarandache [12] through volunteering neutrosophic theory. This is a result of having a significant aptitude for developing approaches using vague and erratic information. The neutrosophic theory is distinguished by three separate membership functions that represent the roles of truth, indeterminacy, and falsity.

Interval valued neutrosophic theory is inspired by neutrosophic theory. Therefore, in this study SVNS combined with MCDM methods, especially CODAS method for handling the multi-criteria RnESs to choose optimal one.

This study is organized into a set of sections; each one plays a certain role. Whereas the motives on where the study was based are illustrated in Section 2. Through prior studies we aggregated essential sources of renewable energy in Section 3. These sources need to be analyzed and evaluated, hence we constructed hybrid model for evaluating these sources in Section 4. After that we are applying this model to verify it through evaluating 6 sources based on 22 criteria. Finally, we exhibit synopsis for the study.

2. Motivations of the Study

This section represents motivations for conducting this study. These motivations are illustrated through set of aspects as following:

- **Societal Aspect:** According to [13], utilization of fossil fuels or improper RnESs leads to environment problems; i.e. global warming is caused by greenhouse gas (GHG) emissions such as carbon dioxide, methane oxide, and nitrous oxide in the atmosphere. Which in turn affects human life and threatens health.
- **Technical/Practical Aspect:** Selecting suitable and optimal RnES is vital to lessen the hazards associated with selecting renewable energy incorrectly, which jeopardizes sustainability. Therefore, it is important to utilize flexible and efficient techniques which can analyze various alternatives of RnESs based on a set of criteria. Herein, the study uses MCDM methods to rank the sources of renewable energy with support of neutrosophic theory especially Interval valued neutrosophic to strength CODAS of MCDM to generate robust hybrid intelligent model.
- **Experimental Aspect:** We are applying constructed hybrid intelligent framework for ranking six renewable energy sources as alternatives based on 22 criteria. Herein, the utilized alternatives **(**A_n) are solar energy, wind energy, hydro energy, biomass energy, geothermal energy, and wave energy.

3. Essential Principles of Renewable Energy Sources

This section exhibits the different RnESs based on prior studies which related to our interested scope. For instance, [14]-[15] exhibited set of RnESs where aggregated in Figure 2.

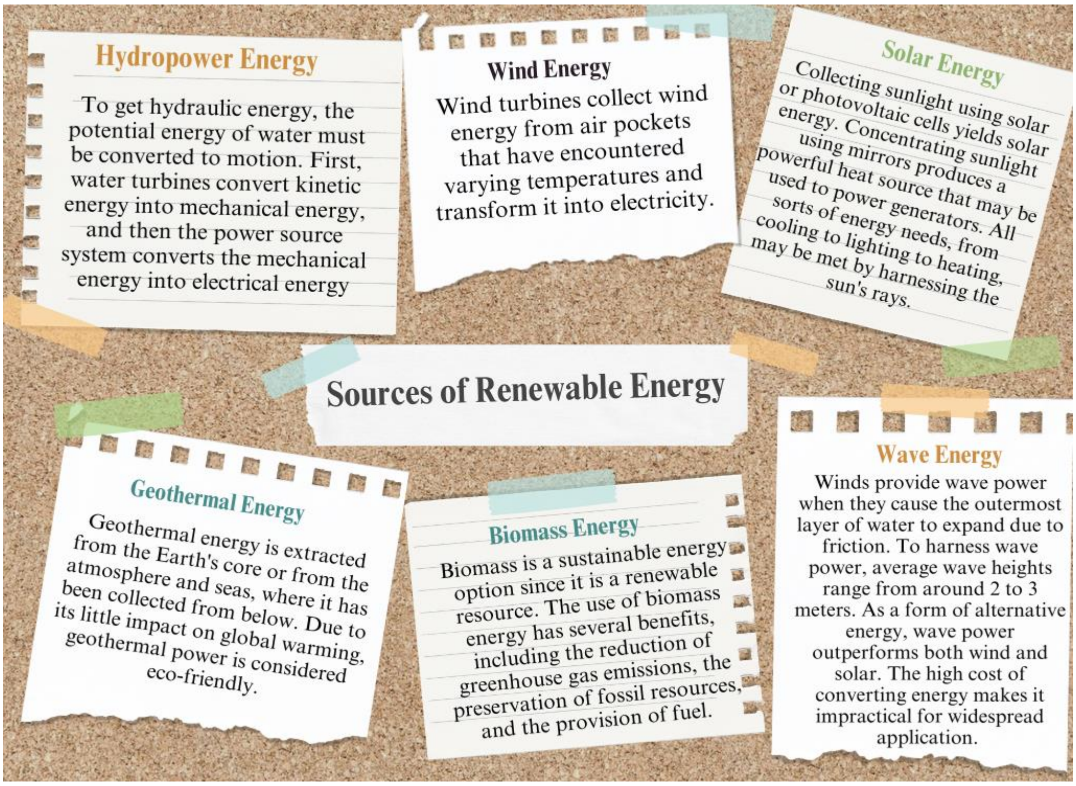

Figure 2. Various sources of renewable energy.

4. Multi-stages Intelligent Decision-Making Model (MsIDMM)

In our constructed model, we use two elements to determine which options are preferable. Both the Euclidean and Taxicab distances of options to the cost-ideal are used as indicators of attractiveness, the greater the distance means the more desirable the option. The CODAS method is integrated with the neutrosophic method to deal with vague data. We evaluate the criteria and alternatives according to [16]- [21].

In this study, the first stage included determining 22 criteria which contribute to selection process for RnESs. After that the second stage is evaluating the determined criteria by formed expert panel. Third stage represented in analyzing process for expert's evaluations through MsIDMM based on neutrosophic theory combined with MCDM methods. The result of MsIDMM is ranking and selecting optimal RnES. Figure 3 summarizes the stages of model.

Step 4.1 *Determine The Criteria of Renewable Energy*

In the first stage, the process aim is established, and the relevant criteria for assessing the options are selected.

Step 4.2 Formulate the Matrix Between Criteria and Resources of Renewable Energy.

The matrix is built by the criteria $i = 1,2,3 \ldots.m; j = 1,2,3 \ldots n$, and the element of matrix is k_{ij}.

Step 4.3 Normalize the Decision Matrix.

$$r_{ij} = \begin{cases} \frac{k_{ij}}{\max_i k_{ij}} \\ \frac{\min_i k_{ij}}{k_{ij}} \end{cases} \quad (1)$$

Step 4.4 Determine the Weighted Normalized Matrix.

$$q_{ij} = e_j r_{ij} \quad (2)$$

Where e_j refers to the weights of criteria.

Step 4.5 Compute the Point of Cost Ideal Solution.

$$cq_j = \min_i q_{ij} \quad (3)$$

Step 4.6 Compute the Taxicab and Euclidean Distances.

$$A_i = \sum_{j=1}^{m} |q_{ij} - cq_j| \quad (4)$$

$$D_i = \sqrt{\sum_{j=1}^{m} (q_{ij} - cq_j)^2} \quad (5)$$

Step 4.7 Compute the Matrix of Comparative Assessment.

$$Ass_{iy} = (D_i - D_y) + (\alpha(D_i - D_y) \times (A_i - A_y)) \quad (6)$$

Where $y = 1,2,3, \ldots n$, and α refers to the function of threshold.

$$\alpha(k) = \begin{cases} 1, if\ |k| \geq \beta \\ 0, if\ |k| < \beta \end{cases} \quad (7)$$

Where β *between* 0.01 *and* 0.05 refers to the expert's threshold.

Step 4.8 Compute the Evaluation Score.

$$U_i = \sum_{y=1}^{n} Ass_{iy} \quad (8)$$

Step 4.9 Rank the Sources of Renewable Energy

The renewable energy resources are ranked according to the Maximum value of U_i

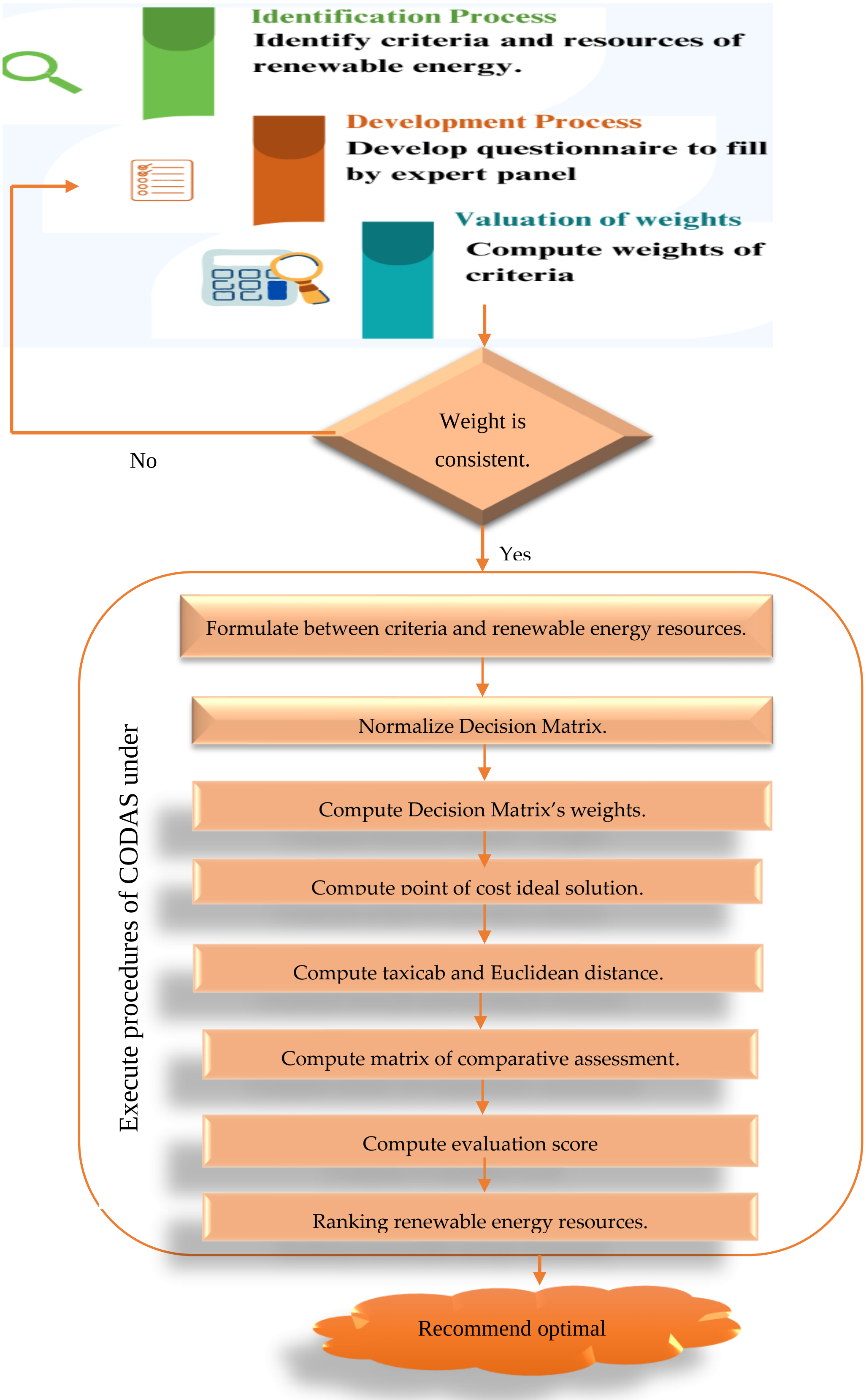

Figure 3. Various stages of Multi-stages Intelligent Decision-Making Model.

5. Validation of Renewable Energy Resources based on MsIDMM

Herein, the study validates the constructed MsIDMM for assessing determined RnESs. It computes the weights of criteria for determined RnESs highlighted by earlier studies as [14] ,[5]. Whereas there are 22 criteria. There are six renewable energy sources like solar, wind, hydro, biomass, geothermal, and wave energy. Figure 4 reveals the utilized criteria and alternatives.

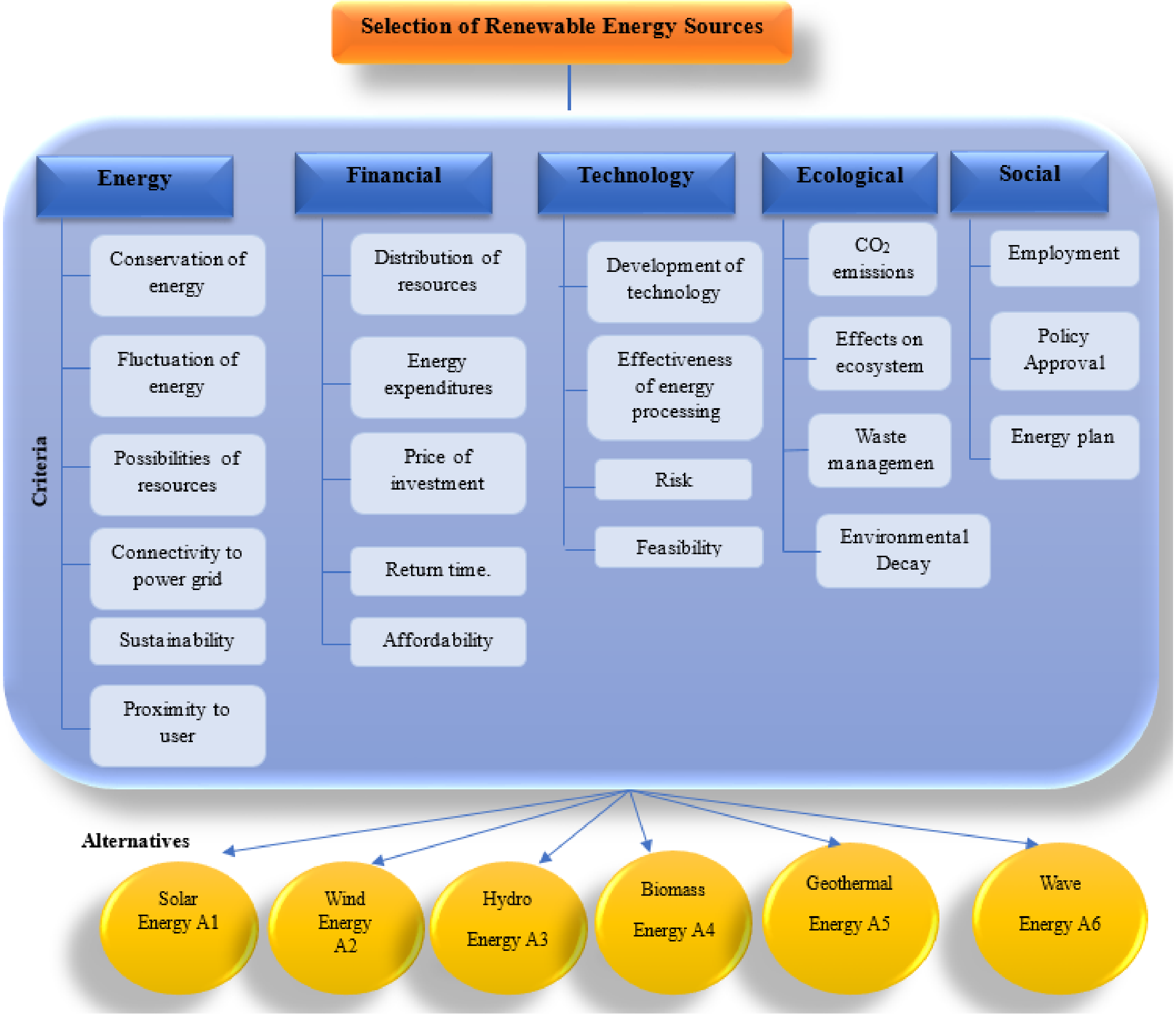

Figure 4. Selection alternatives of renewable energy sources based on criteria.

Decision makers (DMs) and experts evaluate the renewable energy criteria and sources to create decision matrix between criteria and alternatives by using interval valued neutrosophic numbers. Then the decision matrix is normalized as shown in Table 1 by using Eq. (1). After that the weights of renewable energy criteria are computed. Then the weights of the criteria are multiplied by the normalization matrix using Eq. (3).

Then the point of cost for the ideal solution is computed using Eq. (3). Then the taxicab is computed as shown in Table 2 and Euclidean distances using Eqs. (4-5) as shown in Table 3. After that the matrix of comparative assessment is computed using Eqs. (6-7). Then the evaluation score is computed using Eq. (8) as shown in Figure 5. The second renewable energy source is the best and the third renewable energy source is the worst.

Table 1. The normalization matrix between renewable energy criteria and sources.

	RNC_1	RNC_2	RNC_3	RNC_4	RNC_5	RNC_6	RNC_7	RNC_8	RNC_9	RNC_{10}	RNC_{11}
RNA_1	0.623306	0.422764	1	0.467681	0.369408	0.566038	0.659218	0.639566	1	0.125102	1
RNA_2	0.642005	1	0.590862	0.721166	0.532468	0.72119	0.414763	0.996201	0.203188	0.186068	0.654023
RNA_3	0.642005	0.639566	0.383178	0.494297	0.369408	0.192453	0.996201	0.996201	0.548755	0.517518	0.272299
RNA_4	0.642005	0.97561	0.383178	0.324461	0.532468	0.34688	0.987448	0.907692	0.550847	0.26886	0.793103
RNA_5	0.642005	0.639566	0.383178	0.878327	0.950938	1	0.311798	1	0.501931	1	0.309195
RNA_6	1	0.639566	0.590862	1	1	0.342525	1	0.395973	0.147895	0.175193	0.413793
	RNC_{12}	RNC_{13}	RNC_{14}	RNC_{15}	$RNsub_{16}$	$RNsub_{17}$	RNC_{18}	RNC_{19}	RNC_{20}	RNC_{21}	RNC_{22}
RNA_1	1	0.669412	0.42907	0.51236	0.639326	1	1	0.99803	1	0.639295	0.246002
RNA_2	0.800203	0.302235	0.146512	0.26618	0.265169	0.713561	0.339398	0.516524	0.338109	1	0.245067
RNA_3	0.240264	0.305447	0.298721	0.26618	0.265169	0.467681	0.339398	0.52309	0.338109	1	0.133956
RNA_4	0.84787	1	1	1	1	0.340938	0.338109	0.516524	0.338109	0.885908	1
RNA_5	0.272819	0.536471	0.277907	0.265169	0.640225	0.299113	0.528653	1	0.339398	0.642005	0.265836
RNA_6	0.462475	0.654118	0.42907	0.51236	0.414607	0.300253	0.654585	0.807617	0.815186	0.642005	0.369678

Table 2. The taxicab distance from cost ideal solution.

	RNC_1	RNC_2	RNC_3	RNC_4	RNC_5	RNC_6	RNC_7	RNC_8	RNC_9	RNC_{10}	RNC_{11}
RNA_1	0	0	0.053351	0.004747	0	0.013086	0.011171	0.008073	0.009949	0	0.056863
RNA_2	0.000386	0.008088	0.017963	0.013148	0.003749	0.018521	0.003311	0.019893	0.000646	0.005366	0.029828
RNA_3	0.000386	0.003038	0	0.005629	0	0	0.022007	0.019893	0.00468	0.034541	0
RNA_4	0.000386	0.007746	0	0	0.003749	0.005409	0.021725	0.01696	0.004705	0.012654	0.040696
RNA_5	0.000386	0.003038	0	0.018356	0.013371	0.028287	0	0.020019	0.004134	0.077009	0.002883
RNA_6	0.007782	0.003038	0.017963	0.022389	0.014499	0.005257	0.022129	0	0	0.004409	0.011056
	RNC_{12}	RNC_{13}	RNC_{14}	RNC_{15}	RNC_{16}	RNC_{17}	RNC_{18}	RNC_{19}	RNC_{20}	RNC_{21}	RNC_{22}
RNA_1	0.067282	0.018765	0.009365	0.010124	0.019122	0.049669	0.041495	0.019721	0.041495	0	0.002384
RNA_2	0.049588	0	0	4.14E-05	0	0.02937	8.08E-05	0	0	0.007643	0.002364
RNA_3	0	0.000164	0.005045	4.14E-05	0	0.011946	8.08E-05	0.000269	0	0.007643	0
RNA_4	0.053809	0.03566	0.028287	0.030096	0.037554	0.002964	0	0	0	0.005225	0.018427
RNA_5	0.002883	0.011971	0.004355	0	0.019167	0	0.011946	0.019801	8.08E-05	5.74E-05	0.002806
RNA_6	0.019679	0.017983	0.009365	0.010124	0.007637	8.08E-05	0.01984	0.011922	0.029909	5.74E-05	0.005016

Table 3. The Euclidean distance from cost ideal solution.

	RNC_1	**RNC_2**	**RNC_3**	**RNC_4**	**RNC_5**	**RNC_6**	**RNC_7**	**RNC_8**	**RNC_9**	**RNC_{10}**	**RNC_{11}**
RNA_1	0	0	0.053351	0.004747	0	0.013086	0.011171	0.008073	0.009949	0	0.056863
RNA_2	0.000386	0.008088	0.017963	0.013148	0.003749	0.018521	0.003311	0.019893	0.000646	0.005366	0.029828
RNA_3	0.000386	0.003038	0	0.005629	0	0	0.022007	0.019893	0.00468	0.034541	0
RNA_4	0.000386	0.007746	0	0	0.003749	0.005409	0.021725	0.01696	0.004705	0.012654	0.040696
RNA_5	0.000386	0.003038	0	0.018356	0.013371	0.028287	0	0.020019	0.004134	0.077009	0.002883
RNA_6	0.007782	0.003038	0.017963	0.022389	0.014499	0.005257	0.022129	0	0	0.004409	0.011056
	RNC_{12}	**RNC_{13}**	**RNC_{14}**	**RNC_{15}**	**RNC_{16}**	**RNC_{17}**	**RNC_{18}**	**RNC_{19}**	**RNC_{20}**	**RNC_{21}**	**RNC_{22}**
RNA_1	0.067282	0.018765	0.009365	0.010124	0.019122	0.049669	0.041495	0.019721	0.041495	0	0.002384
RNA_2	0.049588	0	0	4.14E-05	0	0.02937	8.08E-05	0	0	0.007643	0.002364
RNA_3	0	0.000164	0.005045	4.14E-05	0	0.011946	8.08E-05	0.000269	0	0.007643	0
RNA_4	0.053809	0.03566	0.028287	0.030096	0.037554	0.002964	0	0	0	0.005225	0.018427
RNA_5	0.002883	0.011971	0.004355	0	0.019167	0	0.011946	0.019801	8.08E-05	5.74E-05	0.002806
RNA_6	0.019679	0.017983	0.009365	0.010124	0.007637	8.08E-05	0.01984	0.011922	0.029909	5.74E-05	0.005016

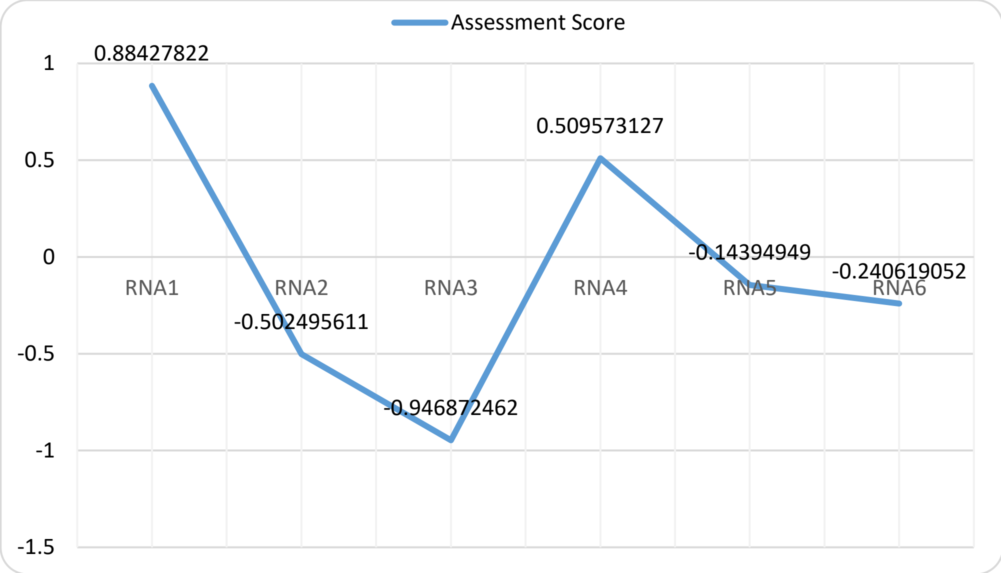

Figure 5. Evaluation score of each renewable energy sources.

6. Conclusions

There is no doubt that the quick advancement of energy is enticing owing to the growth in population and production firms, as well as the rise in air pollution and greenhouse gas emissions, which has resulted in significant advancements in renewable energies and the technologies that are related to them.

The overall objectives of this study are fulfilling two aims. Firstly, MCDM methods (i.e., CODAS) have been strengthened by neutrosophic theory as supporter in uncertainty situations and incomplete data. Secondly, hybrid techniques of CODAS based Interval value neutrosohic have been employed for analyzing RnESs alternatives based on a set of determined criteria from earlier studies. For achieving such objective, we constructed MsIDMM.

DMs are formed and volunteered for rating determined 6 alternatives of RnESs which being in wind energy, solar energy, hydro energy, biomass energy, geothermal energy, and wave energy. While 22 criteria are determined based on conducted survey for prior studies. These criteria have been rated by DMs. Consequently, MsIDMM analyzes DMS' rating of 6 alternatives and 22 criteria in order to produce the optimum solution that overcomes all environmental and local challenges in real-time application. Finally, the optimal and suitable RnES is obtained by constructed MsIDMM to sustain sustainability and its aspects. According to evaluation score for 6 RnESs in Figure 5, solar energy (A1) is the most appropriate and sustainable one with score value 0.88 followed by biomass energy (A4) with score value 0.509. Otherwise, hydro energy is the worst and least sustainable renewable energy resource with a score value -0.946.

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.

Conflict 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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