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Neutrosophic Multi-Criteria Decision-Making Framework for Sustainable Evaluation of Power Production Systems in Renewable Energy Sources

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Abstract: To make the change to a cleaner, more sustainable energy future, it is essential that power production systems be evaluated sustainably. To estimate the overall sustainability performance of various power production systems, this evaluation takes into account a wide range of parameters. Impact on the environment, availability of renewable resources, resource efficiency, social and economic implications, economic feasibility, grid integration and dependability, technical maturity, and scalability are all taken into account. Stakeholders may make better judgments and give higher priority to power production systems that take into account environmental impacts, resource efficiency, social impacts, and economic viability by evaluating these factors. So we used the multi-criteria decision-making (MCDM) approach VIKOR to assess the power production systems in the sustainability criteria. The VIKOR method is used to rank the several alternatives. We integrated the neutrosophic set with the VIKOR method to deal with inconsistent information. We used seven criteria and ten alternatives in this study. The development of a sustainable and resilient energy sector is aided by the sustainable evaluation of power production systems, which in turn helps to reduce the effects of climate change and safeguard the environment.

Keywords: Renewable Sources of Energy, Sustainability, Neutrosophic MCDM Framework, Power Generation Systems.

1. Introduction

In the quest for a cleaner and more sustainable energy future, the evaluation of power production systems from a sustainability standpoint is of critical relevance. Power-generating technologies must be assessed for their effects on the environment, resource efficiency, social ramifications, and economic feasibility in light of the growing worldwide demand for energy and the urgent need to combat climate change. For better decision-making and the prioritization of clean and renewable energy sources, a sustainable evaluation of power production systems is essential [1], [2].

Greenhouse gas emissions, air pollution, and resource depletion are only some of the negative environmental impacts linked to conventional power production systems that rely heavily on fossil fuels like coal, oil, and natural gas. Renewable energy sources, such as solar, wind, hydro, biomass, and geothermal, are the focus of sustainable power-generating systems. Greenhouse gas emissions may be greatly reduced and environmental damage can be kept to a minimum by switching to energy that comes from these renewable sources [3], [4].

Multiple aspects of sustainability must be considered when assessing power production systems for sustainability. Greenhouse gas emissions, air and water pollution, land and habitat effects, and resource depletion are all things to keep in mind while thinking about the environment. Additionally, energy inputs, materials consumed, and waste produced during the power production system's life cycle are all evaluated by resource efficiency and lifecycle studies. In addition to environmental considerations, the social implications of a power-producing technology should be taken into account. Finally, the cost of energy production, together with financial viability and long-term economic advantages, plays a significant part in determining a power-generating system's sustainability [5], [6].

By completing a thorough sustainability evaluation, policymakers, energy producers, and stakeholders may determine which forms of power production are the most environmentally friendly and useful in a given situation. Aligning with global climate goals and sustainable development objectives, this evaluation supports the shift towards a low-carbon, resilient, and sustainable energy sector. It also aids in spotting prospective difficulties, alternatives, and openings for enhancing the eco-friendliness of power plant's output [7], [8].

Typical of a multi-criterion decision-making (MCDM) dilemma, the sustainability assessment of a power production system incorporates many criteria for assessment from various perspectives, such as capital cost from an economic perspective and potential for climate change from an environmental perspective [9], [10]. In this study, we used the VIKOR MCDM method to rank the alternatives. The VIKOR method is used with the single-valued neutrosophic set. The neutrosophic set was proposed to deal with vague and uncertain data. The neutrosophic set has three functions truth, indeterminacy, and falsity function to deal with uncertainty [11], [11].

Evaluation of the environmental, social, and economic implications of various energy technologies is made possible by the framework provided by the sustainable evaluation of power production systems. Power-generating systems may aid in the fight against climate change, the preservation of the natural world, and the adoption of a greener energy future by giving preference to renewable energy sources and cutting down on waste. Accelerating the adoption of clean and renewable energy sources, fostering energy security, and guaranteeing a sustainable and resilient energy system for future generations all depend on the incorporation of sustainability evaluations in decision-making processes

2. Power Production Systems

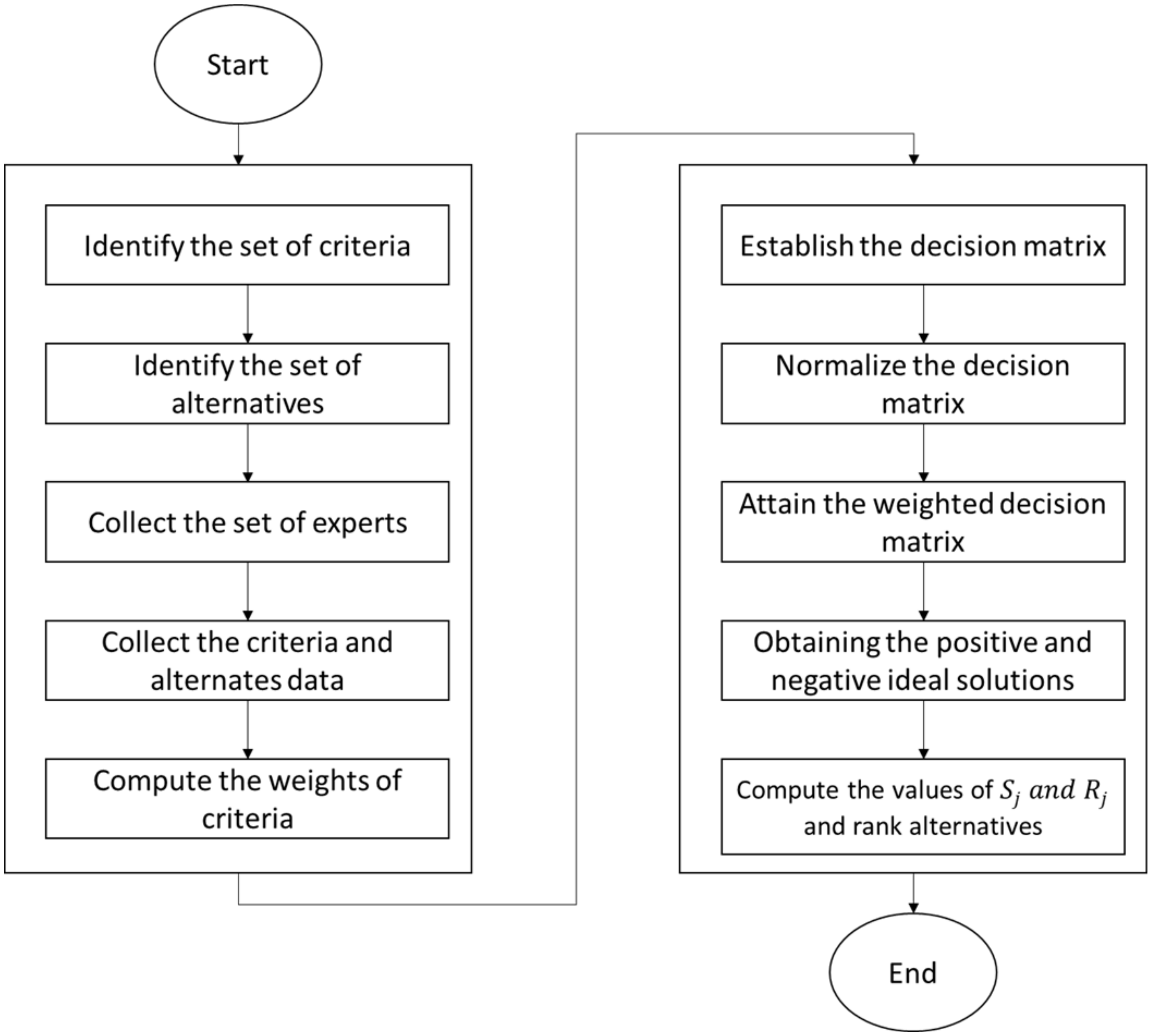

Figure 1. The steps of the single valued neutrosophic VIKOR method.

Electrical power-generating systems consist of the equipment and components necessary to generate electricity. They are crucial in helping the world keep up with the rising power demand. Electricity is produced by power plants, which use a wide range of basic energy sources and conversion technologies to produce electricity [12], [13]. Various power production technologies exist, each with its own set of pros, downsides, and environmental impact factors. Electricity is produced by facilities that burn fossil fuels like coal, oil, or natural gas. They've been in use for a long time but are a cause of pollution and depletion of natural resources and greenhouse gases[14], [15]. Renewable energy power plants use renewable resources, such as sunlight or water, to produce electricity. Some of them are:

- Solar power plants: Solar power plants transform sunlight directly into energy using photovoltaic (PV) cells or concentrated solar power (CSP) systems[16], [17].

- Wind turbines at wind power plants transform the kinetic energy of the wind into electricity.
- Using the momentum of moving or falling water to turn turbines, hydroelectric power plants produce energy.
- Electricity is generated in biomass power plants by burning wood, agricultural waste, or specially grown energy crops.
- Electricity may also be produced by geothermal power stations, which use the Earth's internal heat.
- A nuclear power plant is a facility that generates electricity by splitting atoms, a process known as nuclear fission. Nuclear power facilities, although generating a lot of clean energy with zero emissions of greenhouse gases, are not without their detractors[16], [18].
- Systems that generate both electricity and heat from the same fuel source are called combined heat and power (CHP) systems. Compared to traditional power plants, they make the most efficient use of energy by recycling the waste heat produced during the generation process.
- Systems that produce energy using electrochemical processes and use hydrogen as a fuel are called fuel cells. When hydrogen is created using renewable or clean energy sources, they are very efficient and emit little emissions[19], [20].

Several considerations, such as the accessibility of resources, environmental effects, economic feasibility, grid compatibility, and legislative frameworks, play a role in determining which power production method is chosen. Climate change prevention, pollution abatement, resource preservation, and electricity reliability are only a few of the reasons for this newfound interest in renewable energy sources. There is a wide variety of methods for transforming different forms of energy into electricity, all of which are included in power production systems. The choice of power production technology has substantial effects on environmental sustainability, resource efficiency, and total energy system resilience, from conventional fossil fuel power plants to renewable energy systems. If we want a cleaner, more sustainable, and more resilient energy future, we must move towards sustainable power production technologies [21], [22].

3. Neutrosophic VIKOR Method

The VIKOR technique ranks alternatives based on how close they are to the optimal solution, allowing for the simultaneous determination of both the compromise solution and the extremum solution. By incorporating the single-valued neutrosophic set into VIKOR, this research establishes the VIKOR approach to prioritize the power-producing system while maintaining the objective uncertainties[23], [24]. Following is a detailed explanation of how to apply the single-valued neutrosophic VIKOR approach as shown in Figure 1.

3.1 Establish the decision matrix.

The decision matrix is built between the criteria and alternatives. This matrix is built by the single-value neutrosophic numbers. The experts evaluate every alternative based on every factor.

$$T = \begin{pmatrix} t_{11} & \cdots & t_{1m} \\ \vdots & \ddots & \vdots \\ t_{n1} & \cdots & t_{nm} \end{pmatrix} \tag{1}$$

3.2 Normalize the decision matrix.

After the decision matrix was built with the criteria and alternatives, we normalized the decision matrix to normalize the performance value. We normalized the decision matrix as a positive and negative criterion:

$$L = l_{ij} = \frac{t_{ij}}{\max t_{ij}} \tag{2}$$

$$L = l_{ij} = \frac{t_{ij}}{\min t_{ij}} \tag{3}$$

$$L = \begin{pmatrix} l_{11} & \cdots & l_{1m} \\ \vdots & \ddots & \vdots \\ l_{n1} & \cdots & l_{nm} \end{pmatrix} \tag{4}$$

3.3 Attain the weighted decision matrix.

We compute the weights of criteria, then multiply these weights by the normalized decision matrix as:

$$h_{ij} = w_j * l_{ij} \tag{5}$$

3.4 Obtaining positive and negative ideal solutions.

The positive ideal solution is the best alternative based on all criteria (P_i^+). The negative ideal solution is the worst alternative based on all criteria (P_i^-).

3.5 Compute the values of S_j and R_j

$$S_j = \begin{cases} S_j^+ = \sum_{i=1}^{n} \left(\frac{h_{ij} - P_i^-}{P_i^+ - P_i^-} \right) \\ S_j^- = \sum_{i=1}^{n} \left(\frac{h_{ij} - P_i^+}{P_i^+ - P_i^-} \right) \end{cases} \tag{6}$$

$$R_j = \begin{cases} R_j^+ = \max_i \left(\frac{h_{ij} - P_i^-}{P_i^+ - P_i^-} \right) \\ R_j^- = \max_i \left(\frac{h_{ij} - P_i^+}{P_i^+ - P_i^-} \right) \end{cases} \tag{7}$$

3.6 Rank the alternatives.

4. Results and discussions

This study introduces the sustainable evaluation of power production systems in renewable energy sources with the single-valued neutrosophic set. This study used ten alternatives and seven criteria.

The examination of power production systems from a sustainability perspective entails looking at many factors. Using these indicators, we may compare the relative costs and benefits of other methods of producing electricity. To evaluate power production systems sustainably, it is usual practice to take into account the following criteria:

Greenhouse gas emissions, air and water pollution, land usage, habitat loss, and resource depletion are only some of the environmental impacts that are taken into account when assessing a power production system against this criterion. The impact of this technique on global warming, pollution, drinking water, and conservation of natural resources is evaluated.

Obtainability of Renewable Resources: This criterion looks at the reliability and longevity of the power system's energy supply. It takes into account whether or not the energy source is sustainable, plentiful, and regenerative. Technologies that make use of renewable energy sources including the sun, wind, water, biomass, and geothermal heat are often regarded as more environmentally friendly.

Efficient use of resources is measured by looking at how much energy, materials, and waste a power plant produces during its entire operational lifetime. Recycling and reusing resources, as well as the efficiency with which energy is converted, are all taken into account.

Community involvement, new employment opportunities, effects on public health, and distribution of wealth are only a few of the social aspects that are taken into account when evaluating a power production system against this criterion. It considers things such as how the project will affect the local community, how many jobs will be created, how well people will be protected, and how fair costs and benefits will be shared. The economic feasibility of a power-producing system is determined by an analysis of its financial implications. It takes into account the financial viability, economic advantages, and potential for future cost reductions of energy production. This criterion takes into account factors such as initial investment, operating expenses, maintenance needs, and the availability of financial incentives or subsidies.

The ability of a power production system to connect to the current electrical grid and maintain a steady and dependable power supply is evaluated using this criterion. Compatibility with the grid, capacity factors, intermittency, storage capacities, and grid resilience are all things to think about. This criterion assesses the level of development and scalability of a power production system's technical components. The potential for future improvements and cost reductions, the availability of proven commercial initiatives, and the suitability of the technology for large-scale deployment are all taken into account. Stakeholders may make better judgments and give higher priority to technologies that minimize environmental impact, maximize resource efficiency, consider social ramifications, and show economic feasibility if the sustainable evaluation of power production systems takes these factors into account. Such evaluations help in achieving global climate goals and sustainable development objectives by fostering the growth of a sustainable and resilient energy industry.

4.1 The decision matrix is built by Eq. (1) based on seven criteria and ten alternatives. These criteria and alternatives are collected from related work by experts who have expertise in decision-making and power generation systems. The data was collected from interviews, questionnaires, and previous research.

4.2 We normalize the data in the decision matrix to obtain the normalization decision matrix by Eqs. (2-4) as shown in Table 1.

Table 1. The normalization data between seven criteria and ten alternatives.

	$POWC_1$	$POWC_2$	$POWC_3$	$POWC_4$	$POWC_5$	$POWC_6$	$POWC_7$
$POWA_1$	0.24002	0.54621	0.507683	0.967608	0.54621	0.245067	0.130854
$POWA_2$	0.259372	0.383178	0.546096	0.403862	0.54621	0.566978	0.244509
$POWA_3$	0.975684	0.888889	0.721553	0.439161	0.68432	0.590862	1
$POWA_4$	0.867275	1	0.546408	1	0.969055	0.656282	0.783465
$POWA_5$	0.576494	0.656282	0.657392	0.992525	0.54621	0.469367	0.723684
$POWA_6$	0.640324	0.61163	0.469581	0.999066	0.967809	1	0.675839
$POWA_7$	0.462209	1	1	0.657081	0.68432	0.659398	0.245441
$POWA_8$	0.867275	0.888889	0.266715	0.656146	0.888889	0.888889	0.886863
$POWA_9$	0.374671	0.775286	0.33804	0.715324	1	0.338525	0.26523
$POWA_{10}$	1	0.662513	0.612542	0.656146	0.430945	0.54621	0.382304

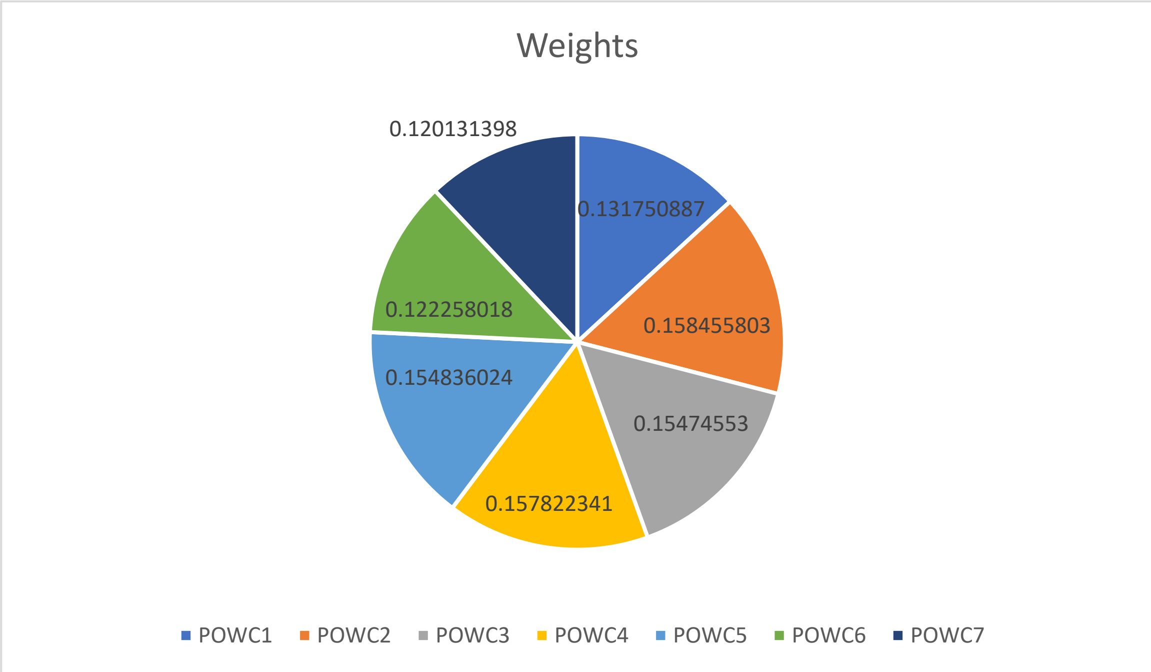

Figure 2. The weights of criteria of power production system.

4.3 We compute the weights of criteria by the average method as shown in Figure 2. Then we obtained the weighted decision matrix by Eq. (5) as shown in Table 2.

Table 2. The weighted decision matrix between seven criteria and ten alternatives.

	$POWC_1$	$POWC_2$	$POWC_3$	$POWC_4$	$POWC_5$	$POWC_6$	$POWC_7$
$POWA_1$	0.031623	0.08655	0.078562	0.15271	0.084573	0.029961	0.01572
$POWA_2$	0.034172	0.060717	0.084506	0.063738	0.084573	0.069318	0.029373
$POWA_3$	0.128547	0.14085	0.111657	0.069309	0.105957	0.072238	0.120131
$POWA_4$	0.114264	0.158456	0.084554	0.157822	0.150045	0.080236	0.094119
$POWA_5$	0.075954	0.103992	0.101728	0.156643	0.084573	0.057384	0.086937
$POWA_6$	0.084363	0.096916	0.072665	0.157675	0.149852	0.122258	0.08119
$POWA_7$	0.060896	0.158456	0.154746	0.103702	0.105957	0.080617	0.029485
$POWA_8$	0.114264	0.14085	0.041273	0.103555	0.137632	0.108674	0.10654
$POWA_9$	0.049363	0.122848	0.05231	0.112894	0.154836	0.041387	0.031862
$POWA_{10}$	0.131751	0.104979	0.094788	0.103555	0.066726	0.066779	0.045927

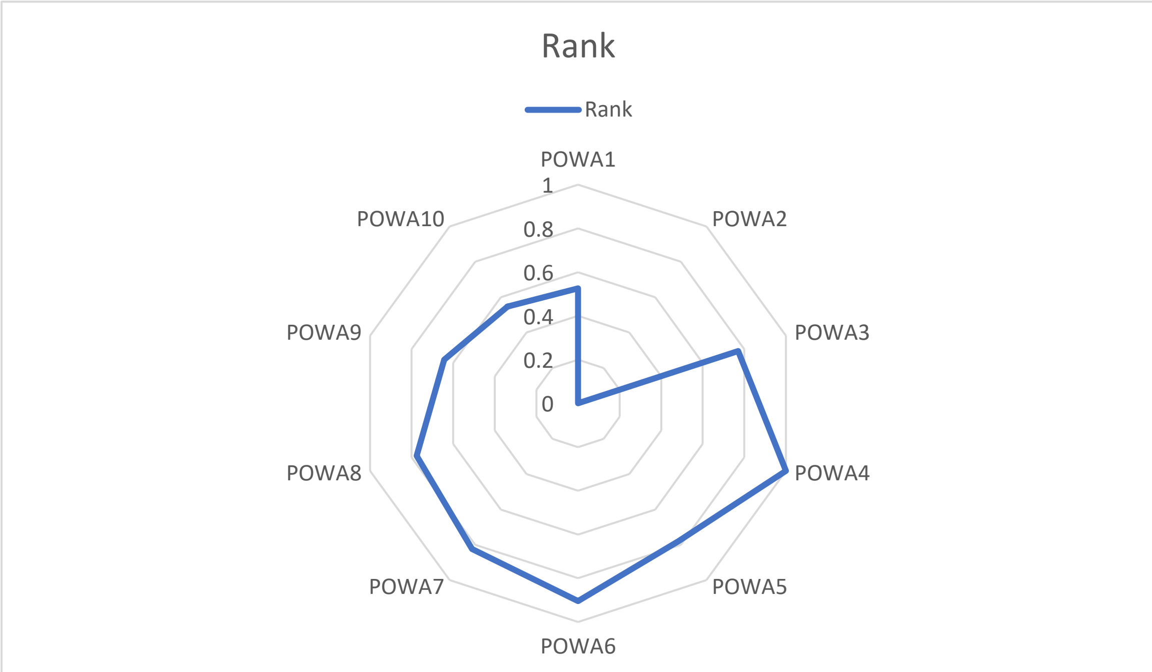

Figure 3. Rank the alternatives of power production systems.

4.4 Then we obtained the positive and negative ideal solution.

4.5 Then we obtain the values of S_j *and* R_j by using Eqs. (6 and 7).

4.6 Then we ordered the power production system as shown in Figure 3. Alternative two is the best and alternative four is the worst.

5. Conclusion

Promoting a shift towards a cleaner and more sustainable energy sector requires a thorough evaluation of existing power production systems from a sustainability perspective. Stakeholders can identify and prioritize power generation technologies that are in line with sustainability goals by evaluating criteria like environmental impact, renewable resource availability, resource efficiency, social impacts, economic viability, grid integration and reliability, and technological maturity and scalability. Greenhouse gas emissions, air and water pollution, land usage, habitat loss, and resource depletion are just some of the environmental variables that are taken into account throughout the assessment process. It stresses the significance of using plentiful, replenishable, and environmentally benign renewable energy sources. Integration with the current electrical grid and the dependability of the power supply are two factors taken into account in this evaluation. By considering grid compatibility, capacity factors, intermittency, and storage capacities, this criterion highlights the relevance of technologies that can be easily connected to the grid and supply dependable electricity. We used the concept of MCDM to deal with various criteria, then we selected a VIKOR MCDM method to rank the alternatives based on seven criteria and ten alternatives. We obtained that alternative two is the best and alternative four is the worst.

Supplementary Materials

Not applicable.

Author Contributions

The authors equally contributed to this work.s

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Ethical approval

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

Conflicts of Interest

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

Informed Consent Statement

Not applicable.

Data Availability Statement

All data supporting the findings of this study are included within the paper. Raw data and additional materials are available upon request.

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