Sustainable Soft Computing Techniques for Site Selection of Optimal Renewable Energy Source to Reduce Carbon Emission in India - A Mini Review

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Abstract: ***Over the past decade, Multi-Criteria Decision Making (MCDM) has become a foundational tool in energy system design. Numerous technical methodologies and algorithms are available for evaluating and designing energy systems, optimizing either single or multiple criteria. MCDM aids decision-makers (DMs) in solving complex problems, such as site and supplier selection, ranking, and assessment. This paper provides a comprehensive review of both historical and contemporary MCDM techniques referenced in the literature. India is a rapidly developing and highly populated country with a high demand for energy to sustain its economic growth. To meet this demand, the Indian government want to achieve a target to increase the share of renewable energy upto 40% of the total installed capacity by year 2030. This target is a clear indication of the potential for hybrid renewable energy in India. We select solar and wind energy sources among various renewable energy sources based on various study that choose the optimal site selection criteria among them. we provide an overview of recent research on the application of MCDM for the selection of renewable hybrid power plants and identify that social factor is one of the main criteria that play a crucial role in site selection. Several MCDM methods have been applied to the selection of renewable hybrid power plants and compare them for optimal result. The use of sustainable MCDM techniques can help in the evaluation of the suitability of the sites based on multiple criteria. It increases the flexibility and sensitivity of the decision-making efforts in such type of approach. This approach allows to comprehensively and effectively assess and tackle the impending issues in the field of renewable energy. These techniques can use in site selection in other industry.***

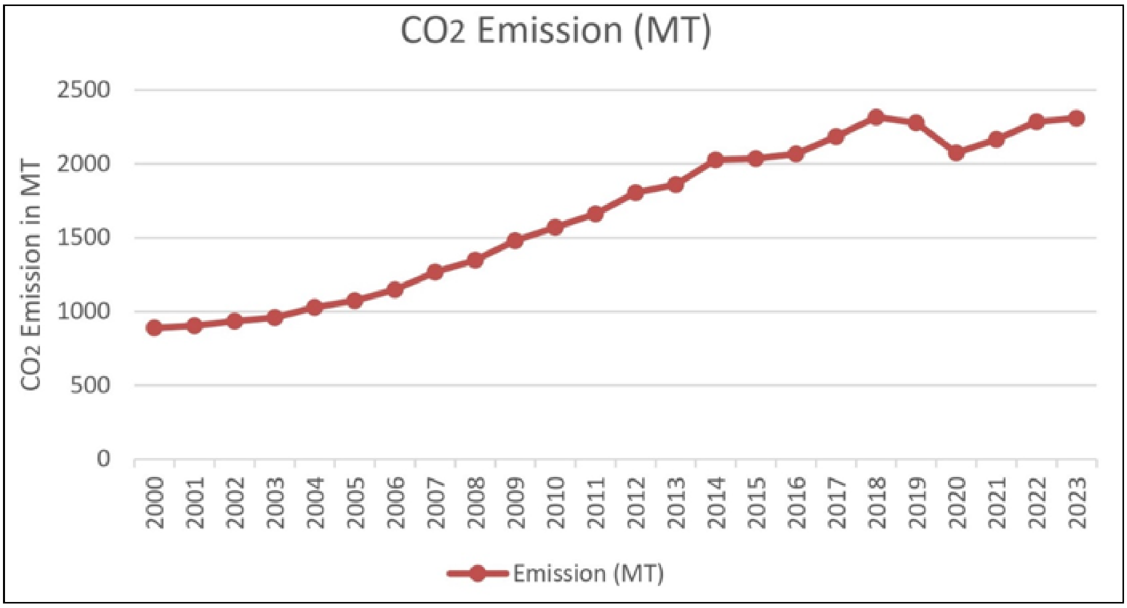
Keywords: Site Selection, MCDM, Renewable Energy

1. Introduction

Due to the ongoing population increase, about 1.2 billion people, or roughly 17% of the global population, lack access to electricity. Of these, approximately 635 million are in Africa and 237 million are in India. Many others have electricity for only a few hours daily or endure frequent power outages.[1] Additionally, 2.7 billion people worldwide still rely on traditional energy sources like solidified dung cakes and firewood to meet their energy requirements[2]. As per United Nation (UN) general assembly unanimously the decade of 2014 to 2024 is declared the, "Decade of Sustainable Energy for All", namely to "ensure access to affordable, reliable, sustainable and modern energy for all". In the context the India current situation is very far from this and condition is not much favorable in this regard.[3] Here we mentioned the various site selection factors for sustainable renewable energy, which are selected by the review of different literature based on the goal of sustainable development of renewable energy or hybrid renewable energy. In countries like India, around 30% of energy demand is met through Renewable Energy Sources (RES), including hydro, small hydro projects (SHP), biomass gasifiers (BG), biomass power (BP), urban and industrial waste (U&I), and wind energy. Despite the availability of these resources, efficient energy use remains crucial.[4] To address this, new governmental policies aim to transform the current energy systems into highly efficient, sustainable renewable energy systems. In India, these policies focus on increasing renewable energy capacity from 32 GW in 2014 to 175 GW by 2022. Achieving such ambitious goals requires meticulous planning to ensure the development of sustainable energy systems. According to the Ministry of New and Renewable Energy (MNRE) annual report, India's renewable energy capacity reached 104.88 GW as of December 31, 2021.

The rising energy demand, high CO2 levels, climate change, scarcity of fossil fuels, environmental pollution from fossil fuel use, and global warming have all underscored the importance of renewable energy sources. The status of CO_2 emission in India is given in figure 1. . At COP27, some countries, led by India, called for a commitment to phase down all fossil fuels.[5] The emergence of new technologies and alternative energy sources, such as hybrid plants that mitigate the variability of renewable sources, offers a way to reduce fossil fuel consumption. Consequently, generating electricity from renewable sources has become a critical issue, with governments around the world exploring a diverse mix of renewable energy options.

In this research, we aim to develop a fuzzy multi-criteria approach to address this problem, incorporating hesitant fuzzy sets.



Hence, for developing countries like India to thrive on the path of development without hampering the environment, the sustainable and Hybrid renewable energy sources can be proved to be beneficial.

2. Literature review on the criteria for location decision-making

An emerging and dependable methodology for addressing energy related site selection challenges is the utilization of Multi Criteria Decision Making (MCDM) techniques. These methodologies have found favor in among the scholars in recent times, resulting in a substantial body of research in this area. However, it's worth noting that while much progress is made, the incorporation of social criteria into the decision-making process remains relatively limited.

Researcher review on renewable energy can be categorize as in table .1 This table provides a structured overview of the various aspects and methodologies involved in renewable energy site selection.

Table 1

Site Selection Process [6],[7],[8], [6]	The process of site selection for renewable energy generation and the choice of installation sites depend upon the careful evaluation of various criteria
Methodology [9],[10],[11],[12]	Multi Criteria Decision Making (MCDM) techniques are an emerging and dependable methodology for addressing energy-related site selection challenges.
Research and Progress [13],[14],[15],[16]	Substantial body of research exists on MCDM techniques; however, the incorporation of social criteria into the decision-making process remains relatively limited
Energy Planning Assessment [17],[18],[19]	Energy planning is undergoing a comprehensive assessment through technical, economic, social, and environmental lenses facilitated by various MCDM models.
Performance Indicators in Developing Nations [20][21][22]	A study introduced a comprehensive set of 39 performance indicators encompassing technical, economic, social, environmental, and institutional aspects for effective renewable energy site design and selection.
Imprecision or Vagueness [23],[24], [25]	Applied fuzzy MADM methods for criteria with imprecision or vagueness.
Methods[25],[26],[27],[28],[7],	Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), and Multi-Objective Decision Making (MODM).
Application [29][30], [30],	Used in energy planning to assess and prioritize various aspects of energy-related projects and initiatives
Limitations [23],[31]	Highlighted limitations in calculating dynamic weights for criteria; proposed a hybrid approach combining fuzzy logic and TOPSIS for improved risk evaluation.

Recognizing the limitations in calculating dynamic weights for the criteria, a hybrid approach based on a combination of fuzzy logic and TOPSIS was employed to enhance the precision and effectiveness of risk evaluation. TOPSIS is a preferred method in the evaluation of optional electricity supply strategies. The STEP (Simple Multi-Attribute Rating Technique) facilitates direct comparisons among alternative solutions, enabling decision makers to gain a clear understanding of the potential impact they can have by adjusting the weights assigned to different criteria during the decision-making process. The informatic data was cured from the web of science using keyword ‘Site Selection ‘and ‘MCDM ’ on 21 May 2024 as shown in figure 2.

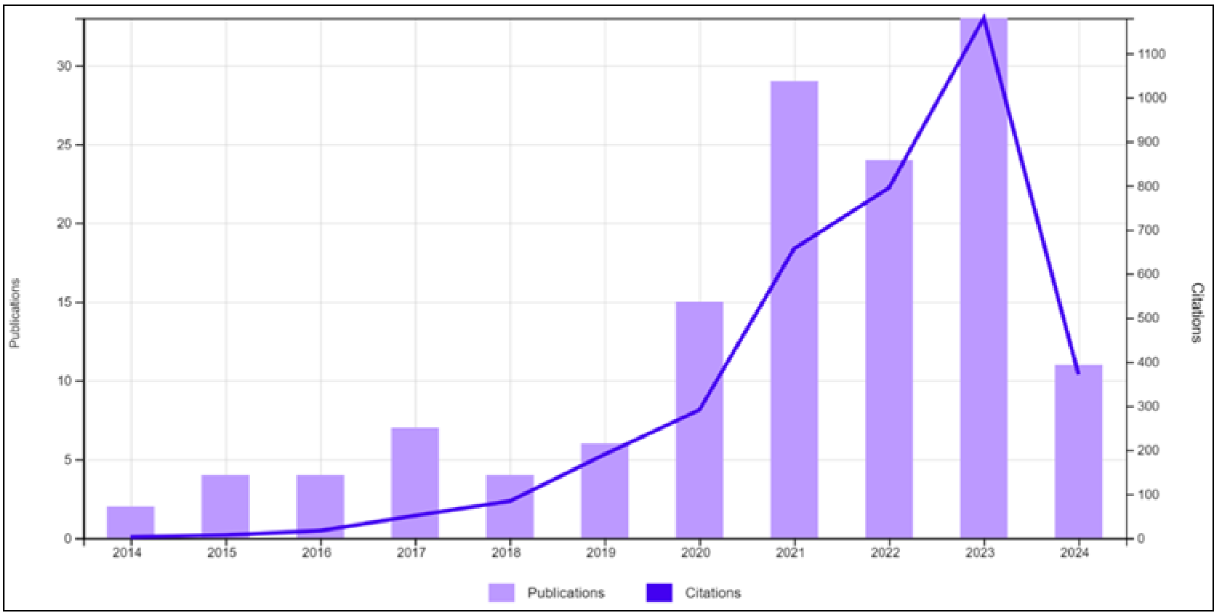


Figure 2: No of citation in last 10 years

The Fuzzy AHP (Analytic Hierarchy Process) is employed in studies addressing global supplier selection issues. One such model is used to determine the weight of parameters for selecting wind power plant locations. Similarly, other research studies have utilized various MCDM (Multi-Criteria Decision Making) methods to prioritize parameters for setting up renewable power plants. These studies aim to identify the key parameters for choosing the optimal Hybrid Power Plant configuration for specific locations.[32]

This study focuses on defining a sustainability index, a valuable tool for decision-makers in their evaluations. We consider Fuzzy AHP and fuzzy DEMATEL (Decision Making Trial and Evaluation Laboratory) methods to weight the criteria, while alternatives are ranked using fuzzy TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) and fuzzy VIKOR (VIšekriterijumsko KOmpromisno Rangiranje) approaches. In AHP, the Saaty Scale is typically used for pairwise comparisons, but it often faces consistency issues in decision-making matrices. To address this, a Fuzzy Scale is applied for pairwise comparisons.Turkey and China lead in publications related to fuzzy MCDM methods in energy-related problems. [33]

Fuzzy AHP has been employed for global supplier selection issues. It has also been used to determine parameter weights for wind power plant location selection. Various other studies have utilized different MCDM methods to prioritize parameters for renewable power plant setup, highlighting the significance of identifying the best configuration for hybrid power plants in specific locations.

Creating a sustainability index is crucial for assisting decision-makers (DMs) with their evaluations, which is the primary focus of this study. To weight these criteria, we use Fuzzy AHP and fuzzy DEMATEL methods, while alternatives are ranked using fuzzy TOPSIS and fuzzy VIKOR approaches. In AHP, the Saaty Scale is commonly used for pairwise comparisons, but it often results in inconsistencies. To address this, a Fuzzy Scale is used to improve consistency in pairwise comparisons.

Turkey and China lead in the number of publications on fuzzy MCDM methods for energy-related issues. In 2011, Denmark set a goal to achieve 100% renewable energy across all sectors by 2050. By 2016, 48 countries committed at COP22 in Marrakesh to reach 100% renewable energy in the power sector at a minimum. Furthermore, over 61 countries have set 100% renewable energy targets for at least the power sector.

3. Research Gap

So many feasible alternative of energy sources is possible, the question is, how to choose the most preferable one. How hybrid alternatives Renewable energy resources affect sustainability index value of two Hybrid alternatives energy technologies How 100% renewable energy systems can power all energy in all regions of the India or world at low cost. Therefore, we can potentially eliminate our reliance on fossil fuels in the future. In a developing country like India, a significant research gap exists between the establishment and utilization of renewable energy systems. To address these gaps, this study aims to develop a sustainability indicator (SI) to evaluate the sustainability of a hybrid renewable energy (HRE) system, incorporating solar and wind energy components.

4. Methodology

The title Initially, the literature will be reviewed to identify potential areas in India for extracting renewable energy, either from a single source or a combination of sources. Decision alternatives for extraction technologies will then be listed, and suitable evaluation criteria will be established. Additional criteria will be derived from expert reviews and opinions. The Fuzzy Delphi Method (FDM) will be employed to identify the essential criteria, while less critical ones will be excluded. Following this, an appropriate method will be applied to analyze the model, and the results will be compared with global experimental observations. The steps of the research are illustrated in the given diagram

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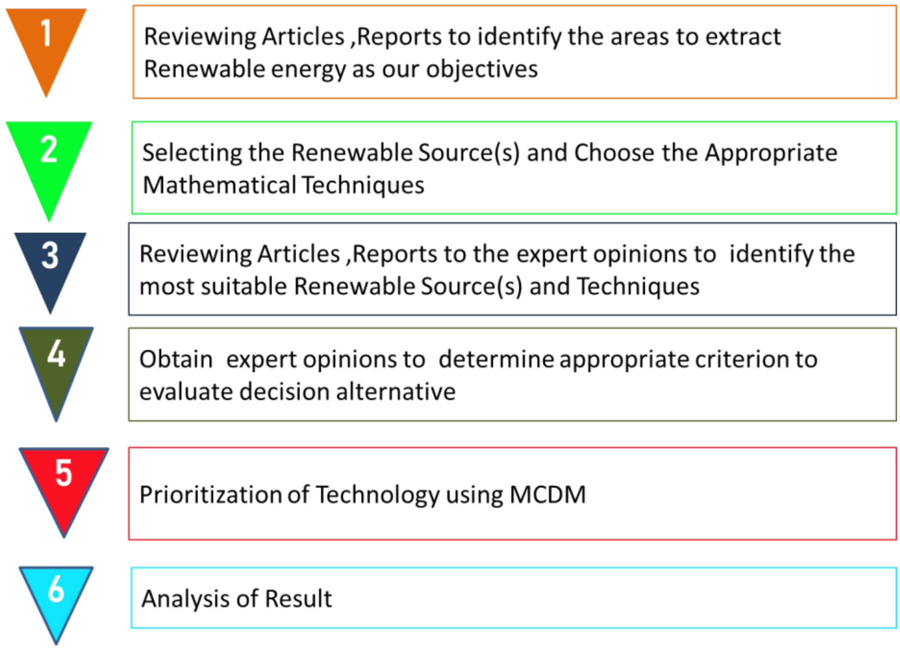

Figure 3: Flow chart for review work

Table 2: Fuzzy Equivalence Number

Preference Weight	Definition	Fuzzy equivalent
1	Equally preferred	(1,1,1)
3	Moderately Preferred	(2,3,4)
5	Strong Preferred	(4,5,6,)
7	Very Strong Preferred	(6,7,8)
9	Extremely Preferred	(8,9,10)
2,4,6,8	Intermediate Preferred	(1,2,3),(3,4,5),(5,6,7),(7,8,9)
Reciprocals	Reciprocal for inverse Comparison	

Various research was undertaken by using mathematical modelling for the sustainability indicator, with the computer-based hybrid energy system simulation and optimum results of the system performance parameters as the inputs database. This section introduces the system description, sustainability assessment, as well as sustainability indicator development strategy[34].

In the real world, many problems cannot be addressed with a simple true or false answer. Therefore, fuzzy logic is employed to provide a "degree of truth." Multi-Criteria Decision Making (MCDM) methods are crucial tools for addressing energy-related decision-making issues as they evaluate alternatives from multiple perspectives, considering several conflicting criteria. The Analytic Hierarchy Process (AHP), introduced by Thomas L. Saaty in 1980[35][36], is one of the most widely used MCDM methods in research. Other common methods for supporting energy policy and planning towards sustainability include Multi-Attribute Utility Theory (MAUT), ELECTRE, PROMETHEE, AHP, and TOPSIS. [37]Since optimal design involves multiple dimensions, decision-makers often need to balance technical and economic parameters. This work explores key aspects of MCDM, various available algorithms, and their applications in energy planning with Renewable Energy Sources (RES). The MCDM techniques discussed can help find effective solutions for energy system design problems with multiple and conflicting objectives.

Hybrid analysis using DEMATEL and TOPSIS may provide more consistent results compared to traditional fuzzy decision-making methods. Additionally, DEMATEL combined with AHP and TOPSIS with VIKOR will be used to test the robustness of the results. Fuzzy VIKOR and fuzzy TOPSIS methods are less frequently used in studies, but they are valuable for identifying optimal renewable energy investments.

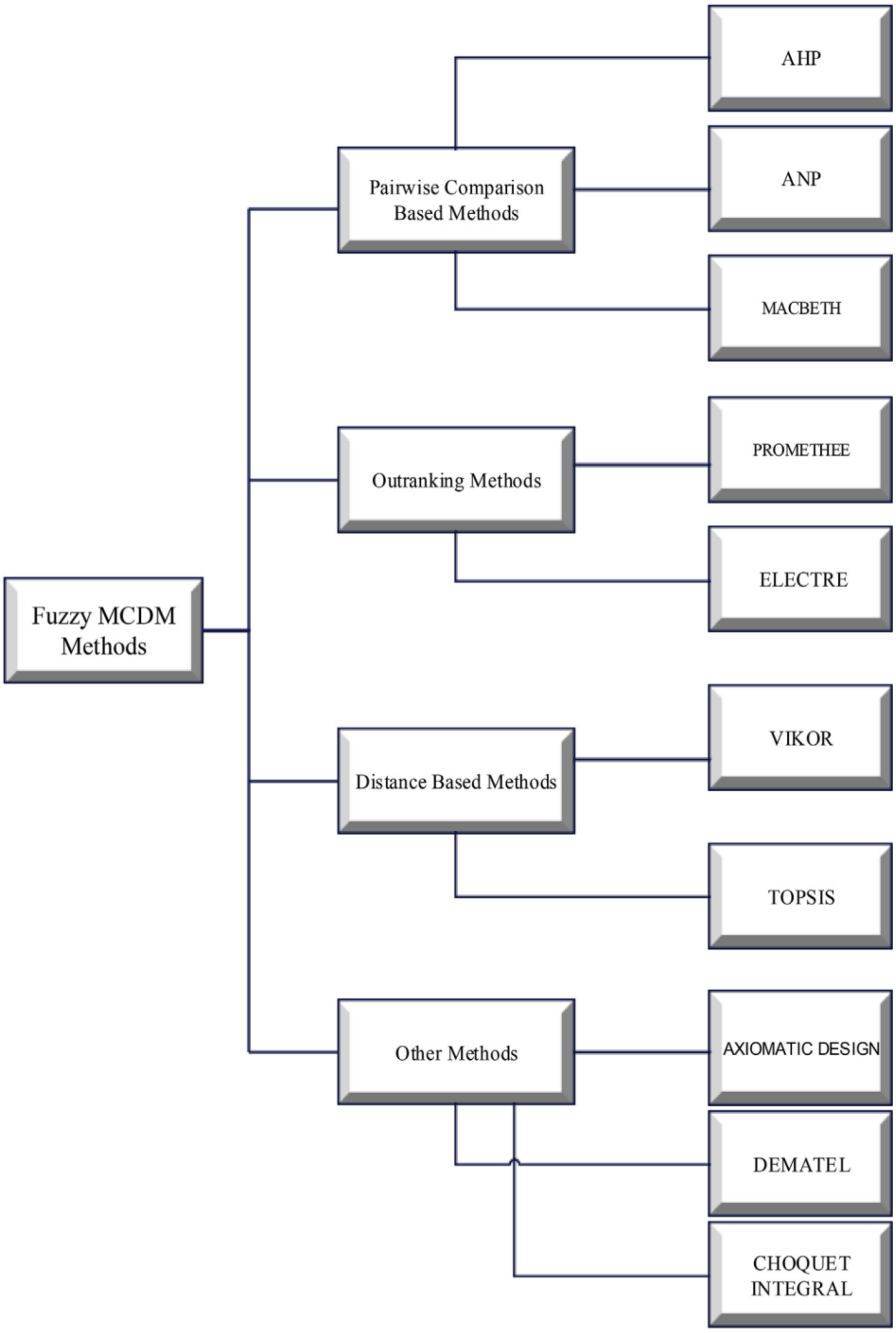

Figure: Classification of fuzzy MCDM methods

5. Future aspect of the work

Since the term "sustainable development" was first introduced by the World Commission on Environment and Development, sustainability has become a prominent topic in discussions about energy, resource use, and environmental policy at both national and international levels. In this context, effective and transparent methods and tools are essential for decision-makers when designing policies for Hybrid Renewable Energy Systems (HRES), particularly in setting priorities for sustainable energy.

Developing a sustainability indicator presents two main challenges. Firstly, sustainability is a broad concept, and different studies have used various indicators to assess it. For instance, Dewulf [38] used energy generation efficiency as a sole criterion for evaluating the sustainability of electricity generation, while emissions, which are closely linked to environmental impact, have often been highlighted as a key sustainability indicator in the literature [39],[40],[41][42][43][44]. Thus, quantifying such complex indicators is challenging. Secondly, integrating all criteria into a unified indicator is difficult due to the varying definitions of sustainability. There is no universally accepted methodology for modeling sustainability, making it challenging to create a standardized assessment criterion. This paper studies the connotation of energy sustainability and builds the hierarchy of sustainability indicator. The indicator with sub-indicators and database is modelled. Through employing the Analytical Hierarchy Processing (AHP) method to analyses the relationship between various indicators and sustainability, the weight of each sub indicator is defined. Based on fuzzy assessment, the measurement model of the indicator is concluded.

6. Recommendations and Summary

This section discusses various challenges faced during the implementation of Multi-Criteria Decision-Making (MCDM) methods and offers several recommendations to address these issues. The goal is to enhance our understanding and assist in selecting the most appropriate methods for our application. A significant problem with pairwise comparison in the Analytic Hierarchy Process (AHP) is that introducing a new criterion necessitates redoing the entire calculation process. AHP relies heavily on expert judgment, which can introduce subjectivity into the process. Decision-makers may also struggle to express their preferences accurately using the specified ratio scale[72]. Meanwhile, ANP utilises fuzzy numbers and is therefore exposed to the subjective bias of DMs [86]. One approach to resolving this issue is to combine the Analytic Network Process (ANP) with an aggregation method like TOPSIS, ELECTRE, or MAUT. For outranking and distance-based methods, ELECTRE I is often favored over TOPSIS because ELECTRE I accounts for both qualitative and quantitative criteria, while TOPSIS does not consider the relative importance of the distance between two reference points[34]. However, ELECTRE has a limitation that necessitates the integration of the fuzzy method to expedite the process. This allows decision-makers to either select or eliminate alternatives that do not meet the desired criteria[24]. The challenge with VIKOR is in how it describes element (criteria/sub-criteria) information in a linguistic context, which can result in misinformation and reduced accuracy. This issue can also be addressed by employing the fuzzy method. From the literature, we provide a summary of the advantages and disadvantages of the MCDM methods discussed in this paper.

Step 1: This study aims to identify the key parameters for selecting the optimal Hybrid Power Plant configuration for a specific location.

Step 2: Initially, criteria are selected based on expert recommendations. The chosen criteria include Data Availability, Data Accessibility, and Requirement of Primary Data.

Step 3: The study considers ten alternatives, which are the main parameters for determining the best Hybrid Hydro Power Plant configuration. These alternatives were selected based on a review of existing literature.

Step 4: Pairwise comparisons of the criteria are conducted using a nine-point Fuzzy Scale. The fuzzy comparison values are then converted to their corresponding crisp values from the scale. The geometric mean of these values is calculated and normalized.

Step 5: Similarly, pairwise comparisons of the alternatives are made using the nine-point Fuzzy Scale. The fuzzy comparison values are converted to their crisp equivalents, and their geometric mean is calculated and normalized.

Step 6: A final decision matrix is constructed using the values obtained from the previous steps, and the weightings are determined.

Step 7: The final weightings are derived from the decision matrix and normalized, making them suitable for further analysis as parameter weightings.

7. Conclusion

The results indicate that 100% renewable energy systems are not only achievable but also economically viable. This finding paves the way for advancing towards net-negative CO2 emissions, which could help stabilize global temperatures and limit the increase to below 1.5°C..MCDM has been utilized across various fields, including energy, transportation, sustainability, and manufacturing, due to its effectiveness in addressing real-world challenges. This approach greatly decreases the time required by decision-makers in complex decision-making processes. MCDM methods can be combined with each other as well as with other techniques, such as fuzzy logic, grey systems, machine learning, and GIS, as discussed in this paper. This paper provides a comprehensive review of well-known MCDM methods, including AHP, ANP, ELECTRE, PROMETHEE, TOPSIS, and VIKOR. Applying these methods is essential for tackling complex problems that straightforward human reasoning alone cannot resolve. However, certain methods may struggle with problems where information is lacking. Consequently, some researchers have combined MCDM with other methods. Another persistent challenge is that applying MCDM often involves significant time and costly calculations. Future reviews should investigate the application of additional MCDM methods, such as MAUT, MAVT, GP, and COPRAS, across various fields. Additionally, future studies could focus on examining modifications of MCDM methods (e.g., modified AHP, TOPSIS, ELECTRE) in relation to uncertain sets (such as fuzzy sets, rough sets, and soft sets).

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Author Profile

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