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Multi-Criteria Decision-Making in Renewable Energy: A Literature Overview

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Abstract:

Making wise selections in this industry is crucial as the significance of renewable energies as long-term, affordable, and ecologically friendly substitutes grows. Robust approaches are essential when considering decision-making in the renewable energy business as a complicated, multi-criteria problem. The flexible framework provided by multi-criteria decision analysis (MCDM) helps decision-makers navigate the interrelated options and criteria at play.

This study investigates the use of multi-attribute and multi-objective decision-making (MODM and MADM) strategies in the context of renewable energy. We provide a thorough overview of current research trends by classifying and analyzing the different topics and approaches used through an extensive evaluation of over ninety articles.

According to our research, the Analytic Hierarchy Process (AHP) is the most widely used MCDM technique, demonstrating its effectiveness in handling the complexity involved in making decisions about renewable energy. This study adds significant understanding of the prevalent trends and preferences in MCDM applications in the renewable energy industry.

Introduction:

Although energy is necessary for human existence, worries about its limited availability and possible effects on the environment are significant. As a result, renewable energy is becoming more and more well-known as a long-term, safe, and affordable substitute. There is hope that traditional energy sources will eventually be replaced by renewable alternatives with competitive long-term pricing in a variety of applications [1, 2]. The process of choosing energy sources is complex and governed by a wide range of regulations and standards. A multi-criteria decision-making (MCDM) challenge arises when selecting renewable energy solutions, forcing decision-makers to manage a plethora of options and considerations. This task is

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made more difficult by the growing complexity resulting from social, technical, environmental, and economic factors. It is believed that conventional single-criteria decision-making methods are inadequate to handle the complexity of these systems [3, 6]. Multi-criteria decision-making techniques (MCDM) have become very adaptable instruments that can manage a wide range of elements evaluated from several angles. These methods provide decision-makers with important assistance when performing in-depth evaluations of problems related to renewable energy [7]. By analysing research trends, this study seeks to assess the literature on MCDM in the context of renewable energy, identifying popular MCDM techniques and their uses [4, 8].

The results of this investigation highlight the value of multi-criteria analysis as a strong technical-scientific tool for decision assistance, especially in the field of renewable energy [5, 9].

II. OVERVIEW OF METHODS FOR MAKING DECISIONS WITH MULTI-CRITERIA (MCDM):

1. Multi-criteria decision making (MCDM) is a well-established field within operations research models and decision-making. These approaches are renowned for their flexibility, resilience in the face of disagreements between criteria and decision-makers, and capacity to take into account both qualitative and quantitative criteria [6]. Although there are a number of further classifications, MCDM techniques can be broadly divided into two groups: Multi-Attribute Decision Making (MADM) and Multi-Objective Decision Making (MODM) [7].
2. Optimising numerous objectives within predetermined restrictions is the main focus of the MODM decision-making issue, which frequently involves trade-offs and competition among objectives [8]. On the other hand, MADM is a common option for handling a variety of issues because it entails assessing a group of alternatives against a set of criteria [9]. Several methods have become well-known in the field of MCDM: AHP (Analytic Hierarchy Process), MAUT (Multi-Attribute Utility Theory), PROMETHEE, and ELECTRE [4]. The literature has detailed extensive comparisons of different MCDM methodologies with regard to planning for renewable energy [6, 10–14].
3. The most widely used MCDM methodology in the energy planning literature, according to a previous analysis by Pohekar et al., was MAUT. It was followed by AHP, PROMETHEE, ELECTRE, fuzzy methods, and Decision Support Systems (DSS) [6]. Finding the option that receives the highest score after accounting for all evaluation factors is the main goal of MADM.
4. The following is a summary of a few well-liked MCDM methods:
5. The AHP, or Analytic Hierarchy Process: AHP, which was first presented by Saaty, places the aim at the top and arranges the criteria and sub-criteria in a hierarchical fashion. Pairwise comparisons are provided by experts and decision-makers, and the best option is chosen based on the highest rank. Additionally, Saaty presented Analytic Network Process (ANP), a more comprehensive version of AHP [15–17].

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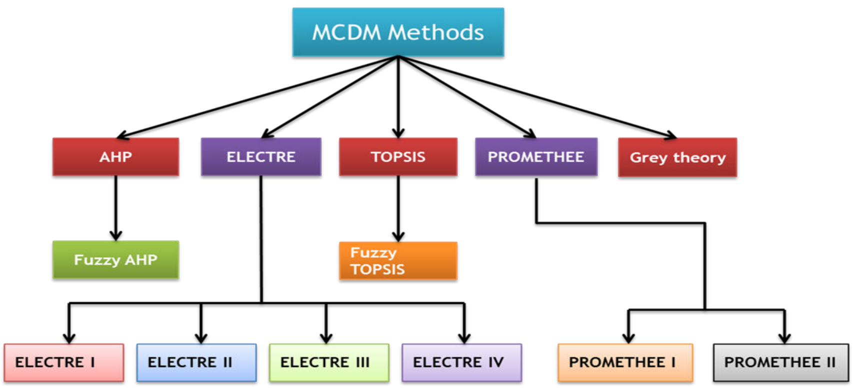
6.PROMETHEE (Preference Ranking Organisation Method for Enrichment Evaluation): PROMETHEE compares alternatives pairwise across a number of criteria and ranks them based on the outranking concept. It is renowned for being straightforward and simple to use [19].
7.8.ELECTRE (Elimination and Choice Translating Reality): This programme efficiently manages both quantitative and qualitative criteria and provides a thorough ordering of possibilities. It makes use of outranking connections and concordance principles to concentrate on the dominance relationship between options. ELECTRE I, II, III, and IV are examples of variations [13].
9. Order Preference by Similarity to Ideal Solution (TOPSIS) Technique: TOPSIS takes into account all relevant factors and attempts to choose the alternative that is most similar to the ideal solution [20].

10. Multi-Attribute Utility Theory (MAUT): MAUT takes into account the preferences of the decision-maker by utilising a utility function that is defined across many features, allowing for non-linear utility for every criterion [9].
11. These methods show how adaptable and useful MCDM is for dealing with difficult decision-making situations, especially in the field of renewable energy.



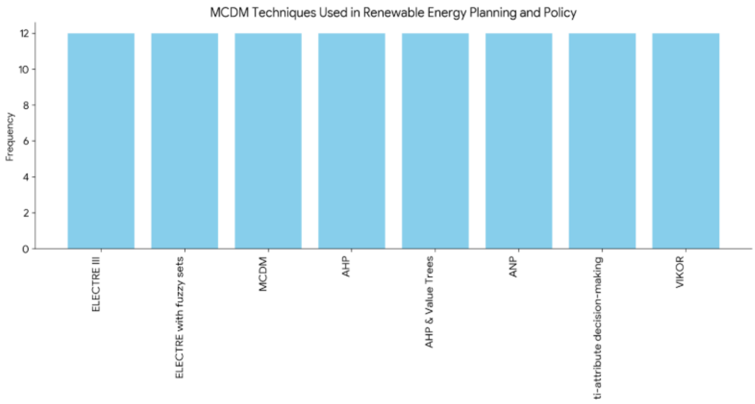
III. MULTI-CRITERIA DECISION ANALYSIS IN RENEWABLE ENERGY:

Adopting alternative energy sources involves a complex decision-making process that takes into account a number of social, technological, economic, an
d environmental considerations [22]. Multi-criteria analysis shows up as a powerful technique in this complicated environment for combining and analysing several points of view while making decisions. Multi-criteria analysis is a powerful technical-scientific technique for decision support in the renewable energy sector. It establishes links among all decision factors to provide transparent and consistent rationale for choices [23]. Given opposing interests and speculative alternatives, it is imperative to recognise that the "optimal" choice generated from multi-criteria decision-making (MCDM) methodologies represents a negotiated solution rather than an unambiguously ideal one.
This study conducts a thorough evaluation of pertinent literature in order to analyse and clarify the application domains and prevalence of commonly used MCDM techniques in renewable energy (RE) analysis. The study uses categorization to

identify research trends in alternative energy decision-making by taking the publication year, application area, and method used into account. After a comprehensive analysis of the literature, the application field of MCDM in renewable energy is divided into four major groups:
Planning and Policy for Renewable Energy: This area includes distributing different renewable energy options and assessing workable energy plans. The use of renewable energy to achieve national goals, decision-making factors, national planning projects, and system indicators are important variables.
Assessment of Renewable Energy: The evaluation of various energy technologies or alternative energy sources falls under this category. Selecting the best energy source for use in thermal, electrical, or other systems might be one of the decision-making processes.
Technology and Project Selection: This area includes the choice of locations, technology, projects, and decision-making assistance for endeavours that utilise renewable energy sources. It includes the processes involved in making decisions on energy-harvesting initiatives.
Environmental Considerations: The literature in this area focuses on alternative technologies from an environmental perspective, covering topics like climate change and associated issues.
Through the classification of these groups, the research illuminates the many uses of MCDM methods in the field of renewable energy and provides insightful information about priorities and decision-making procedures.

A. **Renewable Energy Planning and Policy:**

The choice of alternative energy sources is now guided by factors other than only budget. It is often acknowledged that energy planning involves intricate decision-making involving a multitude of interconnected issues. A thorough examination and analysis of Multi-Criteria Decision Making (MCDM) applications in the renewable energy industry was carried out by Pohekar and Ramachandran [6]. The four main types of criteria that Wang et al. distinguished in their examination of MCDM techniques for energy selection and its applications were technical, economic, environmental, and social[13].



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In order to find compromises, Georgopoulou et al. used ELECTRE III to address regional energy concerns, taking stakeholder comments and outcomes into account [32]. Beccali et al. used ELECTRE and fuzzy set theory in a case study on the

TABLE 1 LITERATURE REVIEW ON MCDM METHODS AND APPLICATIONS TO RENEWABLE ENERGY ISSUES

Application area	AHP/ ANP	ELECTRE	PROMETHEE	Fuzzy sets	others[1]	sum
Renewable energy planning and policy	[24-30][2]	[31, 32]	[33, 34]	[31, 35-37]	[3, 4, 12, 38-42]	23
Renewable energy evaluation	[43-47]	[48, 49]	[19, 50]	[49, 51, 52]	[47, 53-58]	19
Project selection	[1, 18, 59-62]	[23, 63]	[5, 63-65]	[60, 66-68]	[69-73]	24
Environmental	[74, 75]	[76]	[76]		[14, 21, 77-81]	11
sum	20	7	9	11	26	

distribution of renewable energy to investigate the benefits and drawbacks of different approaches [31]. MCDM was used by Diakoulaki et al. to assess energy efficiency-related elements and consider their implications for energy policy formulation [39]. The influence of criterion weights and priority ratings on the choice of alternative energy systems was illustrated by Afgan and Carvalho [3]. For the examination of energy policy, Kowalski combined participatory MAC with scenario modelling [33].

Value trees were created by Keeney et al. to provide standards for assessing alternative energy systems in Germany and apply MCDM to the country's energy strategy [41]. Using AHP, Lee et al. assessed Korea's competitiveness in the development of hydrogen energy technology among 30 nations [28]. Through DEA and AHP, they also gave energy-efficient technology top priority in long-term national energy planning [82].

Facilitating efficient decision-making in line with public preferences is MCDM's main goal. By utilising mixed-criteria decision-making procedures and placing an emphasis on alternate evaluation methods and criteria diversity, Hobbs and Horn developed guidelines for energy planning and policy [12]. In order to foresee such problems, Enzensberger et al. stressed stakeholder involvement in criterion review processes [40].

Using MCDM techniques, renewable energy can be evaluated as a sustainable choice. ANP was used by Köne and T. Büke to determine which alternative power production technology was more successful in Turkey [26]. AHP was used by Zhao et al. to assess several power supply solutions for Guangdong Providence's sustainable development [75]. Using multi-attribute decision-making, Topcu and Ulengin offered a decision support framework for assessing energy resources for the production of electricity in Turkey [34].ANP was used by Önüt et al. to evaluate energy resources for Turkey's industrial sector [29]. Afgan et al. used MCDM to compare renewable energy systems with conventional hydrogen energy systems [38]. Finland's energy policy were evaluated by Hamalainen and Karjalainen [24] using weights derived from AHP and value trees. Kablan used AHP to rank Jordan's energy-saving policy

tools in order of priority.
[25].For the Spanish government, San Cristóbal used the VIKOR approach to assess renewable energy options [4].

B. Renewable Energy Evaluation and Assessment:

To secure a sustainable future, it is essential to assess new energy sources taking into account social, economic, and environmental concerns [83]. Afgan and Carvalho used a sustainability evaluation technique to evaluate hybrid energy systems based on economic, social, and environmental factors [53]. A review of natural gas's possible applications in the energy industry was conducted, taking into account technological, social, environmental, and economic aspects [54]. Burton and Hubacek, on the other hand, looked at the environmental, social, and economic effects of small-scale energy technologies in comparison to larger-scale solutions [55].Chatzimouratidis and Pilavachi assessed different kinds of power plants, comparing new and existing renewable energy technologies according to technological, financial, and sustainability factors, and doing sensitivity assessments for various scenarios [43, 44]. By comparing several options, Roth et al. evaluated the sustainability of Switzerland's current and future power supply systems [58].When choosing alternative energy sources, it is crucial to resolve conflicts between stakeholders and criteria. In order to evaluate renewable energy projects, Haralambopoulos and H. Polatidis created a group decision-making framework based on the PROMETHEE II outranking approach, as shown in a case study on the use of geothermal energy on the Greek island of Chios [50]. In case studies carried out in Greece, Polatidis and Haralambopoulos involved stakeholders in assessing renewable energy options for future investments by applying a participatory, multi-criteria framework [57].Examining various adoption scenarios for renewable energy might help clarify policy disagreements and challenges related to viability. Using ELECTRE-III, Beccali et al. assessed an action plan for choosing and distributing renewable energy technology on the island of Sardinia under several scenarios [48]. To aid in the selection and evaluation of the feasibility of erecting wind energy turbines on the Italian island of Salina, Cavallaro and Ciraolo employed a multi-criteria method [56]. Using MCDA, Daim et al. evaluated the practicality of clean-burning coal and wind power production systems in the Pacific Northwest [84].Multiple MCDM techniques are frequently used by researchers to assess the viability of technologies, comparing results and pinpointing flaws. To find the best renewable energy source for Turkey, Kahraman et al. contrasted fuzzy axiomatic design with fuzzy analytic hierarchy process methodologies [52]. In a community in southern Ontario, Canada, Nigim et al. used the Sequential Interactive Model for Urban Sustainability (SIMUS) and the Analytic Hierarchy Process (AHP) to rank alternative energy [45].In order to examine several possibilities for heat and power supply in a German bioenergy hamlet, Oberschmidt et al. developed PROMETHEE [19]. Pilavachi et al. evaluated nine distinct electricity-producing systems using natural gas or hydrogen as fuel using

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AHP [46]. Using AHP-established relative weights of assessment criteria, Tzeng et al. assessed VIKOR and TOPSIS methodologies to determine which alternative fuel choice was the best compromise for buses operating in Taiwan's metropolitan districts [47].

C.Project Selection and Allocation:

Today's challenge is to use renewable energy sources to guarantee a steady flow of electricity. To fulfil energy demands, new projects must be developed or existing ones must be expanded with the help of efficiently identifying and prioritising resources. The technique of Multi-Criteria Decision Making (MCDM) provides an organised method for sorting through possibilities and choosing the best technology.
Aragonés-Beltrán et al. used two MCDM techniques—a hierarchical AHP model and a network-based ANP model—to assess different photovoltaic solar technologies for investment in a power plant [59].
Begic and Afgan used a multi-criteria sustainability evaluation approach to evaluate energy power system alternatives for Bosnia and Herzegovina's new capacity development [69]. Cavallaro used an MCDA outranking approach to evaluate several PV systems for thin film production [5]. Using an enhanced version of the conventional TOPSIS MCDA approach within the fuzzy-set theory framework, numerous heat transfer fluids in CSP were compared in order to assess the viability of a novel molten salt alternative [67]. In order to choose the optimal location for development in Istanbul and source of renewable energy, Kaya used multi-criteria decision-making analysis [60].
A number of stakeholders must be involved in the complex decision-making process of project selection and allocation in order to engage in environmental opportunity exploration and factor evaluation. AHP was used by Aras et al. [1] to determine the best location for a wind observation station. Cherni et al. used a novel multi-criteria decision support system technique (SUREDSS) to evaluate the best energy option for satisfying local demand and supplying power in a rural Colombian region [70]. By combining the ELECTRE-III and PROMETHEE approaches, Goletsis et al. created a hybrid ranking system for project proposals in Armenia's energy sector [63]. In order to evaluate and prioritise geothermal energy extraction projects, Goumas et al. extended the PROMETHEE methodology to handle fuzzy input data [64, 72].

Ivanova et al. assessed the viability of growing a wind power plant in an electric power system using a hierarchical multi-criteria approach [73]. In order to choose a suitable wind farm project in China, Lee developed a new MCDM model based on AHP related to benefits, opportunities, costs, and risks (BOCR), including expert judgement and stakeholder input [61].

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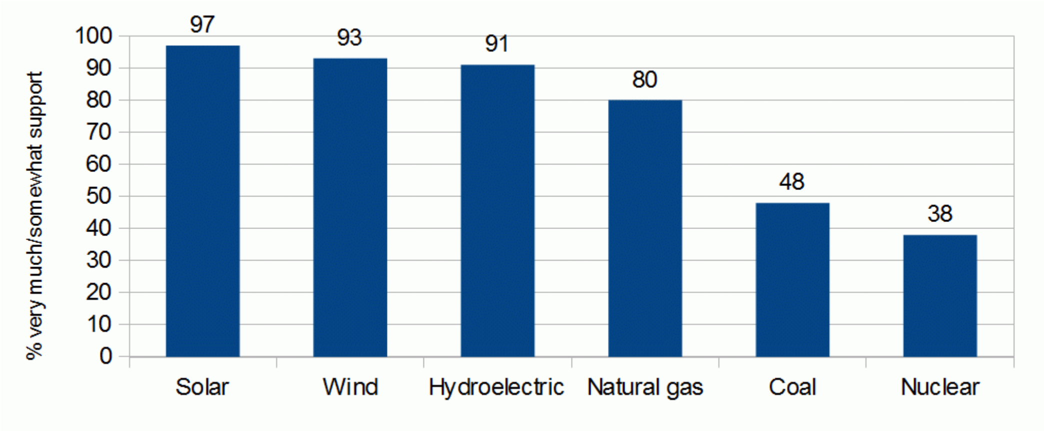
D.Environmental:

A range of multi-criteria methods have been used to evaluate renewable energy sources in terms of the environment [44, 75]. Environmental planning is seeing a rise in the use of multi-criteria decision making (MCDM) as a result of a better knowledge of these problems. Zhou et al. revised Huang's survey on decision analysis in energy and environmental modelling with a thorough survey and literature assessment, emphasising the increasing importance of MCDM techniques in energy-related environmental research since 1995 [14, 71, 77].



Greening and Bernow (2004) recognised the potential of MCDM in the formulation of energy and environmental policies [21]. The use of these methods in environmental planning and management was covered by Lahdelma et al. [78]. An integrated MCDM method was presented by Patlitzianas et al. [81] for assessing the environmental performance of renewable energy producers in the member states of the European Union. Through the use of AHP, Chatzimouratidis and Pilavachi evaluated power plants by contrasting new and traditional renewable power technologies according to sustainability, emissions, and their effect on living standards [43, 44, 74]. In order to analyse the external costs of power plants using various energy sources and describe the environmental impacts on a qualitative level, Mirasgedis and Diakoulaki carried out multi-criteria analyses [80, 79].

CONCLUSION:

Navigating a multidimensional terrain with several indicators and objectives is necessary for evaluating energy systems. Multi-Criteria Decision Analysis (MCDA) approaches provide a trustworthy framework for ranking different renewable energy sources, technologies, and projects in such complicated circumstances. Although there are a number of MCDA strategies available, none can be considered ideal in every case where decisions need to be made. Different approaches can produce different results, even when applied to the same problem with the same data. There is no better or worse method; rather, a technique's efficacy depends on its particular conditions.

Although recent research sheds light on tendencies that are beginning to emerge in the literature, it is unable to definitively predict how these trends will develop. However, it should be noted that of all the MCDA methods, the Analytic Hierarchy Process (AHP) is the most widely applied. The widespread use of AHP can be ascribed to its structure's simplicity and ability to foster compromise until a consensus is reached, rendering it broadly useful in a variety of circumstances.
Still, the central query is unanswered: how can we choose the best MCDA method for alternative energy decision-making? The aforementioned inquiry highlights the continuous want for additional investigation and enhancement of MCDA techniques to guarantee knowledgeable and efficient decision-making in the field of renewable energy.

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