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# A survey of Multi-Criteria Decision Making Technique used in Renewable Energy Planning

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**Abstract**

Fossil based oil, gas and coal reserves will exhaust in few decades and the accelerated demand for conventional energy have forced planners and policy makers to look for alternate sources of Energy. Renewable energies option serves as a solutions for a sustainable, environmentally friendly and long-term cost effective sources of energies to meet our ever increasing needs of energy. Renewable energy sites selection can be viewed as a Multiple Criteria Decision Making (MCDM) problem. MCDM is a complex Decision Making (DM) tools as it involves both quantitative and qualitative criteria. In recent years, several MCDM techniques and approaches have been suggested to solve energy planning problems. The main objective of this paper is to systematically review MCDM techniques and approaches in sustainable and renewable energy planning problems. A review of more than 100 published papers based on MCDM analysis is studied and presented in this paper. Findings of this review paper confirm that MCDM techniques can assist stakeholders and decision makers in unravelling some of the uncertainties inherent in renewable energy decision making. Classification of methodology used, criteria selection and application area are summarized and presented.

***Keywords:*** Multi Criteria Decision Making (MCDM) ; Renewable Energy ; Sustainable energy ; Criteria selection; linguistic variables.

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## 1. Introduction

Fossil-based oil, coal and gas reserves will be exhausted in few decades. There has been tremendous increased in the concentration of greenhouse gases due to burning of fuel which is becoming a major concern of global warming. There has been report of climate abnormality all over the universe. Energy crisis, environmental effect, social and political issues researchers and policy makers are forced to look for an alternate sources of sustainable and renewable energies to meet the ever increasing energy demand and to protect our environment. Renewable energy like hydro power, wind, solar, geothermal and biomass are derived from resources that are regenerative, and do not deplete over time. These sources of energy reduce carbon emissions, clean the air, and offer our generation a chance for a sustainable living. These renewable sources of energy are infinitely available but it become an expensive process to convert it into utilizable form. Feasibility studies for utilization and installation of renewable energy sources are location dependent. Various qualitative as well as quantitative attributes which are usually expressed as linguistic variables, must be considered for appropriate selection and installation of renewable energy power. These makes decision making in this area a complex issue. Decision making method in energy issues includes energy planning and selection [1], energy policy [2] and exploitation [3]. The traditional approaches or single criteria decision making which is normally aimed at maximization of benefits with minimization of costs can no longer deal with the complexity of the current energy problem [4].

Multi Criteria analysis in energy planning has attracted the attention of policy maker as it can provide solution to the increasing complex energy management problems. MCDM has been used extensively as a part of operational research and mathematical tools for supporting the concept of performance evaluation by decision makers [5]. Multi Criteria Analysis (MCA) render useful assistance to policy maker in mapping out the problem as it provide a flexible tool that can handle wide range of attributes appraised by different stakeholders.

This review article intends to study literature related to MCDM in renewable energy sector and provides an overview to analyze trends in major MCDM approaches and techniques proposed over the years and their application in energy planning and management.

## 2. MCDM Method Overview

MCDM methods can be classified into two categories. They are multi objective decision making (MODM) and multi-attribute decision making (MADM) [6]. MODM is a decision making approach in which multiple objective are optimized against a set of available and feasible constraints. In this method of DM, alternatives are not predetermined. In MADM approach different sets of alternatives are evaluated against a set of criteria. We select the best alternatives having the highest score after evaluating it against different criteria. There are several MCDM methods. A brief summary of well-known MCDM are described briefly in the following sections:

***The Elimination and Choice Translating Reality (ELECTRE) Method:***

ELECTRE method was created by Bernard Roy in mid-1960'.This method can handle both qualitative and quantitative nature of data. It can also provide complete ordering of the available alternatives [7]. ELECTRE is further extended to group of family which are called as ELECTRE I, ELECTRE II, ELECTRE III and

ELECTRE IV.

This methodology is based on concordance, discordance indexes and threshold values to analyze the outranking relations among different alternatives [110]. If we have ordered pair alternatives $(A_j, A_k)$, the concordance index $C_{jk}$ will be the sum of all the weights for those criteria where the performance score of $A_j$ is least as high as that of $A_k$, i.e.

$$c_{jk} = \sum_{i:\, a_{ij} \geq a_{ik}} w_i, \quad j,k = 1,..,n, \;\; j \neq k. \tag{1}$$

While, discordance index $d_{jk}$ is: $d_{jk}$=0 if $a_{ij}$>$a_{ik}$, $i$=1, $m$, Otherwise,

$$d_{jk} = \max_{i=1,..,m} \frac{a_{ik} - a_{ij}}{\max\limits_{j=1,..,n} a_{ij} - \min\limits_{j=1,..,n} a_{ij}}, \quad j,k = 1,..,n, \;\; j \neq k \tag{2}$$

Define concordance threshold $c^*$ and discordance threshold $d^*$ such that $0<d^*<c^*<1$.

Then, $A_j$ outranks $A_k$ if the $c_{jk}>c^*$ and $d_{jk}<d^*$.

***Analytic Hierarchy Process (AHP) Method***:

AHP is a MADM method proposed by Thomas L. Saaty [8]. In this methodology, the problem is constructed in a hierarchical manner by breaking down the decision following top to bottom approach. The hierarchy level is such that, the first level is related to the goal(objective), criteria and sub criteria forms the middle levels and the alternative (solution) are at the bottom level. A pairwise comparison is made between input of experts and decision makers. The best alternative is then selected as the one with the highest weight coefficient value.

The matrix of pairwise comparisons for $n$ criteria at a given level can be formulated as follows [111]:

$$D = \begin{bmatrix} C_1/C_1 & C_1/C_2 & .... & C_1/C_n \\ C_2/C_1 & C_2/C_2 & .... & C_2/C_1 \\ : & : & .... & : \\ C_n/C_1 & C_n/C_2 & .... & C_n/C_n \end{bmatrix} \tag{3}$$

The relative importance are scaled as:

i) Equal importance =1

ii) Weak/moderate importance of on over another =3

iii) Essential or strong importance =5

iv) Very strong or demonstrated importance =7

v) Absolute importance =9

vi) Intermediate values between the two adjacent scale values that is used to represent compromise between the priorities listed in (i)-(v) = 2,4,6,8.

The criteria weights can be calculated using arithmetic mean method, characteristic root method, and least square method etc.

***Analytic Network Process (ANP) Method***:

This method is in fact, a general form of AHP which was introduced by Thomas L. Satty [9]. ANP considered the problem as a network having complex relationship between different alternatives and criterion, with all element being well connected. AHP finds it difficult to handle complexity of many problem because of its unidirectional relationship characteristic which could be overcome by ANP.

***Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) Method***:

This method was first introduced by J.P Brans in 1982 [10]. PROMETHEE method uses the outranking principle while ranking the alternatives. It performs a pair wise comparison of the selected alternatives in order to assign ranking with respect to different criteria. This method is further classified as PROMETHEE I, II, III, IV, V and VI [11].

PROMETHEE uses the outranking principle to rank available alternatives [110]. A preference function $\prod(A_j,A_k)$ is usually defined, representing the degree of the preference of alternative $A_j$ over $A_k$ for criterion $C_i$. For multi criteria assessment, the preference index $\pi(A_j,A_k)$ of $A_j$ over $A_k$ can be defined as:

$$\pi(A_j,A_k) = \sum_{i=1}^{m} w_i P_i(A_j,A_k). \tag{4}$$

The index takes values between 0 and 1, and represents the global intensity of preference between the couples of alternatives.

In order to rank the alternatives, the following precedence flows are defined:

*Positive outranking flow*:

$$\phi^+(A_j) = \frac{1}{n-1}\sum_{k=1}^{n}\pi(A_j,A_k). \tag{5}$$

This expresses the degree in which the particular alternative outranks all the other alternatives.

*Negative outranking flow*:

$$\phi^{-}(A_j) = \frac{1}{n-1}\sum_{k=1}^{n}\pi(A_k, A_j). \qquad (6)$$

This expresses the degree in which the particular alternative is outranked by all the other alternatives.

***The Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) Method***:

TOPSIS method which is an alternative to ELECTRE method was developed by Huang and Yoon [12]. The basic idea of TOPSIS method is that the alternative to be selected must be the one which has the best values for all attributes. In geometrical sense it must be the one that have the shortest distance from Negative ideal solution [13,110].

The positive distance between alternative $A_i$ and the ideal solution $A^+$ is defined as follows:

$$S_i^{+} = \sqrt{\sum_{j=1}^{m}(v_{ij} - v_j^{+})^2}, \; j = 1, 2, ..., m \qquad (7)$$

Where $v_j^{+}$ is the j[th] criteria performance of the Positive ideal solution $A^+$.

The negative distance is similarly calculated as follows:

$$S_i^{-} = \sqrt{\sum_{j=1}^{m}(v_{ij} - v_j^{-})^2}, \; j = 1,2,..., m \qquad (8)$$

Where, $v_j^{-}$ is the j[th] criteria performance of the negative ideal solution $A^-$

The relative closeness degree of $A_i$ with respect to $A^+$ is defined as follows:

$$RC_i^{+} = \frac{S_i^{-}}{S_i^{+} + S_i^{-}}, i = 1, 2, ..., m \qquad (9)$$

***Multi-attribute Utility Theory (MAUT) Method***:

In this method, the decision makers preference is taken into consideration in the form of a utility functions, which is defined over a set of attributes [14]. The utility of each criteria or attributes need not be linear. Uncertainty can also be taken into account while using MAUT, which is an advantage in MCDM process.

Finally, the best alternative is one that has the maximum closeness degree and has the shortest distance to the ideal solution.

***Artificial Neural Network (ANN) and Fuzzy theory***:

ANN, a mathematical models which corresponds closely to the organization and functioning of biological neurons has been widely used for solving decision modelling and forecasting problems [15]. Studies has suggests several advantages that ANN have over the conventional statistical methods and can be strongly deal with nonlinear functions.

The idea of fuzzy logic was first advanced by Dr. Lotfi Zadeh of the University of California at Berkeley in the 1960s. Most of the real-life problems are uncertain, vague and imprecise as such fuzzy system remains in a forefront in handling problems with uncertainty [16, 17]. Therefore, Fuzzy set are especially used for decision making where the decision and risk management form two side of the same coin.

## 3. Mcdm in renewable energy

Renewable energy feasibility assessment, evaluation, energy planning and policy implementation has gain importance in order to have sustained energy future. According to the literature in [18-20], renewable energy sources availability is growing rapidly and expected to continue in developed and developing countries. The aim of Renewable energy development and planning is to create an environment friendly technologies that includes renewable energy generation [21-25], energy storage [26-31] and certain transmission components [32-34]. In recent years, due to ever increasing energy demand, use of renewable energy technology (RET) are increasing rapidly. Some of the increasing RET includes small scale hydro power plant [35-37], solar cell [38, 39] and wind energy [40-42].

Selection of energy alternative is a multidimensional decision process involving a number of different parameters such as economic, technical, social, and environmental [43]. Therefore, MCDM approach serves as a suitable tool to merge and analyze all perspectives by establishing a relationship between various alternatives, factors and stakeholders.

In this current literature review the application of MCDM in RE is divided into three categories is presented:

i) MCDM in Renewable energy planning and policy
ii) MCDM in Renewable energy project selection
iii) MCDM in Renewable energy with Environmental perspective

Many researchers have investigated the role of RET in different perspectives of energy issues using MCDM approach. Some of the relevant work are:

***MCDM in Renewable energy planning and policy***

Renewable energy planning and policy refers to the assessment of a feasible energy plan or the diffusion of different renewable energy options. RE planning and policy implementation has become a highly complex decision with many stakeholders and factors involved. Pohekar and Ramachandran [44] presented an extensive analysis of several published research papers on MCDM and highlighted their applications in the RE area; Shen, and his colleagues. [45] applied FAHP to evaluate RE resources, with concerns of energy policy and technology; Kowalski and his colleagues. [46] uses combination of Multi Criteria Assessment (MCA) and scenario planning for analyzing energy policy, where public and diversity of stakeholders' inputs are included in the decision making process. Social, economic, environmental and technical criteria were also considered in the analysis. Enzensberger and his colleagues [60], in their work presented the importance of all stakeholders' participation in the criteria evaluation process. They also explained that policy planners can anticipate possible problems at an early stage by considering different viewpoints in the decision process. Kablan [48], in his work presented AHP based framework for prioritization process of energy conservation policy instruments in Jordan. San Cristóbal[49], presented a methodology using VIKOR to evaluate different RE alternatives for selecting the best project for the Spanish government to achieve its target of 12% total RE in 2010. Luthra and his colleagues. [50], in their work presented AHP technique to identify the barriers for adoption of renewable and sustainable technologies in India; Stein [51] in his work proposed an approach based on AHP for ranking various renewable and non-renewable technologies related to electricity production; Köne and T. Büke [52], presented a Multi Criteria Analysis using ANP, to select the best alternative technology for generation of electricity in Turkey considering sustainability perspective. Doukas and his colleagues. Reference [53] proposed a flexible and direct MCDM approach using linguistic variables to assist policy makers in ranking of sustainable technological energy. Oberschmidt and his colleagues. Reference [54] in their work elaborate the use of PROMETHEE technique combined with AHP for evaluation of performance in energy supply technologies and electricity generation of solar PV, wind farm energy, biomass and solar thermal in Pakistan.

In a real time decision-making situations, it is relatively difficult to obtain precise qualitative information in the form of numeric values for many of the important subjective criteria [55, 56] and it became necessary for such criteria and their weights to be usually expressed in linguistic terms by the decision maker [57]. Thus, fuzzy logic, which can deal with vague information is used by many researchers. In the literatures, different studies have used fuzzy analysis in energy planning and energy policy [61, 65-67, 70, 73, 76-79]. Beccali and his colleagues [61] applied ELECTRE method and a fuzzy set theory in developing a RE diffusion strategic plan. The advantages and drawbacks of both ELECTRRE methodology and fuzzy set theory were presented.

***MCDM in Renewable energy project site selection***

Sites for installation of renewable energy refers to technology selection and decision support in renewable energy harnessing projects. Aras and his colleagues [58] applied AHP for selecting the most suitable for building a wind observatory station in a university campus. Goumas and his colleagues [63, 68], in their work presented an extended PROMETHEE method of ranking alternative projects, to deal with fuzzy input. Their work is applied for evaluation and ranking geothermal exploitation projects. Lee [59], proposed a new MCDM model based on AHP considering stakeholders input and expert opinion like benefits, cost, risk and opportunities for selecting suitable wind farm project in China. Reference [47] used MCDM based on integrated fuzzy VIKOR & AHP methodology to select most appropriate RE and most suitable area to establish it in Istanbul. Chang [62], employed multi goal programming approach for selecting the best location for facilities of RE. The criteria considered includes: investment cost, Power generated, emissions, jobs opportunity, operation cost, maintenance costs, and social acceptance.

Yeh and Huang [64], applied Fuzzy DEMATEL and ANP for selection of wind farm location at Greece. He considered important criteria related to Safety and quality, economy and benefit, social impression, environment and ecology, regulation and policy. Kalyani Sambhoo and his colleagues [80], presented various soft computing technique applying Back propagation Artificial Neural Network (BP-ANN), Learning Vector Quantization (LVQ-ANN), Ant Colony optimization(ACO)-Fuzzy Soft Sets (FSS) and Fuzzy Indexing (FI), in ranking the sites of power plant locations in India.

***MCDM in Renewable energy with Environmental perspective***

Environmental perspective in RE deals with the literature discussing various alternative technologies or location based on environmental perspective and climate issues. In literature, different MCDM approach have been applied to assess renewable energies from an environmental perspective [72, 74-75, 80]. Zhou and his colleagues [69, 71] Showed that the importance of MCDM in energy-environmental related studies have almost tripled since 1995. Lahdelma and his colleagues [85], discussed how Multi Criteria Decision aid (MCDA) could be applied in energy planning process which involves conflicting preferences. Patlitzianas and his colleagues presented an integrated multi-criteria decision-making approach for assessing the environment of renewable energy producers in 14 different member states of the European Union accession [81]. C. Kahraman and I. Kaya [57], proposed fuzzy AHP to select the best energy policy alternatives for Turkey. Environmental attributes like pollutant emissions, land requirements, need of waste disposal were considered in their studies. Cavallaro and his colleagues [66], used NAIADE software for Multi-Criteria Analysis (MCA) in an attempt to find Feasibility assessment for installation of wind turbines in a site on the island of Salina, Italy. The important environmental attribute used includes: CO2 emissions, visual impact, acoustic noise, impact on eco-system, social acceptability. Kaya and his colleagues [77], uses integrated fuzzy VIKOR-AHP methodology in determining best renewable energy alternative and site location selection by considering $NO_x$ emissions, $CO_2$ emissions, land use, social acceptability and job creation etc. Charabi and his colleagues [82], uses Fuzzy Logic Ordered Weighted Averaging (FLOWA) for assessment of land suitability for large PV farms. Implementation. Environmental factor like land accessibility, land use, sensitive areas are considered in their studies. Importance of historical locations, wildlife, urban area and natural reserves were included in the work taken up by Al-Yahyai and his colleagues [83], to derive wind farm land suitability index and classification using AHP with Ordered Weigh Averaging. Environmental quality, impacts on flora and fauna, $CO_2$, $SO_2$, $NO_x$ emissions, land used and social acceptability were treated with importance in the work on promoting use of RET taken up by Mourmouris and his colleagues [84]. Sambhoo and his colleagues [80], stressed on the environmental impact in the process of setting up of different powe plant in India using different soft computing techniques. Chatzimouratidis and Pilavachi, in their works evaluated different power plants generating technologies in terms of sustainability, level, kind of emissions and impact on the living standard using AHP [72, 86,87, 88]. Table 1, gives the summarized different MCDM technique applied in various category.

**Table 1:** Literature review on MCDM methods and applications

| Sl | Categories | MCDM Methodology | References | Total |
|---|---|---|---|---|
| 1 | RE planning & policy | AHP & FAHP | 45,48,50,51,52,53,54,57 | 8 |
| | | Fuzzy theory | 45,55,57,61,65,66,67,70,73,76,77,78,79 | 13 |
| | | Others | 46, 49, 52,53,54, 61 | 5 |
| 2 | RE site selection | AHP & FAHP | 47,58,59 | 3 |
| | | Fuzzy theory | 47,64,80,107 | 4 |
| | | Others | 47,62,63,68,103,107 | 6 |
| 3 | RE from environmental perspective | AHP & FAHP | 57,72,74,77,83,86-88 | 7 |
| | | Fuzzy theory | 77,82,80,107 | 4 |
| | | Others | 66,80,77,103 | 4 |

## 4. Attribute selection

Attribute selection is important in any decision making process. In this section, we reviewed some of the important criteria that are very much important from renewable energy sustainability perspective. The important attributes that can reliably measure sustainability issue includes Technology use, economical parameters, environmental and social parameters.

***Technical Attributes***

***Reliability**:* Energy system reliability is the ability of the system to perform required function without catastrophic consequences for a specific period of time. Energy system reliability is one among the top essential attributes for evaluation [89, 72, 88, 90].

***Efficiency***: Efficiency is the measure of useful energy that we can extract from a source. Efficiency is the most important technical attributes to be considered for evaluating the quality of system [13, 53, 72, 91-93]

***Safety***: Safety measure plays a very vital role in energy system. Safety to workers, society and people's life and environment must be assured while planning and developing an energy system. Safety in energy system can be evaluated based on their effect to persons, society or environment [94-96, 43]

**Economical Attributes**

***Investment Cost**:* Investment cost includes cost incurred on equipment and technological installment, road connectivity, engineering services and construction cost. A wise investor must compare investment cost and benefits. It is the most important economical attributes while planning energy system [13, 43, 53, 66, and 97]

***Operation and maintenance cost (O&M)***: O&M costs includes employees' wages, products and operation service charges. According to the literature [72, 93,98-100], it is also among important economical attributes to be considered.

**Environmental Attributes**

***$SO_2$ emission**:* $SO_2$ is a harmful gaseous which if in excess affects human health when we breathe in. It is the results of emission from industrial plant like power plants. It is related with increased in respiratory symptoms and disease such as coughing, wheezing, shortness of breath etc. It also results in acid rain . As such SO2 emission must be checked and in many work, it has been selected to evaluate its contribution to environment [103, 43, 88,101,102, 90].

***NOx emission***: $NO_x$ is a gas that contributes to air pollution and global climate change. It is emitted especially during combustion of fossil fuel and biomass It can readily react with other compounds to form toxic products. $NO_2$ , if inhaled in excess it may leads to respiratory problems and reduce immunity to lung infections. In power plant planning, $NO_x$ emission is usually selected to evaluate its impact on energy system [103, 102, 92, 93, 13, 43, 87, 88].

***Particles matter***: Particulate Matter is an air-borne particle mainly released from coal, oil, biomass and PV power plant. They are harmful and may cause various diseases including wheezing to asthma, migraine, cancer and heart attacks. It is also one of the main environmental problem of power plant industries. As such, in power plant or energy system planning, particulate matter emission is considered for evaluation [103, 87, 88, 104, 90]

***Land use***: The land required for setting up of a power plant is a matter of concern as it affect our environment [103, 13, 88, 90, 105, and 92,106]. Large forest area will be destroyed especially while setting up mega hydro power plant. This will have negative impact on environment, destabilized ecological balance, loss of cultural heritage. Thus land use is necessarily considered in decision making process [103, 107].

**Social Attributes**

***Social acceptability:*** It is opinion made by important stakeholder i.e local population regarding the hypothesized realization of the energy planning projects. It is extremely important to consider this attributes, as the opinion raised by the local and pressure group influences the amount of time for successful completion of the project. It is a quantitative attributes which are often interpreted in linguistic form. Social acceptance is taken into account for power plant planning and evaluation [103, 107, 88, 90, 108, 104].

***Job opportunity:*** While setting up power plant, one should aim at developing the locality. The energy system that could create more job opportunity for people is preferred as they improve the living standard of the local people. In many literatures, their contribution is being evaluated as attributes in decision making of energy system planning [53, 88, 90, 96, and 92,109]. Table 2, summarized the important attributes and sub attributes considered for evaluation in various literatures.

**Table 2:** The typical evaluation criteria of energy supply systems.

| Sl | Criteria | Sub-criteria | References | Total |
|---|---|---|---|---|
| 1 | Technical | Reliability | 72,88,89,90 | 4 |
| | | Efficiency | 13,53,72,91,92,93 | 6 |
| | | safety | 43,94,95,96 | 4 |
| 2 | Environmental | $NO_X$ | 13,43,87,88,92,93,102,103 | 8 |
| | | $SO_X$ | 43,88,90,101,102,103 | 6 |
| | | Particulate Matter | 87,88,90,103,104 | 5 |
| | | Land use | 103, 107 | 2 |
| 3 | Economical | Investment cost | 13,43,53,66,97 | 5 |
| | | Operational & Maintenance Cost | 72,93,98,99,100 | 5 |
| 4 | Social | Social Acceptance | 88,90,103,104,107 | 5 |
| | | Job opportunity | 53,88,90,92,96,109 | 6 |

## 5. Conclusion

MCDM approach of selecting best Renewable Energy alternatives is gaining momentum as the problems are multi-dimensional in nature. In real world scenario, Renewable energy planning problems are vague and full of uncertainty. Thus fuzzy MCDM approach has been increasingly use to take care of imprecise and vague data. Sustainable energy decision making must consider multi attributes. It is observed that the most common criteria that are used in decision making includes, Technical aspect, Economic aspect, environmental aspects. And Renewable Energy planning from environmental and ecological perspective is becoming more popular recently.

Large technique of MCDM tools are available but there is no better or worst technique, but they are applied to suit different situation and stakeholders needs. Our current literature survey analyzed different MCDM technique and important attributes. This survey does not give details about MCDM technique in different sources of energy like wind power, hydro power, nuclear power, thermal power and PV solar plant etc. This scope of study may be discussed as future extension work

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