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A review of multi criteria decision making (MCDM) towards sustainable renewable energy development

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ABSTRACT

In the current era of sustainable development, energy planning has become complex due to the involvement of multiple benchmarks like technical, social, economic and environmental. This in turn puts major constraints for decision makers to optimize energy alternatives independently and discretely especially in case of rural communities. In addition, topographical limitations concerning renewable energy systems which are mostly distributed in nature, the energy planning becomes more complicated. In such cases, decision analysis plays a vital role for designing such systems by considering various criteria and objectives even at disintegrated levels of electrification. Multiple criteria decision making (MCDM) is a branch of operational research dealing with finding optimal results in complex scenarios including various indicators, conflicting objectives and criteria. This tool is becoming popular in the field of energy planning due to the flexibility it provides to the decision makers to take decisions while considering all the criteria and objectives simultaneously. This article develops an insight into various MCDM techniques, progress made by considering renewable energy applications over MCDM methods and future prospects in this area. An extensive review in the sphere of sustainable energy has been performed by utilizing MCDM technique.

1. Introduction

Approximately 1.2 Billion people i.e. around 17% of the earth population do not have access to electricity, out of which around 635 million are located in Africa and 237 million are in India [1]. Still 2.7 billion global population is dependent on the traditional energy sources such as solidified dung cakes, firewood etc. to fulfil their energy needs [2]. Most importantly 95% of this population is from the rural areas who are deprived of modern energy resources [1,2]. This dependency on the traditional sources are not just causing adverse effects on human health but also on environment due to global deforestation and greenhouse emissions [2]. Highlighting the gravity of energy snag for sustainable development, United Nation (UN) general assembly unanimously declared the decade 2014–2024 as the "*Decade of Sustainable Energy for All*", namely to "*ensure access to affordable, reliable, sustainable and modern energy for all*" [3]. For any developing nations, in order to achieve their development goals and to support its expanding economy, surplus energy is the main key. Nevertheless, the sustainable development provides highly reliable and affordable energy which is also vulnerable by industries causing all types of environmental issues [4]. In order to address the environmental issues coming in the path of sustainable development, the green energy resources can play a very crucial role. Hence, for developing countries to thrive on the path of development without hampering the environment, the sustainable and renewable energy sources can be proved to be beneficial. In countries like India, around 30% energy demand is dependent on Renewable Energy Sources (RES) which include Hydro, Small Hydro Project (SHP), Biomass Gasifier (BG), Biomass Power (BP), Urban and Industrial waste (U & $2 I) and Wind Energy [5]. Even with availability of renewable energy resources, the efficient use of energy is highly necessary. New governmental policies in many countries have been introduced mainly to transform the current energy systems to highly efficient green sustainable energy systems. In many developing nations such as India, the main aim of these policies is to maximize the renewable energy usages by enhancing the infrastructure capacity by more than 5 times from 32 GW in 2014 to 175 GW in 2022 [6]. It is very challenging to achieve such a system without proper planning which meets the aim of sustainable energy. Over the past

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decades, the energy planning methodology has been absolutely transformed from a single objective simple system to a more complex system due to the inclusion of multiple benchmarks, stakeholders and disagreeing aims [4]. Traditional single objective decision making which is basically concerned with either maximization or minimization of a particular element remains beneficial only in a study of small system. Current energy planning scenario has multiple objectives, definitions and criteria making it more difficult to attain a system with a perception of sustainability. Thus, an adequate planning system considering necessary political, social, economic and environmental aspects is essential to overcome rising demand of energy with a vision of sustainable development. In order to solve such complex problems concerning energy planning, multi criteria decision making (MCDM) is proved to be one of the better tool for efficient energy planning. MCDA basically originated from operations research involving a wide range of methodologies, nevertheless with an amusing rational foundation in other disciplines [7]. MCDA techniques have found wide application in public-sector as well as in private-sector decisions on agriculture resource management, immigration, education, transport, investment, environment, defence, health care etc. [8–12]. In the recent decade, MCDM has found its grounding application in energy system design. Various technical methodologies and algorithm exists to evaluate and design energy systems based on optimization of either single or multiple criteria [13–20]. The complexity involved in the various dimensions of energy systems with multiple stakeholders has been illustrated in Fig. 1.

With the increase in the complexity and multiplicity in the problem of energy planning, the single objective optimization/analysis is no longer a prevalent approach. MCDM is considered as an evaluation structure to solve environmental, socio-economic, technical, and institutional barriers involved in energy planning [22]. MCDM has become popular in energy planning as it enables the decision maker to give attention to all the criteria available and make appropriate decision as per the priority. Since a perfect design is governed by multiple dimensions, thus a good decision maker, in certain situations, may look for the parameters like technical or economical that can be compromised. MCDM helps a decision maker which quantifies particular criteria based on its importance in presence of other objectives. This work introduces some important features of the MCDM, various algorithms available and highlights its various features in context to the energy planning based on Renewable Energy Sources (RES). The MCDM techniques presented here can be used to find out an apt solution to the energy system design problems involving multiple and conflicting objectives. The paper is organized as follows: Section 2 highlights the insights in to MCDM and briefly discusses various techniques available. Section 3 illustrates the application of MCDM models in energy planning. Section 4 introduces the key performance indicators and energy schemes; Section 5 presents the discussion followed by conclusion in Section 6.

2. Multi Criteria Decision Analysis (MCDA)

As already outlined in the introduction section decision analysis is a valuable tool in solving issue as characterized with multiple actors, criteria's, and objectives. MCDM problems generally comprises of five components which are: goal, decision maker's preferences, alternatives, criteria's and outcomes respectively [4,23]. MCDM can be classified as given in Fig. 2. Based on the number of alternatives under consideration, differences can be catered between Multi Attribute Decision Making (MADM) and Multi Objective Decision Making (MODM); else both share similar characteristics. MODM is suitable for evaluation of continuous alternatives for which we predefine constraints in the form of vectors of decision variables.

A set of objective functions are optimized considering the constraints while degrading the performance of one or more objectives. In MADM, characteristics that are inherent are covered leading to consideration of fewer number of alternatives and thus evaluation becomes difficult as prioritizing becomes more difficult. The final result is decided by comparing various alternatives with respect to each attributes considered [12,24–26]. Different multi criteria techniques are applied in the field of renewable energy. MCDM models are another broader classification technique. The models developed are as per designer perspective. It can be a direct approach or indirect approach. In direct approach the assignment of priorities or weights are being

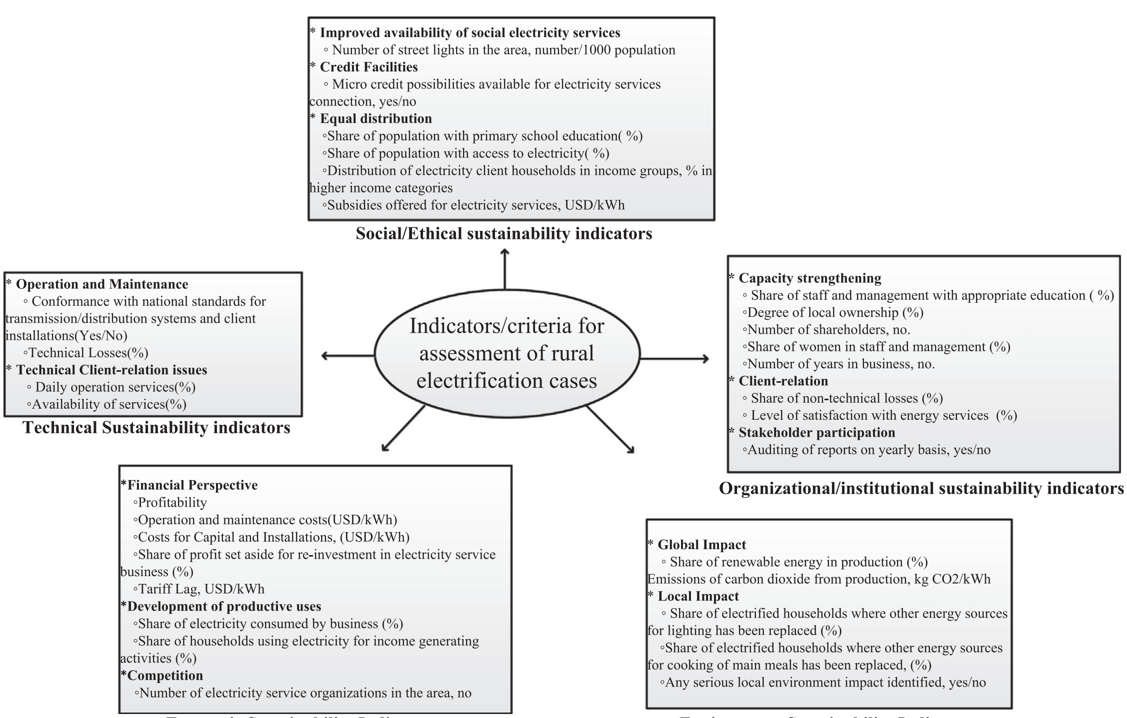

Fig. 1. Complex interaction of energy systems: An Example [21].

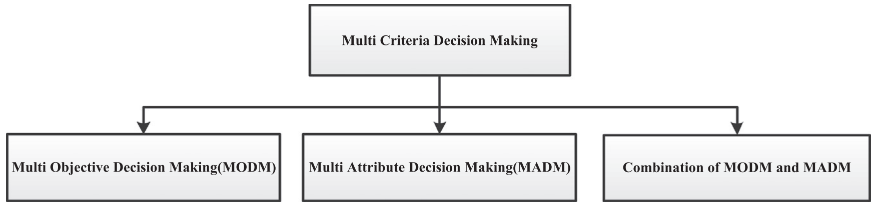

Fig. 2. Classification of MCDM [4].

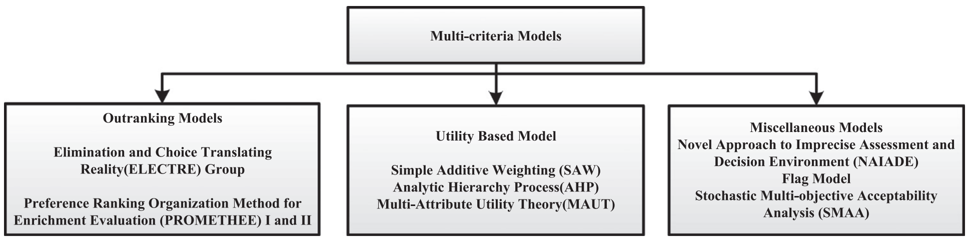

Fig. 3. Multi Criteria Decision Models [27].

done because of inputs from the beneficiary, society or acquaintance based on the survey. In an indirect method, all the possible criterions are separated in components and assigned weights as per previous similar problems, judgment of decision maker based on experience, etc. A classification of such models is given in Fig. 3. MCDM are always complex due to involvement of factors including technical, institutional, standards, social, economic and stakeholders. Thus it involves both engineering and managerial level of analysis. Further, this procedure remains controversial as objectives can lead to different solutions at different times based in the priority set by decision makers or persons involved in the procedure.

Moreover, a particular problem can be approached by different methods based on the functions we define. Every method or model has its own drawbacks and restrictions. A general procedure of MCDM technique is illustrated in Fig. 4.

Following methods are considered in our study [25,28–38].

a) Weighted Sum Model by Fishburn in 1967
b) Weighted Product Model by Bridgman 1922
c) ELECTRE by Benayoun et al. 1966
d) TOPSIS by Hwang and Yoon 1981
e) MAUT by Edwards and Newman 1982
f) PROMETHEE by Brans and Vincke 1985
g) VIKOR by Opricovic 1998
h) AHP by Saaty, 1970's

Table 1 below illustrates brief summary of popular decision analysis methods showing typical steps involved along with their area of application, strength and weakness respectively from the literature.

Even some dedicated software packages are available related to multiple decision analysis. Some of them are commercially or otherwise readily available. A list of such software's is given in Table 2.

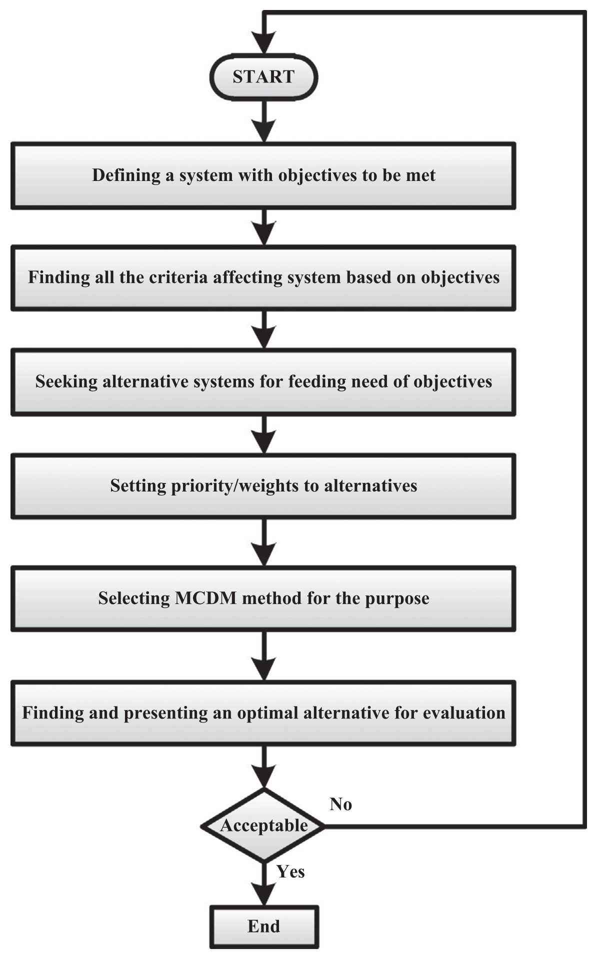

Fig. 4. A common procedure for MCDM analysis.

3. MCDM models in energy planning

MCDA methods has been successfully utilized in energy planning processes and are considered most suitable methods of solving issues related to energy. In this section, a review on the application of various methods with focus on renewable energy planning will be presented variedly and briefly. Broadly, we have three types of MCDM models namely Value measurement models, Goal, aspiration and reference level models and Outranking Models. These models have been used in combination as well.

3.1. Value measurement models

These models are basically utility based models and include methods like MAUT, AHP, Weighted Sum Method, and Weighted Product Method. These are mostly preferred for ranking energy technologies like application of energy storage devices in the field of renewable energy. Literature suggests that MAUT is not the most preferred method for energy planning as compared to AHP. Although AHP has some flaws as compared to MAUT as such like requirement of

Table 1
MCDM methods, their application, strength and weakness.

Methods	Area of Application	Steps	Strength	Weakness	References
Weighted Sum Method	1. Structural Optimization. 2. Energy Planning.	$J_{weightedsum} = w_1J_1 + w_2J_2 + \ldots.. w_mJ_m$ Where w_i (i=1, 2...m) is a weighing factor for i^{th} objective function and J is a function of designed vector. The best alternative is chosen as max ($J_{weightedsum}$).	1. Simple computation. 2. Suitable for single dimension problem	1. Only a basic estimate of one's penchant function 2. Fails to integrate multiple preferences	[39–43]
Weighted Product method	1. Division of labor in a process based on various elements. 2. Bidding strategies	$P_i = \prod_{j=1}^{M} [(m_{ij})_{normal}]^w$ where P_i is the overall score of the alternative and m_{ij} is the normalized value of an attribute.	1. Labelled to solve decision problems involving criteria of same type. 2. Uses relative values and thus eliminates problem of homogeneity	1. Leads to undesirable results as it priorities or deprioritise the alternative which is far from average	[44–46]
Analytical hierarchy process (AHP)	1. Resource management 2. Corporate policy and strategy 3. Public policy 4. Energy Planning 5. Logistics & $2 transportation engineering	1. Defining objective into a hierarchical model. 2. Determining weights for each criteria. 3. Calculating score of each alternative considering criteria. 4. Calculating overall score of each alternative.	1. Adaptable 2. Doesn't involve complex mathematics 3. Based on hierarchical structure and thus each criteria can be better focussed and transparent	1. Interdependency between objectives and alternatives leads to hazardous results. 2. Involvement of more decision maker can make the problem more complicate while assigning weights. 3. Demands data collected based on experience	[47,48]
Elimination and Choice Translating Reality (ELECTRE)	1. Energy management 2. Financial management 3. Business management 4. Information technology & $2 communication 5. Logistics & $2 transportation engineering	1. Based on three pillars: a. Determination of threshold function. b. Concordance index and Discordance index. c. Outranking degree. 2. Assigning rank based on above calculation.	1. Deals with both quantitative and qualitative features of criteria. 2. Final results are validated with reasons 3. Deals with heterogeneous scales	1. Less versatile 2. Demands good understanding of objective specially when dealing with quantitative features.	[49–53]
Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS)	1. Logistics 2. Water resource management 3. Energy management 4. Chemical engineering	1. Calculation of matrices 2. Normalised and decision 3. Calculation of positive and negative ideal solutions 4. Calculation of separation and relative closeness.	1. Works with fundamental ranking 2. Makes full use of allocated information 3. The information need not be independent.	1. Basically works on the basis of Euclidian distance and so doesn't consider any difference between negative and positive values. 2. The attribute values should be monotonically increasing or decreasing.	[54–58]
VlseKriterijumskaOptimizacija I KompromisnoResenje(VIKOR)	1. Mechanical Engineering 2. Manufacturing engineering 3. Energy Policy 4. Business Management 5. Medicine and health	1. Determination of best and worst values 2. Calculation of values of S_j and R_j, where S_j is weighted and normalized Manhatten distance, R_j is weighted and normalized Chebyshev distance 3. Calculation of Q_j based on above calculation 4. Ranking of alternatives and sorting by values of S, R and Q leading to formation of three list 5. A compromise solution from the final three rank lists.	1. An updated version of TOPSIS 2. Calculates ration of positive and negative ideal solution thereby removing the impact	1. Difficulty when conflicting situation arises. 2. Need modification while dealing with some terse data as it become difficult to model a real time model.	[59–63]
Preference Ranking Organisation Method (PROMETHE)	Risk analysis Structural analysis Mining Engineering	1. Finding evaluation matrix and comparing them pairwise considering every single criteria 2. Assignment of preference function with values from 0 to 1 depending on the difference between pairs 3. Calculation of global matric and determining the rank by adding the column which express the supremacy of one alternative over the other	4. Involves group level decision 5. Deals with qualitative and quantitative and qualitative information 6. Incorporate uncertain and fuzzy information.	1. Doesn't structure the objective properly 2. Depends on the decision maker to assign weight 3. Complicated and so users are limited to experts.	[35,64–69]
Multi attribute utility theory (MAUT)	City planning Economic policy Government policy	1. Identify dimensions of each objective and assign weight to each. 2. Calculation of % weight and updating values based on weight assigned to	1. Accounts for any difference in any criteria 2. Simultaneously	1. Difficult to have precise input from decision maker. 2. Outcome of the	[33,70–77]

(continued on next page)

Table 1 *(continued)*

Methods	Area of Application	Steps	Strength	Weakness	References
		options of each dimension. 3. Multiplication of updated vales of weight and previously obtained values 4. Add product of each dimensions to get final sum for each options and thereby determine the decision.	compute preference order for all alternatives 3. Dynamically updates value changes due to any impact.	decision criteria is uncertain.	

a mutual outcome environment for defining utility functions and procedural complexity in calculating the scaling constants [81]. AHP and MAUT have been used in alternative electricity supply strategies as mentioned in [82–84].

Gavanidou and Bakirtzis [85] suggested design of an independent system comprising of renewable energy sources using trade-off methods in which main focus was given in finding attributes and uncertainties and eliminating inferior objectives. The outcome was not a unique optimal solution rather it was a group of robust designs eliminating inferior designs. Social factor as indicated in various published articles have always played a very important role in energy planning and policing. Some of the important factors like energy price, environmental impacts, and financial security have been considered in Ref. [86].

Drawbacks and benefits of MAUT have been discussed precisely in Ref. [83,87,88]. Although MAUT has many advantages in making decisions that include risk, social factor but AHP has emerged as a better tool. Energy storage, power quality issues, energy allocation, optimal dispatch, sustainability in the field of renewable energy are some of the important criteria in the segment of energy planning. Janjic et al. [89] have discussed criteria's like production, cost and other constraints in case of distributed generation for optimal dispatch. They have used AHP to have choice of the dispatching action. A case study of Iran was presented in [90], which used AHP to assess power generation system from sustainability perspective based on an upgraded policy making structure. An AHP based model for taking decisions in energy system policy was presented in [91,92]. It proposed and analysed outcome of different energy usage and changeover path. Athanasios and Petros [93] concluded a fact that renewable energy power generating is the best resolution for the future with technological, economic and sustainability as criteria. The evaluation was based on the study of 10 power plants including renewable, nuclear and fossil based plants, being paired for better weighing. Selecting location of a wind power plant has always been a cumbersome job. In [94], authors used AHP to simplify this process and build a wind power station in a campus of university resulting in evaluation of criteria with topography and security as most important. AHP has been used with other MCDM techniques as well like Gaol Programming (GP) and fuzzy logic. Fuzzy logic is more apt to approach decision making problems in an unresolved environment [95]. The use of AHP and fuzzy logic for selection of storage energy technologies with concern in power quality context considering efficiency, load management, technical maturity, cost, and life-cycle as criteria have been studied in [96]. In [97], by prioritizing criteria considering three different scenarios using AHP and fuzzy logic for evaluating the operation of energy storage is reported. AHP is simple, flexible, and intuitive and has the ability to handle criteria qualitative and quantitatively although it becomes more complex when it is applied over number of criteria as mentioned in [98].

3.2. Goal, aspiration and reference level models

Goal programming is defined of multiple objective functions while linear programming is defined when we have only one objective. Recent days had come up with wide application of Goal Programming (GP) in energy resource application. Lucia and Andrez [99] presented a GP procedure for solving issue of maintenance scheduling of thermal generating units concealed by economic and reliability criteria by optimizing system operating costs and flattening thermal reserve margins. In [100] authors identified various challenges and uncertainties in a deregulated power system. They projected an amalgam of multi-objective planning method using goal programming for transmission expansion with security assessment. An explanation to interior point methods in combination with goal programming and linearly combined objective functions as the basic optimization techniques applicable in power system networks was given by Rosehart et al. [101]. Goal Programming is less subjective and also offers a straightforward procedure. Ramanathan and Ganesh [98] combined AHP with GP for resource allocation including qualitative and quantitative criteria. STEP and TOPSIS are few other GP methods being used for energy planning [88,98,102]. Drawbacks of TOPSIS was presented in [103] stating the failure in calculation of dynamic weights of the criteria and thus a hybrid method based on fuzzy and TOPSIS was used for risk evaluation. TOPSIS is a preferred method in the evaluation of optional electricity supply strategies [84]. STEP allows direct comparison with the alternative solutions and thus while making decisions decision makers become aware of the impact that they can have while assigning weights to different criteria [104].

3.3. Outranking models

Outranking models include PROMETHE and ELECTRE of which ELECTRE methods are popularly used in energy planning. They are preferred by the decision makers because of the broad perception they provide for the problem statement giving a practical view inculcating all the queries or suspicion. These methods are more preferred in applications related to the choice of allocating energy in demand side. Flourentzou et al. [105] presented the use of ELECTRE in renovating and rating the present building scenarios considering parameters like energy used for heating, cooling and various other appliances impact on foreign and indoor environment quality and cost. ELECTRE III method and its application to power distribution system planning was demonstrated using an example in [106] followed by presentation of simple ranking method. They concluded that ELECTRE III, fits the pragmatic necessity of healthy and reliable planning, thus is an empirical and realizable approach for supporting power distribution system planning. Cynthia, Hwang and Frank [107] compared five MADM techniques; dominance, additive weighting, linear assignment, ELECTRE, and TOPSIS by simulating them over estimation methods traditional Bayes, maximum likelihood and Brender's Bayes inculcating criteria's like proximity to steady state, discrepancy between samples, computer execution time, ease of programming, simplicity in dealing and priority setting/weight assignment. They concluded that Brenders Bayes was superior of the two.

ELECTRE III has remained popular among ELECTRE group. Researchers [106,107] presented the use of outranking models in distributed energy systems. In [108] economics of investment in the field of PV is considered. They featured an inclusive decision-making structure using ELECTRE III that administer a complete mathematical analysis that would help photo voltaic (PV) system owners, bureaucrats

Table 2
MCDM based software [78–80].

Sl. No.	Name	Type (Open source or Proprietary software licenses)	Developer	About	Uses
1	1000Minds	Internet-based and free for academic use.	1. Paul Hansen 2. Franz Ombler	Based on PAPRIKA (*Potentially All Pairwise rankings of all possible Alternatives*) method.	MCDM, prioritization and resource allocation
2	BENSOLVE	Free and open source software	1. Andreas Löhne 2. Benjamin Weibing	Implement Benson's algorithm and its extensions	To solve linear vector optimization problems a subclass of multiple objective linear programs (MOLP)
3	Bubble Chart Pro OPTIMAL	Proprietary software licenses	George Huhn	A powerful all-in-one project prioritization and real optimization system in an easy-to-use application	A linear programming optimizer and prioritize based on SMART (Simple Multi-Attribute Ranking Technique).
4	ChemDecide	Proprietary (Ph. D Thesis Work)	Richard Hodgett	A software package based on AHP, ELECTRE III and MARE	Used to aid route selection, chemical storage, equipment selection and sourcing decisions
5	DECISIONARIUM	A website to be used for academic purpose only	Project Leader: Raimo P. Hämäläinen	The website provides multicriteria decision tools for individual and group decision making.	Used for purposes like decision support, global participation, voting, surveys, group decisions, robust portfolio modelling, preference programming, etc.
6	DEXi	Free to use	Marko Bohanec	A computer program for multi-attribute decision making	For supporting complex decision-making tasks based on Multi Attribute decision making
7	D-SIGHT	Proprietary	Company	Based on PROMETHEE methods, MAUT and AHP.	Used in corporate for taking various decision
8	ElectioVis	Open source	Maximiliano Ariel López	A decision-aiding software tool	It lets one to fill all the data and then simulate results
9	FLO	Free use for academic purpose	Institute for Mathematics of the Martin Luther University Halle-Wittenberg.	It is a project for development of a MATLAB-based software tool.	Used for solving location problems.
10	GUIMOO	Free software	**Project Admins**: 1. El-Ghazali Talbi 2. Emilia Tantar 3. Ulrich Van Den Hekke	GUI (Graphical User Interface) based mainly used for Multi-Objective Optimization.	Mostly used to design of efficient metaheuristics.
11	IDS	Free	1. Dong-Ling Xu 2. Jian-Boyang	An IDS (Intelligent Decision System) used for MCDA under conditions of uncertainty	It can be used for total quality management (TQM) in corporate an also for business excellence
12	IDSS Software	Free version available for students	Roman Słowiński and team	It is based on a team including top-level scholars and consultants with specialization in decision support based on various methodologies of operational research and artificial intelligence.	1. Preference Modelling, ranking and sorting. 2. Multi objective programming in fuzzy environment, interactive procedures for multicriteria choice. 3. System programming for water supply, regional planning, agriculture, software engineering, surgery, environment.
13	IND-NIMBUS	Free for academic purpose	University of Jyväskylä, Department of Mathematical Information	Aimed at solving nonlinear multi-objective optimization problems and it can be applicable for solving real-world problems.	Suitable for both differentiable and non-differentiable multi-objective and single objective optimization problems.
14	Interalg	Free	Dmitrey	A solver for multi-objective optimization with specifiable accuracy, with general logical constraints and categorical variables.	It can be used for the purpose of solving Multi Objective optimization problem where we have user defined accuracy.
15	IRIS and VIP and Decision Deck	Open Source	**IRIS** 1. Luis Dias 2. Vincent Mousseau 3. Carlos Gomes Silva 4. Rui Lourenço **VIP** Luis Dias	**IRIS** - Interactive Robustness analysis and parameters' Inference software for multicriteria Sorting problems **VIP** - Variable Interdependent Parameters: uses aggregation of multicriteria performances by means of an additive value function under imprecise information. **Decision Deck** is a project aimed to collaboratively develop Open Source software tools implementing Multiple Criteria Decision Aid (MCDA)	Can be used for sorting, risk analysis specially risk assessment and remediation risk management.
16	MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique)	Commercial	1. Carlos Bana e Costa 2. Jean Marie De Corte 3. Jean-Claude Vansnick	An interactive approach that requires only qualitative judgments about differences. It helps a decision maker or advising group to quantify the relative importance of options.	1. Strategic plan development 2. Resource allocation 3. Participative evaluation of social, economic and environmental impacts for major infrastructures 4. Public policy planning

(continued on next page)

Table 2 (continued)

Sl. No.	Name	Type (Open source or Proprietary software licenses)	Developer	About	Uses
					5. Feasibility of projects and plans 6. Performance evaluation for employees, suppliers, tender evaluation.
17	MakeItRational	Proprietary	Company	An AHP based platform	Project Management
18	modeFRONTIER	Commercial	ESTECO Spa	multi-objective optimization and multi-disciplinary design tool, which provides an easy interface to many Computer Aided Engineering (CAE) tool	For optimization and multi objective decision making
19	Decision Explorer	Commercial	BANXIA Software	A Windows based mapping tool of ideas.	Used to develop feasible, practical and acceptable solutions by considering opinions for different people and negotiating for a shared understanding.
20	Criterium Decision Plus	Commercial	Infoharvest	A visual decision tool that helps you make decisions by communicating and inculcating recommendations effectively.	Used for decision support for environmental, aerospace, engineering, defense and space
21	Winpre	Available free for research purpose	1. Raimo P. Hämäläinen 2. Jyri Helenius	Workbench for Interactive Preference Programming.	Decision support, Spontaneous decision conferencing in parliamentary negotiations, Traffic planning
22	SANEX	Non-commercial computer program	Thomas Loetscher	University of Queensland, Australia in collaboration with Swiss Development Cooperation (SDC)	Applicable in sanitation system designs for rural communities in developing nations.
23	Expert Choice[79]	Commercial	1. Thomas Saaty 2. Ernest Forman	Developed by Thomas Saaty and Ernest Forman 1983, is currently one of the leading companies in providing cutting edge decision making solutions globally. Software is based on AHP and comes in two different version know as Expert Choice Comparison and Expert Choice Riskion.	Riskion is widely used in all type of industries such as aerospace, asset management, automotive, banking, Energy, government, health care and many more for risk management processes. Comparison is being used in project management, capital budgeting, strategic planning, vendor source management's, trade studies etc.
24	Triptych[80]	Commercial	Statistical Design Institute, LLC	Basically it is a Microsoft Excel based add-in providing not only decision support but also helping to understand the voice of customers, generation and selection of design alternatives. It incorporates many methods such as Quality Function Deployment methods, affinity diagram, AHP, Theory of Inventive Problem Solving TRIZ, TOPSIS etc.	Currently used in industries such as aerospace, biomedical, mining & $2 oil, automotive, equipment developers and also in academic research.

and the business communities to decide on PV technologies, financial support systems and business strategies. Researchers [109], focused on the use of PROMETHE II in a Group Decision Support System (GDSS) for advising the decision makers in promoting the use of Renewable Energy Sources (RES). Ghaderi et al. [110] applied SAW and PROMETHE I and PROMETHE II in making superlative installation of wind turbine farms in Iran. Criteria's were average wind speed, frequency of natural disasters, geological properties, geographic features and land cost [110]. They also introduced a new model, which is linear and logarithmic supposed to be used for sensitivity analysis. Analysing the above works, a firm conclusion can be drawn that these models are best suited for finding priority setting of criteria available and deciding if the alternatives are relevant or irrelevant [111]. Remote control and automation in power sector is at its peak. Flexibility of MCDM makes it possible to use it for optimal placement of PMU providing a lead in wide area monitoring research and synchro-phasor technology [112]. As mentioned, conventional sources can be made feasible based on few indicators only. A small example is given in [113], which present a study to improve stand-alone diesel generators used in comparison with renewable energy systems in Masira Island.

4. Performance Indicators/criteria and energy planning schemes in MCDM models

As illustrated in available literature, energy planning is broadly being evaluated on technical, economical, social, environmental and institutional indicators using various MCDM models. In context to developing nations authors in [21,114] have presented a total of 39 performance indicators (technical, economical, social, environmental and institutional) which can be used for efficient designing of electrification system. Some of these indicators are shown as an example in the introduction section in Fig. 1. Energy schemes and their structure (centralized, decentralized, standalone or grid connected) generally vary from one demography to other. In Table 3, a summarised information from the relevant literature considered in this review presenting main objective, key performance indices (KPI), study type (area based/local or generalised) and energy scheme (Centralised or decentralised distribution, renewable, standalone or grid connected, transmission and distribution system) is illustrated.

The process of evaluation has become more tedious with introduction of more criteria's and prospects. Different methodologies have diverse solutions, posture towards inclusion of cogent or delicate criteria's. Involvement of environment indicators makes the treatment much uncertain as there exists no historical patterns for any area or taken globally. Most of the criteria are assigned weights based on the

Table 3
Summary information of objectives, KPI's, location and energy schemes in MCDM models.

Sl. No.	Objective	Key Performance Indicator/ Criteria's	Study type	Energy Scheme
1	To comprehensively evaluate the alternation for new energy system development [83]	1. Completeness 2. Decomposability 3. Non-redundancy 4. Operational feasibility 5. Minimum size	Location specific- Taiwan	Decentralized
2	Developing a multi objective optimization approach to generation expansion planning [84]	1. Cost 2. Environmental Impact 3. Fuel import Vulnerability 4. Risk of plant disaster	Generalized but illustrated with example of 4th nuclear power plant of Taiwan	Centralized
3	Developing an interval based MADM approach in support of the decision making process with imprecise information [86]	1. Alternate generation resource expansion 2. Strategies 3. Cost of energy supply 4. System reliability 5. Environmental impact 6. Resource feasibility	Generalized with a case study of a moderate sized US electric utility	Moderate sized electric utility
4	Application of recent theoretical advances in multi-objective planning under uncertainty in design of standalone system with RES [87]	1. Load demand 2. Wind and solar source availability 3. Hardware component availability	Generalized	Standalone system with RES
5	To use MCDM when disagreement exists between various stake holders thereby building insight and confidence [88]	1. Economic Objective a. Provide quality energy service to customers at minimum cost b. Minimize rates c. Provide utility shareholders value for their resource investments 2. Environmental / Social a. Minimize environmental cost/impact b. Optimize social and economic impacts	Generalized	NA
6	Application of Multi criteria decision in optimal distributed generation dispatch [92]	1. Technical 2. Economic 3. Environmental 4. Social	Generalized	Distributed Generations (DG) based on RES connected to Utility for DG scheduling
7	MCDM applied to study Iran power generation system from sustainability point of view [90]	1. Human a. Economical b. Social c. Security 2. System (Technical) 3. Nature (Environmental)	Location based- Iran	Centralized
8	Proposes a novel decision support tool for decision makers to evaluate the consequences of different energy usage and transform pathways [91]	1. Social 2. Technical	Location based (UK)	Centralized
9	Evaluation of technological, economic and sustainability evaluation in power plant using AHP [93]	1. Technological sustainability a. Efficiency coefficient b. Availability capacity c. Reserves of production ratio. 2. Economic sustainability a. Capital cost, operational cost and maintenance cost b. Fuel costs c. External costs	Generalized	Ten types of power plant was studied
10	Application of AHP to determine a wind observation station [94]	1. Cost 2. Topography 3. Infrastructure 4. Security 5. Convenience of transformation	Location based- Osmangazi University (Campus of Meselik)	Decentralized
11	Use extended VIKOR for decision making problem with rating of alternatives being expressed using intuitionistic fuzzy sets and criteria weight is completely unknown [95]	1. C_1 (Economical) 2. C_2 (Function) 3. C_3 (Being operative)	Generalized	NA
12	Use of AHP and Fuzzy logic to determine the best energy storage technologies in power quality scenario [96]	1. Power Quality 2. Efficiency 3. Load Management 4. Technical maturity 5. Life cycle 6. Cost	Generalized	Decentralized due to presence of ESS
13	Energy resource allocation using goal programming and AHP [98]	1. Lifecycle costs 2. System efficiency	Generalized with few key performance indices taken to represent city of	Decentralized (Study is based on household end uses).

(continued on next page)

Table 3 *(continued)*

Sl. No.	Objective	Key Performance Indicator/ Criteria's	Study type	Energy Scheme
		3. Petroleum products 4. Employment 5. Local resources 6. Long term availability 7. Fuel wood products 8. Carbon oxides 9. Sulphur oxides 10. Nitrogen oxides 11. Convenience 12. Safety	Madras	
14	Application of Multi objective optimization in rural energy policy analysis [102]	1. Economic objectives a. Reduced cost b. Increased efficiency c. Reduced energy input 2. Equity objectives a. Increased employment b. Use of local resources 3. Environmental objectives a. Reduced pollution	Rural Electrification System with a case study in Nepal.	Deregulated
15	To use goal programming for scheduling of generation units for maintenance in large scale power system [99].	1. Economic criteria 2. Reliability	Localized (Spanish power system)	Centralized
16	MCDM with dynamic programming/production simulation for generation expansion planning [84]	1. Cost 2. Environmental Impact 3. Fuel impact vulnerability 4. Risk of plant disaster	Generalized with an example of nuclear power plant of Taiwan	Decentralized (based on one nuclear power plant)
17	To check compliance of a building with [105] a. Regulation of b. Evaluate the efficiency of retrofit c. Perform a comparison of a number of building qualities.	1. Energy use for heating, cooling and other appliances 2. Impact on external environment 3. Indoor environment quality 4. Cost	Localized (University of Athens)	NA
18	To use MADM – ELECTRE III for power distribution system planning [106]	1. Annual energy losses (MWh); 2. System security 3. Supply availability 4. Capacity constraints 5. Environmental impact 6. Capital cost	Generalized	Decentralized (distribution system)
19	Application of outranking techniques for PV technologies [108]	1. Technical a. PV (Contribution solar fraction) b. Module design 2. Environmental a. Net kg-eq CO_2 b. Aesthetic 3. Economic a. Net present value b. Maturity	Generalized (illustrated with a case study in UK)	Grid connected PV system
20	Develop a decision support system for renewable energy exploitation [109]	1. Cost involved (Investments) 2. Proportion of cost being utilized in foreign currency 3. Fossil fuels import costs 4. Electrical Generation Cost 5. Economic Development of target region 6. National economy contributions 7. Power supply safety 8. Climate Risks 9. Pollution compared to the year 1992 10. Energy Sources conservations (Non-renewables) 11. Land 12. Accidental Risk 13. Acceptance by people 14. Creation of job	A case study of Greek	Distributed (involved Renewable energy sources)
21	Optimal placement of PMU using MCDM [112]	1. Bus observability index 2. Voltage control area 3. Observability index 4. Tie line oscillation observability index	Generalized (illustrated using IEEE 14 bus system, New England 39 Bus system, Northern regional power grid −246 bus Indian system)	Distributed System
22	Evaluation of solar farm location applying	1. Land Use	Location based (Southern Morocco)	Decentralized

(continued on next page)

Table 3 *(continued)*

Sl. No.	Objective	Key Performance Indicator/ Criteria's	Study type	Energy Scheme
	geographic information system and MCDM [115]	2. Orography 3. Location 4. Climate		
23	To identify and prioritize the barriers existing in developmental path of solar power in Indian perspective [116]	1. Institutional barrier 2. Technical barrier 3. Political and regulatory barrier 4. Market barrier 5. Social Cultural and behavioural barrier 6. Finance barrier 7. High cost of capital	Location based (India)	Decentralized
24	Application of multi criteria analysis over options for energy recovery from municipal solid waste on India and UK [117]	1. Benefit 2. Opportunity 3. Cost 4. Risk	Location based (India and UK)	NA
25	Combined application of AHP and VIKOR for electric supply planning in rural and remote areas [118]	Broadly technical, economic, environmental and social criteria	Localized Venezuelan Andes.	1. Dispersed Decentralized Generation 2. Compact Decentralized Generation 3. Centralized Generation
26	Building a location suitability index for wave energy production [119]	1. Unpredictability 2. Ecological impact 3. Noise and visual pollution 4. Obstruction to navigation 5. Impact on marine life 6. High initial costs 7. Reduced sea usage	Location specific (Coastal Region)	Decentralized
27	Evaluation of wind energy investments and aims to select the appropriate wind energy technology to help investors [120]	1. Reliability 2. Technical Characteristics 3. Performance 4. Cost factors 5. Availability 6. Maintenance 7. Cooperation 8. Domesticity	Generalized with a case study of Turkey	Decentralized (Renewable Energy Source)
28	A framework to negotiate among the multiple goals by defining optimal mutual objectives for each PCG to achieve sustainability using MCDA [121].	1. Daily Averages of energy level 2. Available number of prosumers 3. Resource and storage related constraints, 10,000 kW h 4. Assumed demand of external energy, 6000 kW h 5. Rate of Income (assumed) 6. Assumed expected income, $15,000 7. Cost (assumed weights) 8. Cost based constraint involved in total budget (assumed) $5000 9. Sustainability participations (Ns) 90%	Generalized	Smart grid
29	To identify a portfolio of biomass conversion technologies appropriate for Central America, considering technical, economic, environmental and socio-political aspects [122]	1. Technical 2. Economic 3. Environmental 4. Socio-political	Location based (Central America)	Decentralized (Biomass considered)
30	A MCDA based framework evaluating the impacts of diverse financial policies regarding their lure for domestic PV systems on multinational levels [123].	1. Net Present Value (NPV) 2. Rate of Return 3. Payback Time 4. CO2 contribution 5. Support Cost	Generalized	NA

historical data or any survey at present time, but they change with rolling time and thus need to be updated and adjusted. Thus, accommodation of these changes is another important aspect in decision analysis. The selection of various key indices/criteria while designing or selecting alternatives for energy projects itself requires involvement of multiple actors such as experts, people from targeted community, government organizations, NGO etc. Also accommodating maximum number of criteria's for evaluating and finding their relative weights itself is very complex issue. However, commercial software are available (listed in Table 2) which can help practitioner and researchers to accommodate many criteria's for evaluation. In [27], a new approach which can be utilized to accommodate as many criteria and to find their relatives weights using AHP method is illustrated. Table 4 illustrates some examples from recent scholarly work considering the various applications of MCDM in different regions of world in several fields and not only confined to energy planning.

As shown in previous sections, MCDM has indeed emerged as a popular tool and has a wide application in many subject areas. Based on the data obtained from Quacquarelli Symonds (QS) world ranking, a graphical representation is shown in Fig. 5,which indicates the number

Table 4
MCDM application in other disciplines.

S. No.	Region	Application	Method	Ref.
1.	Africa	1. Analysis of efficiency of African airlines	TOPSIS and Artificial Neural network (ANN)	[124]
		2. Building assessment	AHP and Additive Ratio Assessment (ARAS)	[125]
		3. Maintenance policy selection in naval ships	AHP	[126]
		4. Sustainable development for Gulf Cooperation council countries	Weighted Goal Programming	[127]
		5. Selecting or picking Start-Up Businesses in a Public Venture Capital Financing	Fuzzy-PROMETHE	[128]
		6. Agricultural adaptation and mitigation	AHP and Goal Programming	[129]
2.	Asia	1. Risk management	Fuzzy AHP and Fuzzy TOPSIS	[130]
		2. Tactical Freight Forwarder of China Southern Airlines	Heterogeneous multiple criteria group decision, TOPSIS, FUZZY	[131]
		3. Rail transit systems of Istanbul	MCDM and Fuzzy	[132]
		4. Small Medium Enterprises (SMEs)	AHP, TOPSIS	[133]
		5. Road safety risk evaluation	TOPSIS	[134]
		6. Evaluation of service innovation in the hotel industry	Fuzzy and TODIM	[135]
		7. Competitiveness of Sea Transport	TOPSIS and Fuzzy	[136]
		8. Assorting of strategic alliance partner in airline industry	AHP; Fuzzy TOPSIS	[137]
		9. Tourism strategy development	Fuzzy Delphi method (FDM), decision-making trial and evaluation laboratory (DEMATEL) and analytic network process (ANP)	[138]
		10. Evaluating Intangible Resources Affecting Port Service Quality	Fuzzy TOPSIS	[139]
		11. Assessing cloud services adoption	AHP	[140]
		12. Dry Port Location in Developing Economies	Simple multi-attribute rating technique (SMART), AHP	[141]
3.	Australia	1. Agriculture- AHP	AHP	[142]
4.	Europe	1. Differentiation of housing market sustainability in European countries	COPRAS	[143]
		2. Evaluation of green operations initiatives	Fuzzy extent analysis, TOPSIS	[144]
		3. A case study European Foundation for Quality Management	Fuzzy Logic, AHP.	[145]

of top 200 universities in the world those adopted the MCDM techniques for interdisciplinary research [146].

5. Discussion

Energy projects accompanied with sophisticated technologies and promise affordable electricity even tend to fail many of times, due to ignorance or less importance of social factors. For any energy project to be efficient and successful especially when considered in developing regions, a synergy has to be found considering different scenarios with

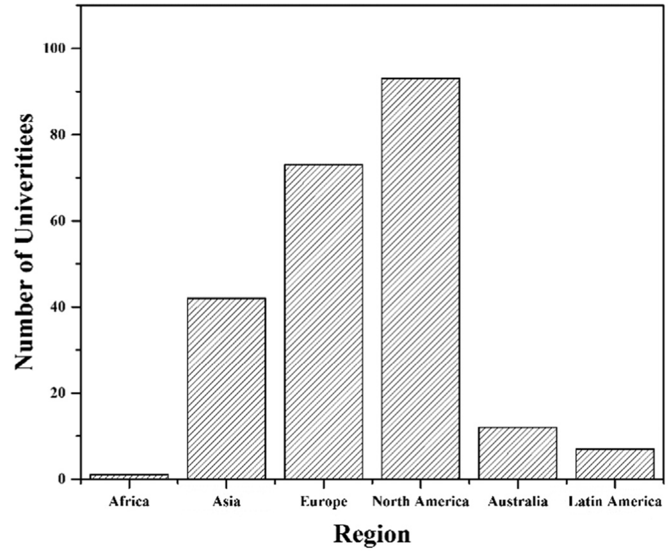

Fig. 5. Number of universities in QS world ranking statistics and operational-research.

multiple indicators. Different scenarios must be created by prioritizing criteria/indices considering different constraints in order to achieve a real time solution. Most of the times, the evaluation has been done based considering only single scenario. Social factors play a key role for electrification projects in rural developing areas. As mentioned in quote [147], the "*technology needs to be created for people, people need not be created for technology*". So, an energy system design must take account of social factors by giving it equal importance as other factors. Due to inclusion of multiple participants, complexity in the problem statement has increased. AHP due to its simplicity in procedure has gained popularity although few outranking techniques ELECTRE III and PROMETHE also are popular. But no single MCDM model can be ranked as best or worst. Every method has its own strength and weakness depending upon its application in all the consequence and objectives of planning. Hybrid techniques are thereby developing to tackle such situations. Nonetheless, MCDM is not only the method but it seems to capture all the consequence, objectives of planning. The MCDM still seems missing at local organizational level. Most of them are implemented in the areas where we have national, regional or a particular geographical location. Analysis need to be done considering local resources for local environment. Most importantly, a process of hierarchy can also be implemented in the process, as of moving from local environment to global scenario. Independency analysis of energy generating system basically distributed to connected grid is another domain left blank. Hence, energy planning with an aim of sustainability should be evaluated not only considering a single scenario based on multiple criteria but evaluation should be done considering multiple scenarios based on multiple criteria. A general methodological framework considering different scenarios with a detailed process for electrification especially for rural developing world has been reported by the author [147]. New modus operandi could be formulated to tackle diverse dimensions of energy and environmental planning.

6. Conclusion

In developing countries the policies are restructured for providing modern energy needs at disintegrated levels which requires a better evaluation in synergy with multiple benchmarks. Considering the multiple sustainability scenario and factors, MCDM model are best suited for such revolutionary objective. In order to achieve best solution overcoming all the environmental and local issues in real time application, MCDM model have to be utilized on multiple criteria involving multiple scenarios. This paper summarizes the essential aspects of MCDM techniques; energy based MCDM models and outlines various performance indicators which can be utilized to address the core issues for achieving the goals of sustainability in developing nations especially at rural levels.

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