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A Critical Review of Multi Criteria Decision Making Methods for Infrastructure Planning and Sustainability Assessment of Infrastructure Projects

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Abstract: Infrastructure sector offers the basic support system for other sectors of the economy and is considered as a requirement to support the economic development. Cost-effective, reliable, and affordable infrastructure services are the requirements for sustainable infrastructure development and forms a necessary condition for achieving goals from the perspective of economic, social and environment dimensions. Sustainability assessment (SA) is viewed not only as an impact assessment process tools but also as an integrated assessment tool. The SA of infrastructure is a challenging and multi-faceted process demanding a holistic assessment of the diverse settings and environment under which infrastructure systems operate. The infrastructure planning, development and management and SA of infrastructure projects using multi criteria decision making (MCDM) methods has drawn the attention of decision makers for a long time. This paper performs a critical literature review of common MCDM methods, applicability of various methods for infrastructure planning and SA of infrastructure projects including the relative merits of the identified methods.

Keywords: *Sustainable infrastructure, Sustainability assessment, MCDM methods, SAW, WPM, AHP, PROMETHEE, ELECTRE, TOPSIS, VIKOR, MAUT, Fuzzy, SMART.*

1. Introduction

Infrastructure sector offers the basic support system for other sectors of the economy [1] and as Horvath [2] observed, it is considered as a requirement to support the economic development. According to Shaikh Saleem [3], environmental outcomes and consequences of economic activity should be considered in any development process and should not accept unsustainable depletion and deterioration of natural resources. As enumerated in UNESCAP [4], a holistic approach is necessary in infrastructure development, factoring a) consumption and production aspects, b) physical and non-physical aspects, c) different stages of infrastructure development, d) different levels of organizations and e) role of different stakeholders. Sustainability of infrastructure will occupy centre stage in development process.

According to WCED [5] report, the concept of sustainable development [SD] implies integration of environmental issues with the imperatives of economic and social development in order to meet the immediate needs of the present without jeopardizing the aspirations of the future. The exploitation of resources, the direction of investments, the orientation of technological development and institutional change happen in harmony in the process of SD while enhancing both current and future potential to meet human needs and aspirations.

Cost-effectiveness, reliability, and affordability of infrastructure services are the requirement of sustainable infrastructure development (SID) and forms a necessary condition for achieving goals towards economic, social, and environment dimensions [6, 7].

SID concept is an integrated approach encompassing various aspects as illustrated in figure 1. Both eco-efficiency or smart development and socio-efficiency are considered essential in the infrastructure sector to promote economic sustainability on a long term basis.

Bond et al. [8] viewed that in the literature on sustainability assessment (SA), different interpretations and implementations of SA concept are available and the subject is wide and steadily growing.

A robust operational approach that try to define and derive sustainability criteria or pillars to make the concept of sustainability implementable is the Triple bottom line (TBL). In TBL approach, equal importance is given in the decision-making process for the environmental, economic and social pillars [9, 10, 11, 12, and 13].] The TBL approach, according to Gibson [10], is widely adopted as it augers well with organizational bodies and professional agencies mandated with the assessment of each of the sustainability pillar.

Since different dimensions of sustainability are addressed in the SA, it is viewed not only as an impact assessment process tools but also as an integrated assessment tool. The key differentiation that SA offers from other integrated assessment tools is that SA does not merely sum up separate economic, environmental and social assessments but also emphasizes their interconnection and interdependence. As measurement of sustainability is an important and integral part of the sustainable development policy, various innovative methods and tools are developed and practiced to aid the SA.

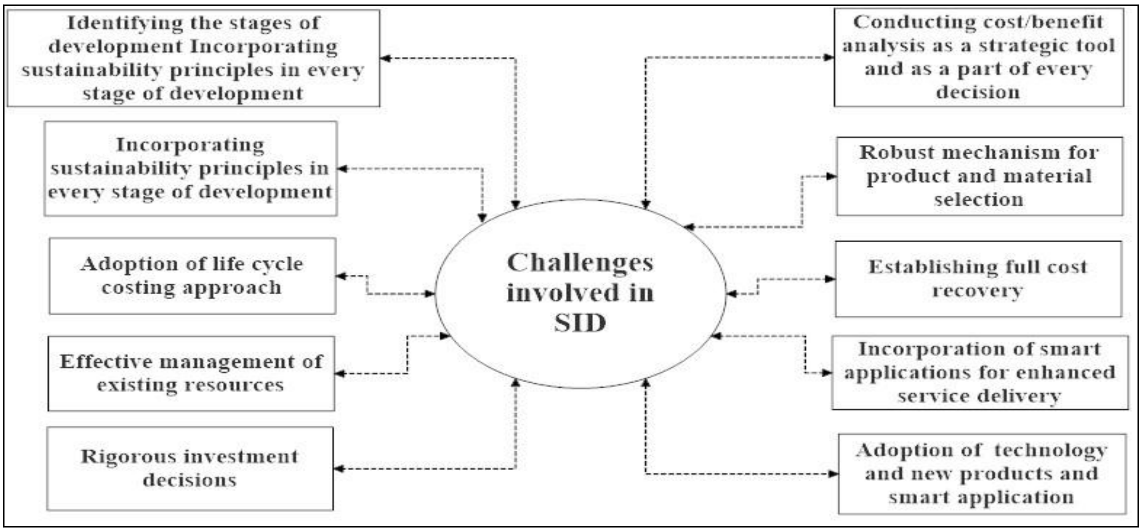

Figure 1 *Challenges involved in SID*

The concepts underlying weak and strong sustainability are discussed by Neumayer [14]. Munda [15] indicated that appropriate techniques that are capable of aggregating multiple indicators are required to be developed for SA, because of its multi dimensionality nature. A variety of Multi criteria Decision Making (MCDM) methods have been developed to address the challenge of making decisions when multiple options (alternatives) and criteria (attributes) exist in a given problem.

The subject matter of infrastructure planning, development and management using MCDM methods has drawn the attention of decision makers (DM) for a long time. The reason for increasing use of multicriteria (MC) approaches in infrastructure sector may be cited to the need for incorporating environmental and social considerations in infrastructure planning, development and management.

This paper reviews several common MCDM methods and their potential applicability in the infrastructure planning and SA of infrastructure projects. Section 2 briefly reviews the theoretical foundations of MCDM methods. Section 3 presents the conceptual framework of MCDM methods. Section 4 discuss on the grouping approach of MCDM methods. The merits and demerits of MCDM methods and application potential in infrastructure projects are discussed in Section 5. The main conclusions are presented in Section 6.

2. Theoretical Foundations of MCDM Methods

The Table 1 presents the theoretical foundations of MCDM methods.

Table 1: *Theoretical foundations of MCDM methods*

S.No.	Description
1	Pohekar and Ramachandran [16] observed that MCDM methods can be viewed as a branch of a general class of operations research models dealing with the decision problems under the presence of a number of decision criteria.
2	Finding a feasible solution through a decision making process considering MC by defining a problem over a criterion space or a decision space.
3	SA can be conducted using MCDM methods, an effective and appropriate set of tools, by considering different sustainability spheres, perspectives, stakeholders, values, uncertainties and intra and inter-generational considerations [8, 15, 17, 18 and 19].
4	According to Marco et al. [20], by considering interrelations and interdependencies among them, accounting for the different importance that they might have, and adopting different degrees of aggregation, MCDM methods are an integrated assessment that try to handle the information from an individual indicator in a comprehensive manner.
5	Belton and Stewart [21], viewed that MCDM methods is a group of approaches allowing to account explicitly for MC, so as to support individuals or groups to rank, select and/or compare different alternatives (e.g. technologies, solutions, products, policies, projects).

6	Long-term time horizons, uncertainties, risks and complex value issues can be effectively dealt in MCDM methods as pointed out by Ananda and Herath [22].
7	Encouraging the role of participants in decision making processes, offering better clarity on inherent features of decision problem, facilitating compromise and collective decisions and providing an excellent platform for understanding the perception of models' and analysts' in a realistic scenario are some of the inherent features of MCDM methods as observed by Marco et al. [20].
8	Being a structured framework, MCDM methods can analyze decision problems characterized by complex multiple objectives [23, 24].
9	MCDM methods typically a) defines objectives, b) chooses the criteria to measure theobjectives, c) specifies alternatives, d) transforms the criterion scales intocommensurable units, e) assigns weights to the criteria that reflect theirrelative importance, f) selects and applies a mathematical algorithm forranking alternatives, and g) chooses an alternative [25, 26, 27, 28].
10	MCDM methods have potential to conduct SA [15, 20, 29, 30, 31, and 32].

Increasing complex problems of infrastructure systems requires comprehensive solutions and MCDM methods are viewed as an appropriate and effective assessment tool. Ashraf et al. [33] pointed out that measuring the performance of an infrastructure in terms of the sustainability indicators facilitates SA of infrastructure. Interdisciplinary approach involving social, environmental, economic, and engineering sciences are required as per DCLG manual [34] for analysing and examining the SA of infrastructure systems. Being hard and complex process, SA necessitates a holistic assessment of the diverse settings and environment under which infrastructure systems operate.

3. Conceptual Framework of MCDM Methods

Figure 2 present the basic stages of applying a MC evaluation tool [35, 36].

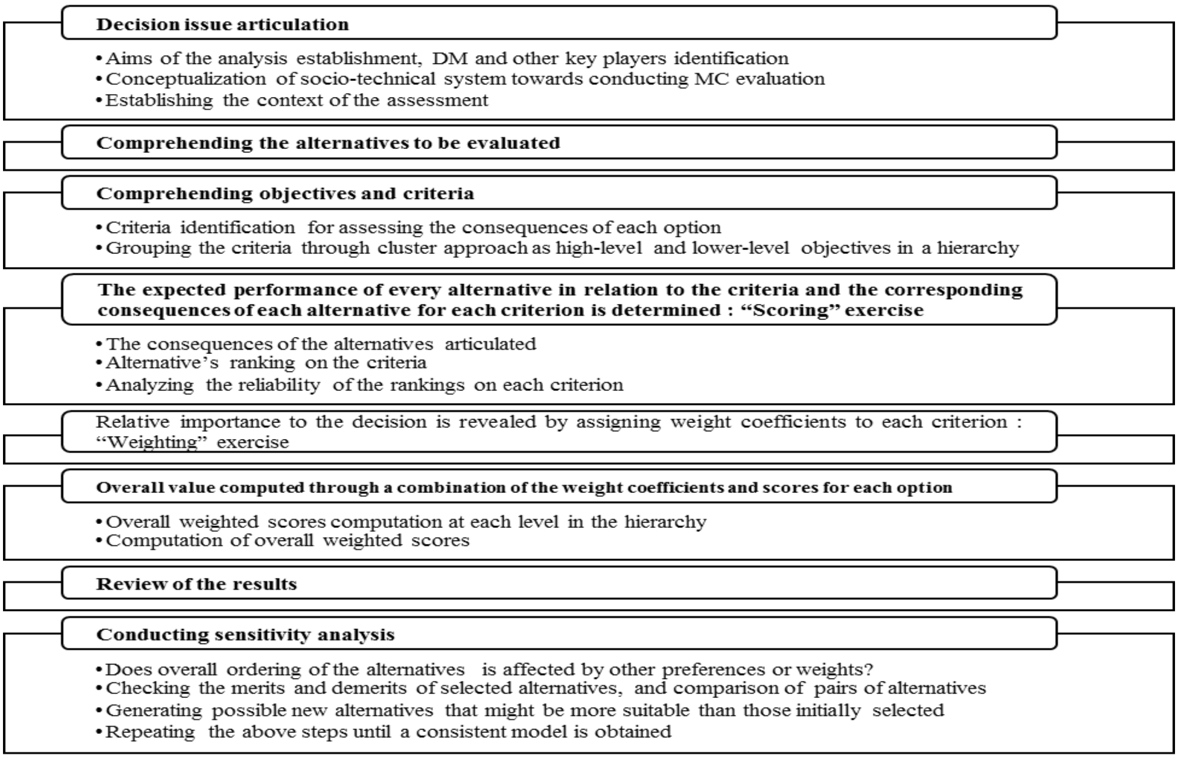

Figure 2: *Basic stages of applying MC evaluation tool [35, 36]*

Even though ranging from a simple to complex MCDM methods have been developed over a period of time, it is pertinent to understand that all the MCDM methods follow the same decision process as explained in figure 3 [36, 37].

Papadopoulos and Konidari [36] observed that the decision process of MCDM methods typically includes:

(a) alternative solutions
(b) different criteria
(c) matrix of specific values for each criteria
(d) weighting indicators for each criteria, and
(e) an evaluation of each alternative solution in respect to other alternatives

The underlying assumption in the multiple objective decision procedures is that at a certain point of the solution process, DM will be involved through interactive approach in the analysis [38, 39]. As observed by Korhonen et al. [40], for resolving different types of MCDM problems, three solution principles can be conceded. Evolved on these solution principles, Papadopoulos and Konidari [36] formulated the corresponding general approaches for solving MC problems. The conceptual framework based on these principles was evolved by various authors [36, 38, 39, 40,41,42,43 and 44].

4. Main Categories of MCDM Methods

For facilitating the selection of an appropriate MCDM method, understanding of decision making classification assumes importance. Several categories of MCDM methods are found in the literature, according to Papadopoulos and Konidari [36], depending on the type of input data, the initial assumptions, the adapted method of analysis and the output result [36]. Figueira and Salvatore [45] made a very thorough review of MCDM methods.

Categorization of the MCDM methods can be based on the type of the data [46], the nature of the alternatives to be evaluated [47], data processing, [48, 49], by number of answers [49, 50, 51], availability of data perspective [49]. Priority based, outranking, distance based and mixed methods are different kind of analysis applied to various problems.

The table 2 presents an overview of classification of MCDM methods.

Table 2 *Overview of classification of MCDM methods*

<table>
<tr><th>Approach / Author</th><th>Classification</th></tr>
<tr><td>Janssen [47] classified according to the nature of the alternatives to be evaluated.</td><td>Continuous and discrete methods are twomajor groupings classified by Hajkowicz [52]</td></tr>
<tr><td>Continuous methods</td><td>These methods, as per Ananda and Herath [22], aim to identify an optimal quantity, which can vary infinitely in a decision problem. Linear programming, goal programming and aspiration-based models fall under the group of continuous methods.</td></tr>
<tr><td>Discrete method</td><td>As pointed out by Hajkowicz et al. [53], the discrete method techniques are those that have a finite number of alternatives, a set of objectives and criteria by which the alternatives are to be judged and a method of ranking alternatives, based on howwell they satisfy the objectives and criteria.

As observed by Nijkamp et al. [23], discrete methods can be further categorized into two groups namely weighting methods and ranking methods These categories can be further subdivided into qualitative, quantitative, and mixed methods. Only ordinal performance measures are used in. qualitative methods. Based on the type of data available, different decision rules are applied in mixed qualitative and quantitative methods. All data are expressed in cardinal or ratio measurements in quantitative methods [53].</td></tr>
<tr><td>Based on determination of alternatives (selection problem and design problem)</td><td>Two major groups: Multi-objective decision making (MODM) and multi-attribute decision making (MADM) [54, 55]. Further, as mentioned by Pohelar and Ramachandran [16], there exist a number of methods in each of the mentioned approaches and every method has its own characteristics. Davood [49] compared the MADM and MODM methods and is presented in table 3.

Table 3: Comparison of MADM and MOMD[49]
<table>
<tr><th></th><th>MADM</th><th>MODM</th></tr>
<tr><td>Criteria</td><td>Attributes</td><td>Goals</td></tr>
<tr><td>Goal</td><td>Clear</td><td>Not clear</td></tr>
<tr><td>Attribute</td><td>Clear</td><td>Implicit</td></tr>
<tr><td>Limitations</td><td>Not clear</td><td>Clear</td></tr>
<tr><td>Options</td><td>Finite/clear</td><td>Infinite/unclear</td></tr>
<tr><td>Interactions with DM</td><td>Low</td><td>High</td></tr>
</table></td></tr>
<tr><td>Type of data usage</td><td>Greening and Bernow [56], classified MCDM methods as deterministic, stochastic and fuzzy including combinations of them keeping some of their major characteristics.</td></tr>
<tr><td>Belton and Stewart [21]</td><td>○Category – I Value measurement methods or optimization methods
○Category – II Outranking methods
○Category – III Goal, aspiration or reference level models</td></tr>
</table>

Hajkowicz et.al [53]	○ Category – 1 MC value functions or multi-attribute utility theory (MAUT) • MAUT requires specified weight and utility or scoring function for each decision criteria by one DM [57.] ○ Category – II: Outranking approaches that examine if one alternative outperforms another alternative • Preference Ranking Organization Method for Enrichment and Evaluation (PROMETHEE) [58] and Elimination EtCoixTraduisant la Realite (ELECTRE) [59] are two commonly known outranking methods. ○ Category – III: Distance to ideal point methods • Compromise Programming (CP), [60, 61] and Technique for Order Preference by Similarity to Identical Solution (TOPSIS) [62, 63] are two commonly known methods under this category. ○ Category – IV: Pairwise comparisons. • Analytical Hierarchy Process (AHP), developed by Saaty [64, 65] is the most widely applied pairwise comparison method. ○ Category - V: Fuzzy set analysis • Fuzzy set method deals with problems whose source of uncertainty is due to the absence of sharply defined criteria rather than the presence of randomness. An implementation framework was presented by Buckley [66] where each DM provides a fuzzy membership value for each alternative on each criterion. Chang and Wang [67] developed and applied the fuzziness idea in goal programming with fuzzy goals and fuzzy constraints. ○ Category – VI: Tailor methods. • A tailored method usually extends or adapts a fundamental methodology to a particular application.
Based on a number of answers [50, 51]	○ Category I-innumerable when the admissible answers are infinite ○ Category - II-numerable when admissible answers are finite
Carlsson and Fuller [68]	○ Major family – I the outranking approach and implemented in the ELECTRE and PROMETHEE methods. ○ Major family – II the value and utility theory approaches and then implemented in a number of methods; a special method in this family is the AHP. ○ Major family III - the largest group is the interactive multiple objective programming approach (MOLP) built around utility theory based trade-offs among objectives, with reference point techniques, ideal points, etc. ○ Major family – IV group decision and negotiation theory introduced new ways to work explicitly with group dynamics and with differences in knowledge, value systems and objectives among group members.
Based on the type of decision model by H. Polatidis et al. [69]	○ Category – I Outranking methods, such as the ELECTRE family [70, 71 and 72] the (PROMETHEE) I and II methods [73, 74], and Regime Method Analysis [23]. ○ Category –II Value or utility function-based methods, such as the MAUT [57]; the Simple Multi-Attribute Rated Technique (SMART) [75]; the AHP [76]; and the most elementary MC, the Simple Additive Weighting (SAW) or Weighted Sum Method (WSM). ○ Category – III Interactive - programming methods [77, 78 and 79]. ○ Category – IV Other methods like Novel Approach to Imprecise Assessment and Decision Environment (NAIADE) [80], Flag Model [81], Stochastic Multi objective Acceptability Analysis (SMAA) [82].
Zopounidis and Doumpos [83]	○ Category I -Multi-objective/goal programming ○ Category II - MAUT methods (AHP, MAUT, MACBETH etc.) ○ Category III-Outranking methods (ELECTRE, PROMETHEE, ORESTE etc.) ○ Category IV- Preference disaggregation methods UTilites Additives (UTA), UTilités Additives DIScriminantes (UTADIS), Multi-group Hierarchical Discrimination Method (MHDIS) ○ Category V-Rough set theory methods
Slowinski et al. [84] and	○ Theory – I Utility function. This theory includes methods synthesizing the

Greco et al. [85]	information in a unique parameter (also called performance aggregation based approaches) [57]. ○ Theory – II Outranking relation. This theory involves methods based on comparison between pairs of options to verify whether "alternative a is at least as good as alternative b" (also called preference aggregation based approaches) [86] ○ Theory – III Sets of decision rules. This theory originates from the artificial intelligence domain and it allows deriving a preference model through the use of classification or comparison of decision examples [87].
Guitoni and Martel [88]	○ Elementary methods: WSM, Lexicographic method, Conjunctive methods, Disjunctive method, Maximin method ○ Single synthesizing criterion: TOPSIS, multi-attribute value theory (MAVT), utility theory additive (UTA), SMART, MAUT, AHP, EVAMIX, Fuzzy weighted sum, Fuzzy maximin. ○ Outranking methods: ELECTRE, PROMETHEE, MELCHIOR; ORESTE; REGIME. ○ Mixed methods: QUALIFLEX, Fuzzy conjunctive/disjunctive method, Martel and Zaras method

5. Merits and Demerits of MCDM Methods and Application Potential in Infrastructure Projects

The table 4 provides a brief overview of the merits and demerits of commonly adopted MCDM methods with a focus on its application in infrastructure projects and SA of infrastructure.

Table 4: *MCDM methods - merits and demerits and potential applications in infrastructure*

MCDM method : SAW or WSM

○ **Merits:**

- In this method, as observed by Triantaphyllou et al. [46], by proportional linear transformation of the raw data, the relative order of magnitude of the standardized scores remains equal**.**
- For a single dimensional problem, SAW method is strong as cited by Gayatri et al. [89].
- According to Mark and Patrick [90], SAW method has an ability to compensate among criteria, has intuitive to DM and the calculation is simple does not require complex computer programs.

○ **Demerits:**

- SAW method pose difficulty in multi-dimensional problems as observed by Gayatri et al. [89].
- As observed by Mark and Patrick [90], the estimates revealed do not always reflect the real situation and the result obtained may not be logical.

○ **Some potential applications:**

- Raza et al. [91 compared different energy storage systems for assessing their sustainability.

MCDM method : Weighted product method (WPM)

○ **Merits:**

- As observed by Triantaphyllou et al. [46] in WPM, instead of the actual values, it can use relative ones.
- WPM eliminate any unit of measure and thus it can be used in single and multi-dimensional MCDM [89, 92].

○ **Demerits:**

- In WPM, no solution with equal weight of decision matrices [89].

○ **Some potential applications:**

- Mehdi et al. [93], analyzed the development of a solar collector structure.

MCDM method : AHP

○ **Merits:**

- As observed by Pohekar and Ramachandran [16], the AHP calculates the inconsistency index as a ratio of the DM's inconsistency and randomly generated index. This index is important for the DM to assure him/her that his/her judgments were consistent and that the final decision is made well.
- AHP advantage as identified by Papadopoulos and Konidari [36], is its applicability to the

weighting of fuzzy criteria, along with solid ones, through ratio scales and scoring by decomposing a problem or process in its components and combining them in a rational mode from the large, descending in regular steps, to the smaller, it is plausible to join via simple paired comparison judgments the lesser to the greater.

- AHP is appropriate for group decision matrix and handles MC. AHP doesn't involve complex mathematic. A certain value of consistency is allowed and it is easy to capture and convenient [89].
- AHP is easy to use, scalable, hierarchy structure can easily adjust to fit many sized problems and not data intensive as cited by Mark and Patrick [90].
- Martin Aruldoss et al. [92] observed that AHP is flexible, intuitive and checks inconsistencies. Since the problem is constructed into a hierarchical structure, the importance of each element becomes clear. No bias in decision making in AHP.
- As cited by Vargas [94], the success of the AHP theory is because of its simplicity and robustness.
- As pointed by Rohan [95], users generally find the pair wise comparison form of data input is straightforward and convenient. AHP supports group decision−making through consensus by calculating the geometric mean of the individual pair wise comparisons.
- AHP has ability to handle both quantitative and qualitative judgements according to Macharis et al. [96], while it employs a consistency test that can screen out inconsistent judgements, which makes the results reliable as observed by Kablan [97].

○ **Demerits:**

- As cited by Gayatri et al. [89], perfect consistency is very difficult in AHP and is time consuming with large numbers. Doesn't take into account the uncertainty.
- According to Mark and Patrick [90], weakness of AHP include: problems due to interdependence between criteria and alternatives; can lead to inconsistencies between judgment and ranking criteria; rank reversal.
- As cited by Rohan [95], with AHP, the decision problem is decomposed into a number of subsystems, within which and between which a substantial number of pair wise comparisons need to be completed. The number of pair wise comparisons to be made, may become very large (n (n−1)/2), and thus become a lengthy task.
- The artificial limitation of the use of the 9−point scale.
- According to Macharis et al. [96], sometimes, the DM might find difficult to distinguish among them and for example whether one alternative is 6 or 7 times more important than another. Number of pairwise comparisons to be made may become very large increasing significantly the uncertainty of the process.

○ **Some potential applications:**

- Stein [98], ranked various renewable energy (RE) and non-renewable electricity generation technologies.
- Elbarkouky et al. [99], prioritized damaged infrastructure facilities for developing countries.
- Mohsen et al. [100], Wang and Feng [102], Ramanathan and Ganesh [103] performed RE planning.
- Aras et al. [103] and Lee et al. [104] applied the techniques in the wind farm projects.
- Chatzimouratidis and Pilavachi [105], Nigim et al. [106], Pilavachi et al. [107] and Tzeng et al. [108] applied MCDM techniques in RE evaluation.
- Quaddus and Siddique [109] adopted sustainable development planning.

MCDM method : PROMETHEE

○ **Merits:**

- Trade-offs are avoided in this method and it does not provide structuring possibility.
- As cited by Gayatri et al. [89], PROMETHEE needs much less inputs.
- As all outranking methods, PROMETHEE can simultaneously deal with qualitative and quantitative criteria. Criteria scores can be expressed in their own units.
- According to Mark and Patrick [90], this method is easy to use and does not require assumption that criteria are proportionate.

○ **Demerits:**

- The partial ranking is forced into a complete ranking of the alternatives in this method and this may lead to the loss of data.
- The generalized criteria need to be defined which may be difficult to achieve by an inexperienced

use [89].
- PROMETHEE does not provide a clear method by which to assign weights as viewed by Mark and Patrick [90].
- As cited by Rohan [95], when a new alternative is introduced, PROMETHEE suffers from the rank reversal problem. The possibility to really structure a decision problem is not provided in the PROMETHEE. It may be difficult for the DM, in the case of many criteria and options, to obtain a clear view of the problem and to evaluate the results.

○ **Some potential applications:**

- Tsoutsos et al. [110], adopted MC methodology for sustainable energy planning on the island of Crete.
- Haralambopoulos and Polatidis [111] used MCDM methods for RE projects.
- Goumas et al. [112] analyzed geothermal projects.
- Goumas and Lygerou [113], did ranking of alternative energy exploitation projects.
- Mladineo et al. [114] conducted ranking of alternative locations for small scale hydro plants.
- Pohekar and Ramachandran [115] performed evaluation of cooking energy alternatives for promoting parabolic solar cooker in India.
- Oberschmidt et al. [116] used for assessing energy technologies.

MCDM method : ELECTRE

○ **Merits:**

- As cited by Mark and Patrick [90], the method takes uncertainty and vagueness into account.
- As observed by Martin Aruldoss et al. [92], outranking is used in this method.
- As pointed by Rohan [95], ELECTRE allows using fuzzy analysis because thresholds of indifference and preference, accepts qualitative and quantitative criteria.

○ **Demerits:**

- As observed by Mark and Patrick [90], its process and outcome can be difficult to explain in layman’s terms; outranking causes the strengths and weaknesses of the alternatives to not be directly identified.
- The method is time consuming is difficult to understand, because of the principles used in determining the concordance and discordance matrices. Thresholds can be calculated from these metrics, but are often established according to DM opinion which translates into subjectivity as cited by Rohan [95].

○ **Some potential applications:**

- Optimization of decentralized/ isolated energy systems was performed by Papadopoulos and Karagiannidis, Oberschmidt J et al. [117].
- Haurant et al. [118] utilized the techniques for, photovoltaic plants on farming fields on Corsica island.
- Beccali et al. [119], did ranking of energy planning at regional level for the diffusion of RE technology.
- Georgopoulou et al. [120] utilized MCDM methods for RE option.
- The impacts of energy alternatives was conducted by Siskos and Hubert [121].

MCDM method : TOPSIS

○ **Merits:**

- As cited by Mark and Patrick [90], TOPSIS has a simple process and easy to use and program. The number of steps remains the same regardless of the number of attributes.
- As pointed by Rohan [95], fairly intuitive physical meaning based on consideration of distances from ideal solutions. It takes input as any number of criteria and attributes.

○ **Demerits:**

- As observed by Mark and Patrick [90], its use of Euclidean distance does not consider the correlation of attributes and difficult to weight and keep consistency of judgment.
- TOPSIS in its standard form is deterministic and does not consider uncertainty in weightings. The method is easy and can give unreliable results as pointed by Rohan [95].

○ **Some potential applications:**

- Anjali et al. [122], adopted MCDM methods for location planning for urban distribution centers under uncertainty.

MCDM method : VlseKriterijuskaOptimizacija I KomoromisnoResenje (VIKOR)

- **Merits:**
  - As observed by Tzeng [108], the best alternative is preferred in this method by maximizing utility group and minimizing regret group. The ratio of positive and negative ideal solution are calculated in VIKOR method, thus proposing a compromise solution with an advantage rate.
- **Demerits:**
  - As pointed by Rohan [95], the performance rating is quantified in this method as crisp values. The crisp data are inadequate in many circumstances to model real-life situation. Further, in case of conflicting situations or criteria, a DM must also consider imprecise or ambiguous data as cited by Gayatri et al. [89].
- **Some potential applications of MCDM:**
  - Abrishamchi et al. [61] performed case study of application of MCDM methods for urban water supply.
  - Ansari et al. [123] performed selection of distributed electricity generation through RE in India.
  - Bashiri et al. [124] used MCDM methods for transportation sector.
  - Optimal infrastructure selection to boost regional sustainable economy was conducted by Martin et al. [125].
  - Life cycle sustainabilityty studies was conducted by Ren et al. [126]

MCDM method : MAUT

- **Merits:**
  - According to Mark and Patrick [90], the MAUT method takes into account the uncertainty and can incorporate preferences.
- **Demerits:**
  - The method needs a lot of input and the preferences need to be precise as observed by Mark and Patrick [90].
- **Some potential applications of MCDM:**
  - Golabi et al. [127] selected a portfolio of solar energy projects.
  - Jones et al. [128] used MCDM methods for the study of UK energy policy.

MCDM method : Fuzzy set analysis

- **Merits:**
  - As observed by Mark and Patrick [90], the method allows for imprecise input and takes into account insufficient information.
- **Demerits:**
  - The method require numerous simulations before use and is difficult to develop as cited by Mark and Patrick [90].
- **Some potential applications:**
  - Siskos and Hubert [121] studied the impacts of energy alternatives.
  - Skikos and Machias [129] used MCDM approach for evaluation of wind sites.
  - Mamlook et al. [130] evaluated electric power generation systems.
  - For performance evaluation of solar system in Jordan, Mamlook et al [131] utilized MCDM approach.
  - CaiYP et al. [132] planned community-scale RE management systems.
  - Kahraman et al. [133] performed a comparative analysis for selection among RE alternatives.
  - The selection of location for placing the watershed was performed by Chu [134].
  - Assessment of health-care waste treatment alternatives was conducted by Mehtap et al. [135].

MCDM method : SMART

- **Merits:**

- The method is simple, allows for any type of weight assignment technique and less effort by DM as observed by Mark and Patrick [90].

○ **Demerits:**

- As cited by Mark and Patrick [90], considering the framework involved, the procedure may not be convenient

○ **Some potential applications:**

- Stewart and Scott [136] performed a scenario-based framework for MCDM methods in water resources planning.
- Vegetation and the supply of water analysis was carried out by Joubert et al. [137].

6. Conclusion

Interdisciplinary methodical approach encompassing social, environmental, economic, and engineering sciences are required for analyzing and examining the SA of infrastructure systems [34]. Being hard and complex process, SA necessitates a holistic assessment of the diverse settings and environment under which infrastructure systems operate. The multidimensional, conflicting and uncertain properties of decisions can be effectively addressed through MC tools. Infrastructure planning, development and management using MCDM methods has drawn the attention of DM for a long time. Increasing complex problems of infrastructure systems require comprehensive solutions and due to flexibility and the possibility of facilitating the dialogue between stakeholders, analysts and scientists, the MCDM methods are viewed as an appropriate set of methods towards infrastructure planning and SA of infrastructure projects. The application of MCDM methods in SA of infrastructure projects are steadily gaining popularity and several MCDM methods including their combinations are extensively practiced across diverse infrastructure sub sectors like water, waste management, RE, transportation, environmental evaluation, sustainability evaluation, life cycle SA etc. Each MCDM method has its strengths as per its usage, number of inputs required, complexity, and capability to handle quantitative and qualitative data. Therefore, MC tools should be used in cognizance with the requirements of the infrastructure project.

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