Review and Selection of Multi-criteria Decision Analysis (MCDA) Technique for Sustainability Assessment

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Abstract Multi-Criteria Decision Analysis (MCDA) follows a transparent and structured process for a decision making by considering multiple criteria, whereas sustainability assessment requires to manage and assess multidimensional indicators. Hence, the procedures of MCDA can be useful to assess sustainability. In this chapter, to understand the applicability of MCDA for sustainability assessment the concept, procedure, strength and weakness, and classification of MCDA as well as suitability and the steps require to follow in using MCDA technique for sustainability assessment are discussed. Two case studies of the application of MCDA techniques for sustainability assessment are shown and their advantage and disadvantage are presented with a direction of further research.

Keywords MCDA · Multi-criteria · Sustainability assessment · MAUT · PROMETHE

1 Introduction

Multi-Criteria Decision Analysis (MCDA) is a technique to assist with decision making in the presence of differing criteria [57]. According to Kenney [32], it is an approach that applies common logic to make decisions in the presence of multiple criteria. MCDA techniques are applied to real-world problems related to various socio-economic sectors, such as the water sector, agriculture, tourism, energy, environment, biodiversity and forestry [59].

MCDA is a well-known area of Decision Theory [61] in which decisions are made to reach the final objective under a set of decision-making options [21, 58]. Hipel [28]

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Table 1 Comparison of MPSC and SPMC Decision Making

MPSC	SPMC
A set of decision makers, $\{DM_{i,}\ i = 1, 2, \ldots, n\}$	A set of criteria, $\{C_i\ i = 1,2, \ldots, n\}$
A set of states, $\{U_j, j = 1, 2, \ldots, m\}$	A set of alternatives, $\{A_j\ j = 1,2, \ldots, m\}$
A set of preferences, $\{P_{ij}\ j = 1,2, \ldots, m\}$, for $DM_{i,}\ i = 1, 2, \ldots, n$, over the set of states, $\{U_{j,}\ j = 1, 2, \ldots, m\}$	A set of evaluations, $\{V_{ij,}\ j = 1, 2, \ldots, m\}$, for C_i, $i = 1, 2, \ldots, n$, over the set of alternatives, $\{A_{j,}\ j = 1, 2, \ldots, m\}$

Source Adapted from (Hipel et al. [27]:1186) with permission

divided decision problems into Multiple Participant-Single Criterion (MPSC) and Single Participant-Multiple Criteria (SPMC) types. Most problems in the real-world context can be categorized as multi-criteria decision problems, as a single criterion is judged to be unsatisfactory to help in decision making for complex real-world problems [40]. A comparison of MPSC and SPMC is presented in Table 1.

Doumpos and Zopounidis [17] divided decision-making problems into two groups: discrete and continuous. A discrete set of alternatives is associated with discrete problems in which each alternative is described in terms of attributes. During decision making, these attributes work as evaluation criteria. In continuous problems, infinite alternatives are possible. In decision making, one can only outline the feasible region where the alternatives remain [17].

The process that is followed in making a final decision by applying MCDA is called a problematic. In a discrete decision-making challenge, there are four main kinds of problematics: (i) choice, (ii) sorting, (iii) ranking and (ii) description [17]. See Fig. 1.

MCDA has become a specialized subject in the field of Operations Research (OR), which was initiated by the British Royal Air Force around 1937 to study the network of radar operators and how the judgments they made influenced the results of their radar operations [63]. MCDA is also one of the prominent fields of Management Science [34]. MCDA techniques have been exhaustively described and reviewed by many authors (e.g., [4, 17, 24]. The detailed theoretical underpinnings of different MCDA techniques can be found in Belton and Stewart [4].

1.1 MCDA Procedures

At present, many software programs have been developed to carry out MCDA analysis. In short, the MCDA technique usually takes a four-step procedure. The objectives are defined in the first step. In the second step, the decision criteria are selected based on the objectives to specify the alternative decisions. After deciding on the criteria and the alternatives, in the third step, the units of the criteria are normalized and weights are given to the criteria to reflect their relative value in decision making. The last step is to select and apply a mathematical algorithm to rank each alternative [25]. Table 2 gives more detail about each step.

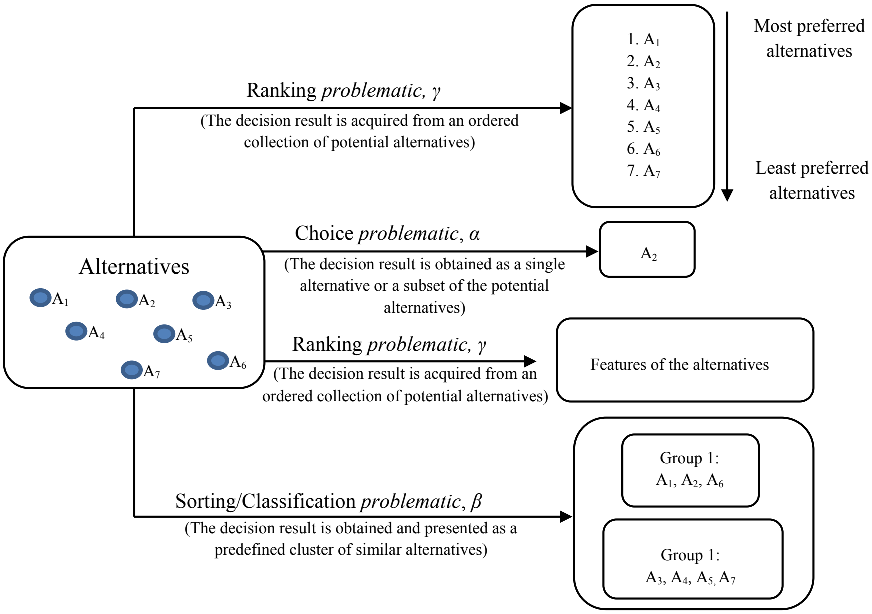

Fig. 1 Decision-making problematics with definitions. *Source* Adapted and modified from [17] with permission

Table 2 Steps in MCDA techniques

Step One: Structuring the decision problem In structuring the decision problem, stakeholders identify the issue about which they want to make a decision. Based on the decision problem, the objectives and the criteria are identified and verified
Step Two: Formulating criteria preferences and modeling To include the preferences of the criteria in decision making, the preference functions are identified. The preference functions can be either proportionate score or utility value
Step Three: Combining alternate assessments (preferences) The MCDA technique is used to evaluate and compare the alternatives based on the requirements of the decision. The selected criteria for decision making are weighted according to the relative importance of stakeholders or objectives of the decision making. Either linear or additive functions are applied for weighting; the weighting can be subjective, objective or a combination of both. The final decision is made based on the best score generated from the weighted average
Step Four: Recommendations After making a decision based on the best score, the recommendations are put forward and guidelines are developed for further examination

Source Based on Vansnick [64], Sadok et al. [55], Wang et al. [67], EAF [18], Talukder [58]

1.2 Strengths and Weaknesses of MCDA

Belton and Stewart [4] presented the strengths and weaknesses of various MCDA techniques. MCDA leads to sensible, justifiable and explainable decisions. It helps to rank different options and find the most desirable outcome [16]. MCDA techniques are capable of considering a broad variety of conflicting but associated criteria [4, 70]. The strengths and weaknesses of MCDA from expert and stakeholder/participant perspectives are presented in Table 3.

1.3 Classification of MCDA Techniques

MCDA techniques come from various "axiomatic groups" and "schools of thought" (Herath and Prato [25]:5) and have been classified in a number of ways [8, 9, 17, 23, 25, 42]. According to Hajkowicz et al. [23], MCDA techniques are either continuous or discrete. Commonly, MCDA techniques are classified into (i) Multi-Objective Decision Making (MODM) and (ii) Multi-Attribute Decision Making (MADM). MODM deals with the decision problems in a continuous decision space, whereas MADM is suitable when all objectives of a decision problem need to be satisfied. In the literature, experts have classified MCDA techniques into many groups. Examples of the classification schemes of MCDA techniques by different experts are presented in Table 4.

1.4 Why Choose MCDA for Sustainability Assessment?

Sustainability assessment must integrate issues of economic, social and environmental interaction into decision making [14, 20, 58], and conflicting dimensions of economic, environmental, social, technical, human and physical issues are involved. Sustainability assessment aims to improve decision making in complex projects by involving the public and experts [19]. This is why MCDA is increasingly being applied to issues related to sustainability [25, 13, 58].

The assessment of sustainability is the key to ensuring sustainable development. For sustainability assessment of any development activities or any socioeconomic system, various information as well as stakeholders' perspectives must be considered and integrated. Therefore, the assessment of sustainability can be considered a decision-making problem [55, 58] that requires a technique that is capable of integrating data from the three pillars of sustainability, following a transparent process, doing robust analysis and taking into consideration stakeholders' opinions of sustainability criteria. MCDA techniques have this capacity as they follow a transparent

Table 3 Strengths and weaknesses of MCDA techniques

Strengths of MCDA techniques according to expert perspectives
• In the process of MCDA, the decision problems are broken down into segments of alternatives, criteria, weights and preferences.[1,2,4]
• MCDA helps to communicate the reasons for decisions in a logical and structured way[1]
• MCDA follows a transparent structural deliberation procedure.[1]
• MCDA can combine facts and social values.[1,6]
• Stakeholders can be involved in the decision making by assigning relative values to the criteria.[1,6]
• Stakeholders can take into consideration individuals' preferences about weights for the criteria.[1,3,6]
Weaknesses of MCDA techniques according to expert perspectives
• For many criteria, quantitative information is difficult to get.[1,2]
• It may be difficult to develop a scale for assessment purposes.[1]
• It is not clear whether the trade-offs of the criteria are considered in mathematical procedures.[1]
• It is assumed that preferences for the criteria are not dependent on each other.[1]
• There may be double counting in case of redundant or non-exhaustive criteria.[1]
• MCDA analysts cannot take part as decision makers as the may make biased decisions.[1,2]
• Resource constraints often restrain stakeholders' involvement in the MCDA procedures.[1,2]
Strengths of MCDA techniques according to stakeholder/participant perspectives
• MCDA allows the stakeholders to understand different points of view in decision making.[1, 2,3,5,6]
• MCDA helps the decision group and stakeholders to learn and move forward.[1,2,6]
• Stakeholders can concentrate on preferences and weights of the criteria rather than the final result.[1,2,6]
• MCDA considers both collective and individual voices for a decision.[1]
Weaknesses of MCDA techniques according to stakeholder/participant perspectives
• Complex procedures of MCDA may cause problems or difficulties because stakeholders may not understand them.[1,2]
• Analysts may focus on things that are not of interest to the stakeholders.[1]
• Stakeholders may not understand the technicalities of MCDA.[1]
• Experts may miss important criteria that are known by the stakeholders.[1]

Source Based on [1]Batstone et al. [2]:7–9, [2]Diakoulaki and Grafakos [15]; [3]Omann [48]; [4]Hobbs and Horn [29]; [5]Lahdelma et al. [36]; [6]Linkov et al. [38], Talukder [58]

structural process, are able to break down complex decision problems, can trigger discussion among stakeholders, can incorporate stakeholders' opinions on criteria and their weight and present the result visually [2, 39, 40, 58, 62, 69]. Therefore, MCDA techniques are applicable for sustainability assessment.

Table 4 Classification schemes of MCDA techniques

Polatidis et al. [50] classified MCDA techniques into three groups:
(i) Outranking group. This group includes
(a) Elimination Et Choix Traduisant la Realité (ELECTRE[1]) family
(b) Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE[2]) I and II methods
(c) Regime Method Analysis[3]
(ii) Value or utility function-based group. This group includes
(a) Multi-Attribute Utility Theory (MAUT[4])
(b) Simple Multi-Attribute Rated Technique (SMART[5])
(c) Analytical Hierarchy Process (AHP[6])
(d) Simple Additive Weighting (SAW[7])
(iii) Other. This group includes
(a) Novel Approach to Imprecise Assessment and Decision Environment (NAIADE[8])
(b) Flag Model[9]
(c) Stochastic Multi-objective Acceptability Analysis (SMAA[10])
Hajkowicz and Collins [22] classified MCDA techniques into six groups
(i) Multi-criteria value functions such as MAUT
(ii) Outranking approaches such as PROMETHEE and ELECTRE
(iii) Distance to ideal point methods such as Compromise Programming (CP[11]) and TOPSIS[12]
(iv) Pairwise comparisons such as AHP
(v) Fuzzy set analysis[13]
(vi) Tailored methods[14]
Browne et al. [8] classified MCDA techniques into three groups
(i) General utility analysis such as AHP
(ii) Outranking methodologies such as PROMETHEE and ELECTRE
(iii) Social multi-criteria evaluation (SMCE) such as NAIADE

[1]For details, see Roy and Vincke [52], Vincke [65]
[2]For details, see Brans and Vincke [6]
[3]For details, see Nijkamp et al. [47]
[4]For details, see Keeney and Raiffa [31]
[5]For details, see von Winterfeldt and Edwards [68]
[6]For details, see Saaty [54, 53]
[7]For details, see Polatidis et al. [50]
[8]For details, see Munda [43]
[9]For details, see Nijkamp and Vreeker [46]
[10]For details, see Lahdelma et al. [35]
[11]For details, see Abrishamchi et al. [1]
[12]For details, see Lai et al. [37]
[13]For details, see Hajkowicz and Collins [22]
[14]For details, see [56]

1.5 Selection of MCDA Techniques for Sustainability Assessment

All MCDA techniques come with pros and cons in terms of their ability to handle diverse information and weighting of the criteria. Specific techniques are suitable for specific situations [58]. For example, MAUT has the advantage of obtaining robust results and PROMETHEE has the advantage in ranking [11, 58]. Here, examples are presented of using MAUT and PROMETHEE to assess agricultural sustainability in light of these methods' capacity. These two methods were selected on the basis of prerequisites (see Table 5) of the nature and scope of the study, available information, selected criteria and stakeholder opinion. Brief descriptions of MAUT and PROMETHEE are given below in Sects. 6.1 and 6.2.

Table 5 Prerequisites of MCDA techniques for sustainability assessment

Prerequisites of MCDA techniques	Justification
Weights elicitation	Provide preference information among the sustainability criteria.
Critical threshold values	Operationalize the assimilative capacity of sustainability in terms of environmental, economic and social aspects
Comparability	Perform an integrated comparison among the agricultural systems
Qualitative and quantitative information	Handle the mixed information usually associated with agricultural sustainability assessment
Rigidity	Give robust results
Stakeholder involvement	Include a diverse audience of stakeholders
Graphical representation	Render the outcome understandable
Ease of use	Familiarize the stakeholders and assessors with the assessment process
Sensitivity analysis	Enhance the transparency of the procedure
Variety of alternatives	Incorporate all possible courses of action
Large number of evaluation criteria	Embrace all aspects of agricultural sustainability
Consensus seeking procedures	Reach a global compromise
Incorporation of intangible aspects	Consider "hidden" dimensions of the assessment
Incommensurability	Keep the decision criteria in their original units and provide a better composition of the issue
Treatment of uncertainty	Explicitly treat imperfect data (uncertain, imprecise, missing, erroneous, etc.)
Partial compensation	Operationalize a strong concept of sustainability
Hierarchy of scale	Decrease ambiguities and provide for explicit consistency
Concrete meaning for parameters used	Improve the reliability of the process
Learning dimension	Acknowledge and accept new information revealed during the evolution of the procedure
Temporal aspects	Consider the urgency of the situation and clarify long- and short-term concerns

Source Adapted and modified from [50] with permission

1.6 Multi-attribute Utility Theory (MAUT)

MAUT is widely applied in multi-criteria-based assessment [11] and is an important theory behind the procedure of MCDA [44]. In MAUT, the criteria can be assessed by integrating criterion values and relative or trade-off weighting [11]. A normalization process is applied to bring the criteria into a common dimension that is without unit [51, 58]. All the values of all the alternative criteria are combined and a single value score is generated, which enables comparison of the multiple preferences [12, 58]. Attributes of all criteria are used to evaluate the criteria. The relative importance of each attribute is reflected by weighting [45, 58]. MAUT can be applied to assess sustainability using the following formula:

$$v(x) = \sum_{i=1}^{n} w_i v_i(x)$$

where

$v(x)$ is equivalent to the overall value of an alternative
n is equivalent to the number of criteria,
w_i is equivalent to the weight of criteria i, and
$v_i(x)$ is equivalent to the rating of an alternative x with respect to a criteria i.

Here, the $v_i(x)$ is normalized in a range of 0–1 and the relative importance (w_i) is given to the attribute i. Relative importance is assigned for each attribute/criterion by the values of worst to best [30]. MAUT structures the problem (value tree), making a reference model and finally conducting analyses [41].

1.7 Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE)

PROMETHEE, proposed by Brans et al. [5], is an outranking technique which is applicable for doing pair-wise comparison of the criteria to make a decision [66]. By considering quantitative and qualitative information of the criteria, it can generate a full ranking of the decisions from best to worst. This method is suitable where stakeholders' participation is required for decision making Hermans et al. [26, 33, 62]. Weighting of the criteria is an important aspect of PROMETHEE and depends on the decision makers' expertise. In this method, the preference function can be any of (i) strict, (ii) threshold, (iii) linear with threshold, (iv) linear over range and (v) stair step (level criterion). A narrative of these preference functions can be found in USACE and CDM [63]. The preference function values range from 0 to 1 [7]. The results of PROMETHEE can be visualised using Geometric Analysis for Interactive Aid (GAIA) software [4]. Figure 2 shows the steps for applying PROMETHEE to assess sustainability.

Steps	Description	Mathematical interpretation	Symbols
1	Problem formulation: Identify alternatives and criteria of the alternatives	(a, b), f_j	(a, b) denotes alternatives, f_j denotes criterion
2	Determination of deviations based on pair-wise comparison	$d_j(a, b) = f_j(a) - f_j(b)$	$d_j(a, b)$ denotes the difference between the evaluations of alternatives a and b on criterion f_j
3	Application of the preference function	$P_j(a, b) = f_j[d_j(a, b)], j = 1, \ldots., k$	$P_j(a, b)$ denotes the preference of alternative a with regard to alternative b on each criterion as a function of $d_j(a, b)$
4	Calculation of an overall or global performance index	$\forall\, a, b \in A$ $\pi(a, b) = \sum_{j}^{k} p_j(a, b) w_j$	$\pi(a, b)$of a over b (from 0 to 1) is defined as the weighted sum $P_j(a, b)$ for each criterion, and w_j is the weight associated with jth criteria
5	Calculation of positive and negative outranking flow	$\emptyset^{+}(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a, x)$ $\emptyset^{-}(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a, x)$	$\emptyset^{+}$(a) denotes the positive outranking flow for each alternative, whereas $\emptyset^{-}$(a) denotes the negative outranking flow for each alternative
6	Calculation of net outranking flow [Complete ranking]	$\emptyset(a) = \emptyset^{+}(a) - \emptyset^{-}(a)$	$\emptyset$(a) denotes the net outranking flow for each alternative
7	Sensitivity analysis of the weighting of the criteria	*Using GAIA* platform	Final ranking and conclusion

Fig. 2 Steps in PROMETHEE analysis. *Source* Behzadian et al. [3], PROMETHEE 1.4 Manual [49], Talukder and Hipel [60] with permission

Table 6 Comparison of MAUT and PROMETHEE

Comparison criteria	MAUT	PROMETHEE
Weighting	Many ways such as direct, swinging weights	When there are many criteria weighting is difficult, but for a small number of criteria weighting is possible
Threshold values	Determining threshold value for the criteria is not possible	Determining threshold value is possible
Compensability	Allow for full complete compensability of the criteria	Limited compensability
Capacity to handle quantitative and qualitative data	Can handle both quantitative and qualitative data	Can only handle qualitative data
Robustness	Preference ranks cannot be reversed	If the non-optimal alternative is considered, then rank reversals may take place
Decision making in a group	Allows group decision making as combination is relatively simple	Requires outside combination
Graphic Representation	Possible	Possible
User friendly	Simple to comprehend	Simple to comprehend
Sensitivity analysis	Possible	Possible
No. of alternatives	In theory no constraints	In theory no constraints
No. of assessment criteria	No limitation, but many criteria can be difficult to manage	Can support a large number of criteria
Incommensurability	Does not allow: all types of data must be normalized	Partially feasible
Uncertainty treatment	Possible	Possible
Hierarchy of scales	Possible	Not possible

Source Based on De Monti et al. [13], Mendoza and Martins [42], Polatidis et al. [50], Munda [44], Buchholz et al. [10], Cinelli et al. [11], Talukder [58]

Both MAUT and PROMETHEE offer advantages and disadvantages depending on the decision-making criteria. A comparison of both techniques is presented in Table 6.

1.8 Application of MAUT and PROMETHEE for Agricultural Sustainability Assessment

Examples of the application of MAUT and PROMETHEE for agricultural sustainability assessment are drawn from Talukder et al. [57] and Talukder and Hipel [60]. In both papers, the agricultural sustainability of five types of agricultural systems

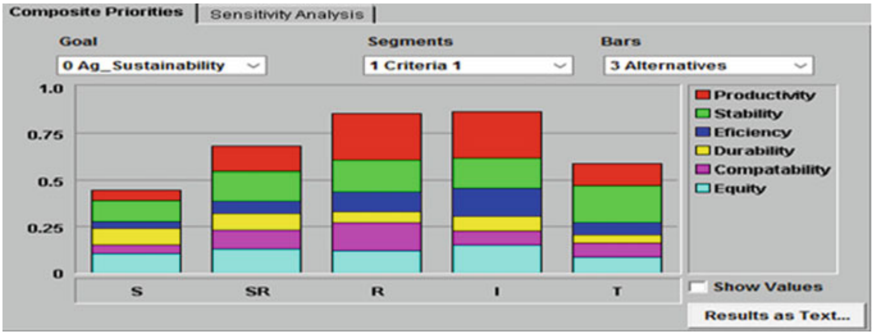

Fig. 3 Overall ranking of sustainability of agricultural systems using MAUT [57], with permission

is assessed: Bagda (shrimp)-based agricultural systems (S); Bagda-rice-based agricultural systems (SR); Rice-based agricultural systems (R); Galda (shrimp)-rice-vegetable-based integrated agricultural systems (I) and Traditional practices-based agricultural systems (T). Fifteen composite indicators (CI) drawn from six sustainability categories were used in the assessment: (i) Productivity (CI: Productivity); (ii) Stability (CI: Landscape stability, Soil health/stability, Water quality); (iii) Efficiency (CI: Monetary efficiency, Energy efficiency); (iv) Durability (CI: Resistance to pest stress, Resistance to economic stress, Resistance to climate change); (v) Compatibility (CI: Human compatibility, Biophysical compatibility); and (vi) Equity (CI: Education, Economic, Health, Gender). Overall assessment results of the two MCDA techniques are presented in Figs. 3 and 4.

A comparison of the merits and drawbacks associated with MAUT and PROMETHEE shows that both techniques are capable of assessing agricultural sustainability by considering a variety of data in different forms. Both techniques have the capacity to consider stakeholders' opinion and values in sustainability assessment to generate complementary information. The capacity to consider stakeholder opinion and weighting for criteria for sustainability assessment is an advantage of both techniques since most sustainability assessment techniques cannot take stakeholder perspectives into consideration [58].

Overall, both case studies feature MAUT and PROMETHEE as useful, systematic, analytical tools for sustainability assessment. The step-by-step methodologies proved to be useful and suitable for assessing and ranking sustainability. MAUT can break down complex problems, structure them in a transparent way, enable participation of the stakeholders and create a space for discussion, incorporate stakeholders' perspectives and present results visually and structurally [2, 39, 58]. Though it has some drawbacks, PROMETHEE's holistic approach makes it useful to assess and compare the aspects of sustainability [58].

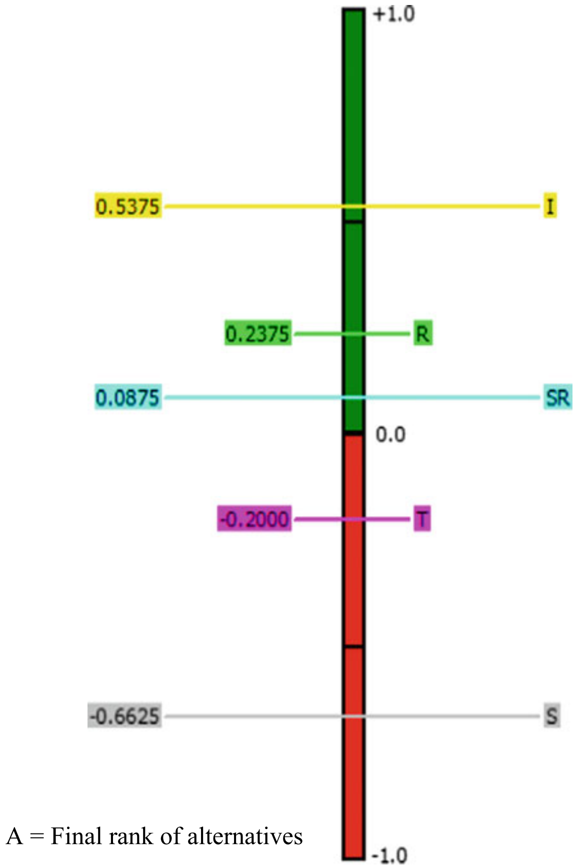

Fig. 4 Overall ranking of sustainability of agricultural systems using PROMETHEE [60]

2 Conclusion

The cases in Sect. 6.1 demonstrate the applicability of MCDA techniques for sustainability assessment. More research is required to make the MCDA technique a commonly used approach to assess sustainability in different sectors. However, MCDA requires substantial mathematical knowledge for computation, which may make it less user-friendly. These challenges should motivate researchers to refine these techniques to assess sustainability.

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References

1. Abrishamchi A, Ebrahimian A, Tajrishi M, Mariño MA (2005) Case study: application of multicriteria decision making to urban water supply. J Water Resour Plann Manage 131(4):326–335
2. Batstone CJ, Baines JM, Goodwin E, Morgan B, Cnard T (2010) Methods for developing sustainability indictor systems for freshwater and estuarine receiving bodies of urban strom water. Prepared for NIWA. Cawthron Report No. 1874. 55 p. Plus appendices. https://niwa.co.nz/sites/niwa.co.nz/files/upsw3.pdf
3. Behzadian M, Kazemzadeh RB, Albadvi A, Aghdasi M (2010) PROMETHEE: a comprehensive literature review on methodologies and applications. Eur J Oper Res 200(1):198–215
4. Belton V, Stewart T (2002). Multiple criteria decision analysis: an integrated approach. Springer Science & Business Media
5. Brans JP, Vincke P, Mareschal B (1986) How to select and how to rank projects: the PROMETHEE method. Eur J Oper Res 24(2):228–238
6. Brans JP, Vincke P (1985) Preference ranking organization method for enrichment evaluations. Manage Sci 31(6)
7. Brinkhoff P (2011) Multi-criteria analysis for assessing sustainability of remedial actions applications in contaminated land development a literature review. Department of Civil and Environmental Engineering. Chalmers University of Technology. Göteborg, Sweden. http://publications.lib.chalmers.se/records/fulltext/150656.pdf
8. Browne D, O'Regan B, Moles R (2010) Use of multi-criteria decision analysis to explore alternative domestic energy and electricity policy scenarios in an Irish city-region. Energy 35(2):518–528
9. Brunner N, Starkl M (2004) Decision aid systems for evaluating sustainability: a critical survey. Environ Impact Assess Rev 24(4):441–469
10. Buchholz T, Rametsteiner E, Volk TA, Luzadis VA (2009) Multi criteria analysis for bioenergy systems assessments. Energy Policy 37(2):484–495
11. Cinelli M, Coles SR, Kirwan K (2014) Analysis of the potentials of multi criteria decision analysis methods to conduct sustainability assessment. Ecol Ind 46:138–148
12. Convertino M, Baker KM, Vogel JT, Lu C, Suedel B, Linkov I (2013) Multi-criteria decision analysis to select metrics for design and monitoring of sustainable ecosystem restorations. Ecol Ind 26:76–86
13. De Montis A, De Toro P, Droste-Franke B, Omann I, Stagl S (2000) Criteria for quality assessment of MCDA methods. In: 3rd Biennial conference of the European society for ecological economics, Vienna, pp 3–6. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.470.2796&rep=rep1&type=pdf
14. Devuyst D (2000) Linking impact assessment and sustainable development at the local level: the introduction of sustainability assessment systems. Sustain Dev 8(2):67–78
15. Diakoulaki D, Grafakos S (2004) Multicriteria analysis. In: European Commission ExternE—externalities of energy: extension of accounting framework and policy applications. National Technical University Athens, Greece. http://www.externe.info/externe_2006/expolwp4.pdf
16. Dodgson J, Spackman S, Pearman M, Phillips LD (2009) Multi-criteria analysis: a manual; department for communities and local Government, London, UK. http://eprints.lse.ac.uk/12761/1/Multi-criteria_Analysis.pdf
17. Doumpos M, Zopounidis C (2002) Multicriteria decision aid classification methods, vol 73. Springer Science & Business Media
18. EAF (EAF planning and implementation tools) (2011) Multi-criteria decision analysis (MCDA) also known as Multi-objective decision analysis (MODA). EAF Tool fact sheets. Text by EAF Net Team. Rome. http://www.fao.org/fishery/eaf-net/eaftool/eaf_tool_31/en. Accessed 31 Jan 2014
19. GWA (Government of Western Australia) (2004) Leading by example: the sustainability code of practice for government agencies and resource guide for implementation, Department of the Premier and Cabinet: Perth. www.sustainability.dpc.wa.gov.au/publications

20. Gibson B, Hassan S, Tansey J (2013) Sustainability assessment: criteria and processes. Routledge
21. Haddad M, Sanders D (2018) Selection of discrete multiple criteria decision making methods in the presence of risk and uncertainty. Oper Res Perspect 5:357–370
22. Hajkowicz S, Collins K (2007) A review of multiple criteria analysis for water resource planning and management. Water Resour Manage 21(9):1553–1566
23. Hajkowicz SA, McDonald GT, Smith PN (2000) An evaluation of multiple objective decision support weighting techniques in natural resource management. J Environ Plann Manage 43(4):505–518
24. Hayashi K (2000) Multicriteria analysis for agricultural resource management: a critical survey and future perspectives. Eur J Oper Res 122(2):486–500
25. Herath G, Prato T (2006) Role of multi-criteria decesion making in natual resource management. In: Herath G, Prato T (eds) Using multi-criteria decision analysis in natural resource management. Ashgate, England
26. Hermans C, Erickson J, Noordewier T, Sheldon A, Kline M (2007) Collaborative environmental planning in river management: an application of multicriteria decision analysis in the white river watershed in vermont. J Environ Manage 84(4):534–546
27. Hipel KW, Radford KJ, Fang L (1993) Multiple participant-multiple criteria decision making. IEEE Trans Syst Man Cybern 23(4):1184–1189
28. Hipel KH (2013) Multiple participant multiple criteria decisions making. SYDE 433. Fall 2013. Courseware. Waterloo University, Canada
29. Hobbs BF, Horn GT (1997) Building public confidence in energy planning: a multimethod MCDM approach to demand-side planning at BC gas. Energy Policy 25(3):357–375
30. Huang IB, Keisler J, Linkov I (2011) Multi-criteria decision analysis in environmental sciences: ten years of applications and trends. Sci Total Environ 409(19):3578–3594
31. Keeney RL, Raiffa H (1993) Decisions with multiple objectives: preferences and value tradeoffs. Cambridge University Press
32. Keeney RL (1982) Decision analysis: an overview. Oper Res 30(5):803–838
33. Kowalski K, Stagl S, Madlener R, Omann I (2009) Sustainable energy futures: methodological challenges in combining scenarios and participatory multi-criteria analysis. Eur J Oper Res 197(3):1063–1074
34. Köksalan MM, Wallenius J, Zionts S (2011) Multiple criteria decision making: from early history to the 21st century. World Scientific
35. Lahdelma R, Hokkanen J, Salminen P (1998) SMAA-stochastic multiobjective acceptability analysis. Eur J Oper Res 106(1):137–143
36. Lahdelma R, Salminen P, Hokkanen J (2000) Using multicriteria methods in environmental planning and management. Environ Manage 26(6):595–605
37. Lai YJ, Liu TY, Hwang CL (1994) Topsis for MODM. Eur J Oper Res 76(3):486–500
38. Linkov I, Satterstrom FK, Kiker G, Batchelor C, Bridges T, Ferguson E (2006) From comparative risk assessment to multi-criteria decision analysis and adaptive management: recent developments and applications. Environ Int 32(8):1072–1093
39. Linkov I, Moberg E (2011) Multi-criteria decision analysis: environmental applications and case studies. CRC Press
40. Løken E (2007) Use of multicriteria decision analysis methods for energy planning problems. Renew Sustain Energy Rev 11(7):1584–1595
41. Marttunen M, Hämäläinen RP (2008) The decision analysis interview approach in the collaborative management of a large regulated water course. Environ Manage 42(6):1026
42. Mendoza GA, Martins H (2006) Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. For Ecol Manage 230(1–3):1–22
43. Munda G (2006) A NAIADE based approach for sustainability benchmarking. Int J Environ Technol Manage 6(1–2):65–78
44. Munda G (2008) Social multi-criteria evaluation for a sustainable economy, vol 17. Springer, Berlin

45. Mustajoki J, Hämäläinen RP, Marttunen M (2004) Participatory multicriteria decision analysis with Web-HIPRE: a case of lake regulation policy. Environ Model Softw 19(6):537–547
46. Nijkamp P, Vreeker R (2000) Sustainability assessment of development scenarios: methodology and application to Thailand. Ecol Econ 33(1):7–27
47. Nijkamp P, Rietveld P, Voogd H (2013) Multicriteria evaluation in physical planning. Elsevier
48. Omann I (2000) How can multi-criteria decision analysis contribute to environmental policy making? A case study on macro-sustainability in Germany. In: Third international conference of the european society for ecological economics, pp 3–6. https://pdfs.semanticscholar.org/d920/0c9965001b2ee00ec024869a9c8dad5366f6.pdf
49. PROMETHEE 1.4 Manual (2013). http://www.promethee-gaia.net/visual-promethee.html
50. Polatidis H, Haralambopoulos DA, Munda G, Vreeker R (2006) Selecting an appropriate multi-criteria decision analysis technique for renewable energy planning. Energy Sour Part B 1(2):181–193
51. Renn O (2003) Social assessment of waste energy utilization scenarios. Energy 28(13):1345–1357
52. Roy B, Vincke P (1981) Multicriteria analysis: survey and new directions. Eur J Oper Res 8(3):207–218
53. Saaty RW (1987) The analytic hierarchy process—what it is and how it is used. Math Modell 9(3–5):161–176
54. Saaty TL (1986) Absolute and relative measurement with the AHP. The most livable cities in the United States. Socio-Econ Plann Sci 20(6):327–331
55. Sadok W, Angevin F, Bergez JE, Bockstaller C, Colomb B, Guichard L et al (2008) Ex ante assessment of the sustainability of alternative cropping systems: implications for using multi-criteria decision-aid methods. a review. Agron Sustain Dev 28(1):163–174
56. Stewart TJ (1992) A critical survey on the status of multiple criteria decision making theory and practice. Omega 20(5–6):569–586
57. Talukder B, Hipel KW, vanLoon GW (2018) Using multi-criteria decision analysis for assessing sustainability of agricultural systems. Sustain Dev 26(6):781–799
58. Talukder B (2016). Multi-criteria decision analysis (MCDA) for agricultural sustainability assessment. Theses and Dissertations (Comprehensive), p 1838. https://scholars.wlu.ca/etd/1838
59. Talukder B (2017) Multi-criteria decision analysis (MCDA) technique for evaluating health status of landscape ecology. In: Landscape ecology for sustainable society. Springer, Cham, pp 39–49
60. Talukder B, Hipel KW (2018) The PROMETHEE framework for comparing the sustainability of agricultural systems. Resources 7(4):74
61. Triantaphyllou E (2000) Multi-criteria decision making methods. In: Multi-criteria decision making methods: a comparative study. Springer, Boston, MA, pp 5–21
62. Tsoutsos T, Tsouchlaraki A, Tsiropoulos M, Serpetsidakis M (2009) Visual impact evaluation of a wind park in a Greek island. Appl Energy 86(4):546–553
63. USACE and CDM (U.S. Army Corps of Engineers and CDM, Inc.) (2010) IWR planning suite MCDA User's Guide. (2010). Institute for Water Resources. http://www.pmcl.com/iwrplan/MCDAUsersGuideSep10.pdf
64. Vansnick JC (1990) Measurement theory and decision aid. In: Readings in multiple criteria decision aid, pp 81–100. Springer, Berlin, Heidelberg
65. Vincke P (1992) Multicriteria decision aid. Wiley, New York
66. Vinodh S, Girubha RJ (2012) PROMETHEE based sustainable concept selection. Appl Math Model 36(11):5301–5308
67. Wang JJ, Jing YY, Zhang CF, Zhao JH (2009) Review on multi-criteria decision analysis aid in sustainable energy decision-making. Renew Sustain Energy Rev 13(9):2263–2278
68. Von Winterfeldt D, Edwards W (1993) Decision analysis and behavioral research. Cambridge University Press, Cambridge, MA
69. Wood MD, Bostrom A, Bridges T, Linkov I (2012) Cognitive mapping tools: review and risk management needs. Risk Anal: Int J 32(8):1333–1348

70. Zietsman J, Rilett LR, Kim SJ (2006) Transportation corridor decision-making with multi-attribute utility theory. Int J Manage Decis Mak 7(2–3):254–266