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Article Review Article

An Overall Assessment of Multi-Criteria Decision Support System Framework in the Context of Sustainability

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ABSTRACT

Sustainability aims to reduce the negative impacts on economic development, the environment, and social factors. It has become a critical goal for many organizations, businesses, governments, and policymakers worldwide. However, achieving sustainability depends on different approaches. Solutions that are good for the environment may adversely affect the economy, and vice versa. This manuscript examines the decision support systems in the context of sustainability and highlights their advantages in assessing and choosing sustainable solutions. It also considers the processes involved in developing decision-support system frameworks. The study reveals that most decision support system frameworks in the context of sustainability are built using multi-criteria decision techniques. It also reveals that the numbers and types of sustainability assessment criteria significantly influence the reliability and effectiveness of the decision-making process on choosing the most "sustainable" solution.

KEYWORDS

Multi-criteria decision-making, Sustainability, Decision support system, Sustainability criteria, Application scale, Energy planning, Supplier selection, Urban development.

INTRODUCTION

Sustainability is an urgent objective that has attracted the attention of many organizations, policymakers, businesses, and governments in many countries. Recent research has highlighted the increasing complexity of sustainable development due to conflicting objectives and diverse stakeholder expectations [1], [2], [3], [4], [5]. Sustainability, previously viewed from a single environmental perspective, is now being approached through integrated frameworks that consider trade-offs, system dynamics, and decision support structures. This is particularly

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relevant in rapidly evolving areas such as urban development, energy systems, and industrial transformation [6], [7]. There is therefore an urgent need for methodologies that can assist policymakers in balancing economic, environmental, and social priorities when making complex decisions. They consider sustainability as a goal of development. Many scholars and policymakers have previously studied and applied sustainability to all areas of life, such as cultural development, tourism, industry, energy, transportation, and construction [8], [9].

Sustainability is considered under multiple criteria in three aspects: environmental sustainability, economic sustainability, and social sustainability [10]. These aspects are also used as goals in developing sustainable options, while criteria are used for evaluating the sustainability of these options. For example, in terms of environmental sustainability, criteria of environmental impacts such as greenhouse gas emissions and ozone depletion, or maximizing the potential for resource conservation, are used [11]. Economic sustainability, on the other hand, is evaluated based on reducing costs and increasing revenue [12]. Creating jobs, social acceptance and working conditions for workers are used to assess social sustainability [13]. However, different sustainable options often have trade-offs among three aspects of environment, economy and society [14], [15], [16], [17]. Options that are beneficial for the environment tend to sacrifice economic criteria, whereas options that are beneficial for the economy tend to be less advantageous for the environment and society. A business model might seek to follow environmentally friendly practices, but doing so could come at a high initial cost and short-term economic sustainability risks for the business [17]. The trade-off between sustainability and cost-effective performance mentioned in this research demonstrates that they vary depending on the supply chain's size. The small markets with small quantities of cargo can use the model supply chain's consolidation warehouse, which indicates low emission and cost. Larger markets, on the other hand, should concentrate more on in-time distribution strategy due to a better possibility of distribution system optimisation, which results in higher cost-effective performance. Whenever a trade-off exists, the selection of the best sustainable option is difficult for all organizations.

In this context, the decision support systems (DSSs) are useful tools for evaluating and selecting the optimal option that balances economic, environmental, and social considerations. Most DSSs employ methodological models based on multi-criteria decision-making (MCDM) approaches. For example, the Analytical Hierarchy Process (AHP) has been widely applied across various sustainability-related decision-making contexts [18], [19]. Cellura et al. [20] applied AHP to assess environmental performance in urban systems under different scenarios in Palermo, Italy. Kumar et al. [21] used AHP to evaluate transportation sustainability in South Delhi by considering pedestrian infrastructure and transit quality. Calabrese et al. [22] used AHP to identify sustainability issues critical to corporate strategy and societal value creation. In the case of Technique for Order Performance by Similarity to Ideal Solution (TOPSIS), Memari et al. [23] implemented a fuzzy-TOPSIS model to select the most sustainable supplier using nine main criteria and 30 sub-criteria. Şengül et al. [24]employed fuzzy TOPSIS combined with Shannon entropy to rank renewable energy supply systems in Turkey, considering economic and environmental performance. The Analytic Network Process (ANP) was applied by García-Melón et al. (2010) [25] to assess tourism sustainability strategies in Venezuelan national parks by considering interdependencies between criteria. PROMETHEE was applied by Morfoulaki and Papathanasiou [26] to rank urban mobility strategies in Greece based on expert input and priority targets. Additionally, Zhang and Xing [27] applied the Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method, integrated with fuzzy logic, to determine the most appropriate timeline for implementing green raw materials in a fashion supply chain.

In addition, fuzzy language is used in DSS to reduce the dependence on the subjectivity of experts in decision-making systems, as its representation is an approximate value rather than a specific value. For instance, Kaya and Kahraman [28] and Afsordegan et al. [29] used fuzzy AHP and fuzzy TOPSIS to address uncertainty in evaluating sustainable energy alternatives.

Shaw et al. [30] combined fuzzy AHP with fuzzy linear programming to support carbon-conscious supplier selection in supply chains. Tayyab and Sarkar (2021) developed an interactive fuzzy goal programming model to support sustainable supplier selection and order allocation in the textile supply chain, addressing cost, quality, and time simultaneously, while incorporating expert judgment and promoting regulatory oversight for dyestuff evaluation [31].

Although DSS and MCDM methods are widely applied in the context of sustainable development, existing reviews tend to focus narrowly on specific tools or application areas. This paper aims to fill this gap by providing a broadly structured synthesis of the trade-offs, applications, and limitations of major MCDM methods when applied to sustainable development. In particular, this review contributes a new taxonomy of DSS methods based on methodological characteristics, the degree of integration of sustainable development (economic, environmental, social), and the scale of application (project, enterprise, country). Furthermore, this review develops a comparative analytical framework that allows for an assessment of how each method addresses sustainable development criteria, stakeholder engagement, and uncertainty.

Several issues need to be comprehensively considered and analysed in this paper, including:

- Methodological approaches and techniques: A review of the methodologies and techniques employed within the sustainability context, along with an evaluation of their respective advantages and limitations in practical applications.
- Scale of application and sustainability assessment criteria: An investigation into the appropriate application scale of DSS, for example at an enterprise, or for a country, and the selected sustainability assessment criteria, and the classification of criteria and sub-criteria utilized in assessing sustainability at these distinct scale.
- Enhancing the effectiveness of the decision making process: Exploration of strategies to improve the effectiveness of the decision-making process on selecting the most "sustainable" options under different conditions, such as selected sustainability assessment criteria, trade-offs among different sustainability goals and inherent uncertainties.

The main contribution of this paper is to go beyond descriptive summaries by providing a structured and critical review of MCDM methods within the (DSS framework in the context of sustainable development. This review not only synthesises the current state of research but also proposes a conceptual classification framework that connects the methods with their scope of application, the nature of the sustainability criteria (quantitative vs. qualitative), and the scale of decision making (corporate, regional, or national). The findings are intended to assist researchers, practitioners, and policy makers in selecting and applying appropriate DSS methods to complex sustainability problems that require balancing environmental, economic, and social objectives under conditions of uncertainty and trade-offs.

The structure of this paper is organized as follows: Section 2 outlines the methodology used to identify, screen, and select relevant literature. Section 3 provides a comprehensive review of DSS approaches and considers their practical applications in the context of sustainable development. Section 4 explores the sustainability assessment criteria and sub-criteria commonly used in the reviewed studies. Section 5 discusses the scale of DSS application—from the corporate to the national level—and highlights the broader benefits of these systems in sustainable development planning. Finally, Section 6 presents the main conclusions and outlines future research directions.

MATERIALS AND METHODS

In this paper, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram, which is an evidence-based set of guidelines designed to help authors conduct and report systematic reviews and meta-analyses, was used to visually present the process of choosing studies for systematic literature reviews [32], [33]. This diagram offers a consistent way of recording and reporting the search process and supports making sure that the studies chosen are accessible, comprehensive, and well-documented. This will help reviewers avoid biases and make sure the literature search is accurate and relevant to the research question [32]. The PRISMA diagram is presented in Figure 1.

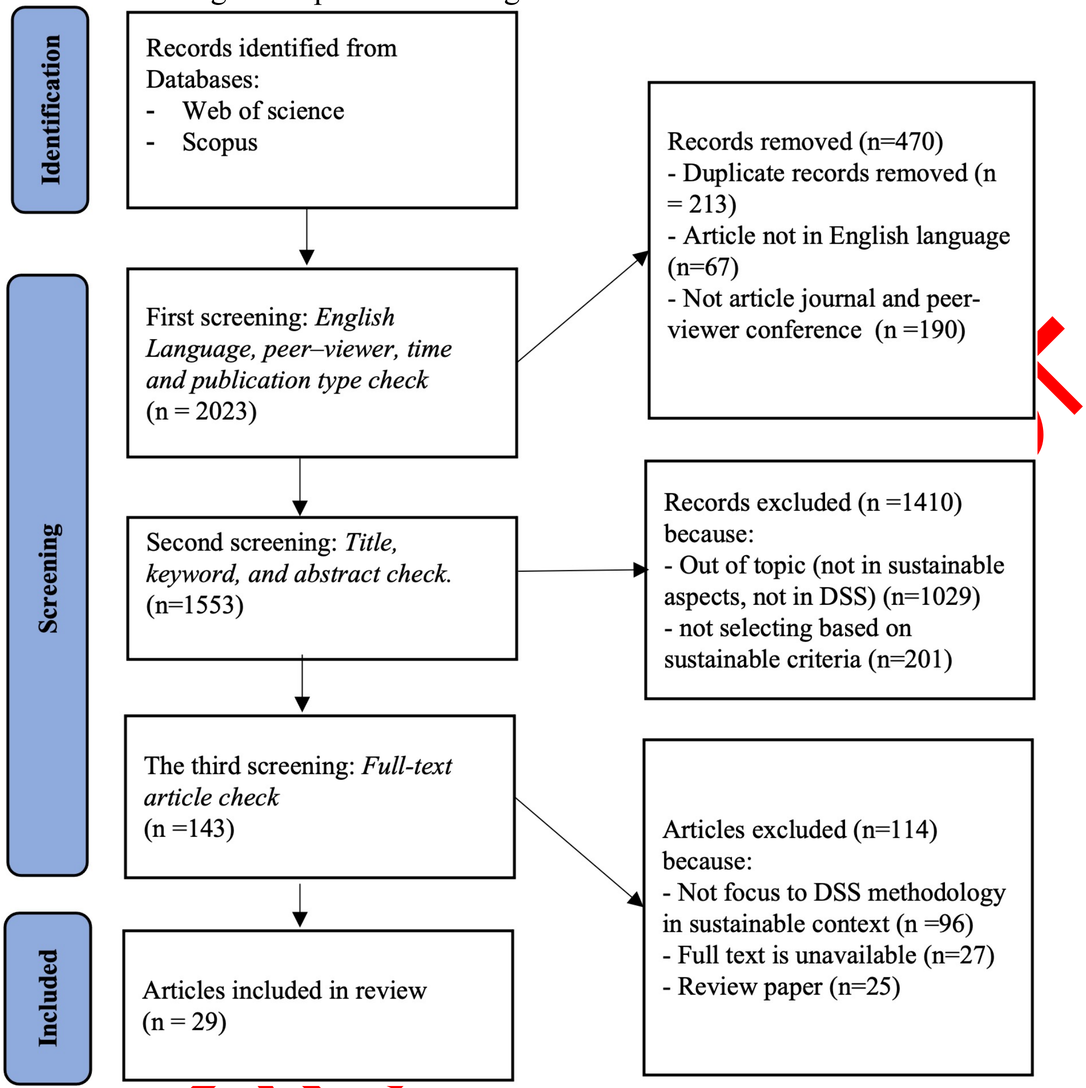


Figure 1. PRISMA diagram of searching documents

A systematic literature search was conducted on several prominent scientific databases, including Scopus, Web of Science, and ScienceDirect. These databases were chosen because of their extensive coverage of peer-reviewed literature in decision sciences, computer science, engineering, and environmental studies, which is highly relevant to Decision Support Systems (DSS) and sustainability research.

Keywords were carefully selected based on the core issues identified in the introduction: "decision support systems," "multi-criteria decision making," "fuzzy logic of decision support," and "sustainability." To maximize the relevance and scope of our search, these keywords were combined into the following integrated search string: ("decision support system" OR "multi-criteria decision making" OR "fuzzy logic decision support") AND ("sustainability" OR "sustainable development").

The search was conducted for peer-reviewed journal articles, review articles, and conference papers published between 2000 and May 2024. This time frame was chosen to capture the development of DSS and MCDM applications in sustainability over two decades, reflecting recent advances and established practices. Only papers published in English were considered to address language constraints.

The selection process included several screening stages to identify the most relevant and high-quality studies for in-depth review:

1. Initial search and first screening: The initial search on the designated databases yielded 2023 papers. A first screening was then conducted based on titles and abstracts to exclude clearly irrelevant articles, resulting in 470 papers being excluded.
2. Second screening (Titles, keywords and abstracts): The remaining papers underwent a more rigorous second screening process. During this stage, 1410 papers were excluded if their topics were deemed irrelevant to DSS, lacked a clear sustainability aspect, or were not relevant to the selection based on sustainability criteria.
3. Full text review and final selection: In the final screening stage, 143 papers were read in their entirety to assess their suitability for the specific inclusion criteria. The main criteria for paper selection included:
   - The study presented a clear methodological framework for making decisions about using MCDM or DSS.
   - The article type was original research or comprehensive review.
   - Full text available.

During the full text review, a qualitative assessment of the quality of the study was conducted. This included assessing the methodological soundness of the MCDM application, the robustness of the data sources, the clarity of the presentation of the results, and the direct relevance of the study findings to sustainability dimensions (environmental, economic, social). Studies with significant methodological flaws or unclear contributions to the field were carefully considered for exclusion.

After this rigorous process, 29 articles were finally selected as core case studies for in-depth review and evaluation, forming the foundation for the subsequent analysis. Building on these selected studies, the following sections develop a structured analytical lens to evaluate how key MCDM methods operate within DSS frameworks in sustainability, linking them to context-specific needs and decision scales. Rather than limiting the analysis to individual techniques, author develop a comparative perspective that links each method to (1) the decision logic of the method, (2) the integration of the method with sustainability dimensions (economic, environmental, social), (3) the support of the method for qualitative versus quantitative criteria, and (4) the typical scale of application of the method (enterprise, region, country). This structured methodological framework is developed based on a synthesis of 29 case studies and highlights the trade-offs, strengths, and integration potential of key methods such as AHP, ANP, PROMETHEE, TOPSIS, and VIKOR. The review therefore helps practitioners and researchers better understand how each approach fits into different sustainability decision-making contexts and where a hybrid or fuzzy approach is more appropriate.

MULTI-CRITERIA DECISION-MAKING FRAMEWORKS IN THE CONTEXT OF SUSTAINABILITY

To effectively address sustainability challenges, policymakers often rely on structured frameworks that support transparent and systematic assessments. This section introduces a widely used methodological framework for DSSs that incorporates MCDMs. These frameworks help users to balance economic, environmental, and social objectives.

A methodological framework is a tool to guide the developer and user through a sequence of steps to complete a procedure [34]. The methodology is identified as the group of methods used in a specified field, and a framework is defined as a structure of rules or ideas [33]. According to methodologies used in case studies, multiple criteria for sustainability assessment were the primary ones used for creating the DSS framework.

The methods apply to many different audiences in the context of sustainability assessment but essentially include the main stages as shown in Figure 2. Under this framework, the first step is the selection of indicators for sustainability assessment, and followed by proposing weighting factors of sustainability indicators. The total of all weighting factors equals one. At the same time, different sustainability scenarios are evaluated according to each criterion.

Finally, the sustainability indicators and weighting factors are combined to rank different scenarios.

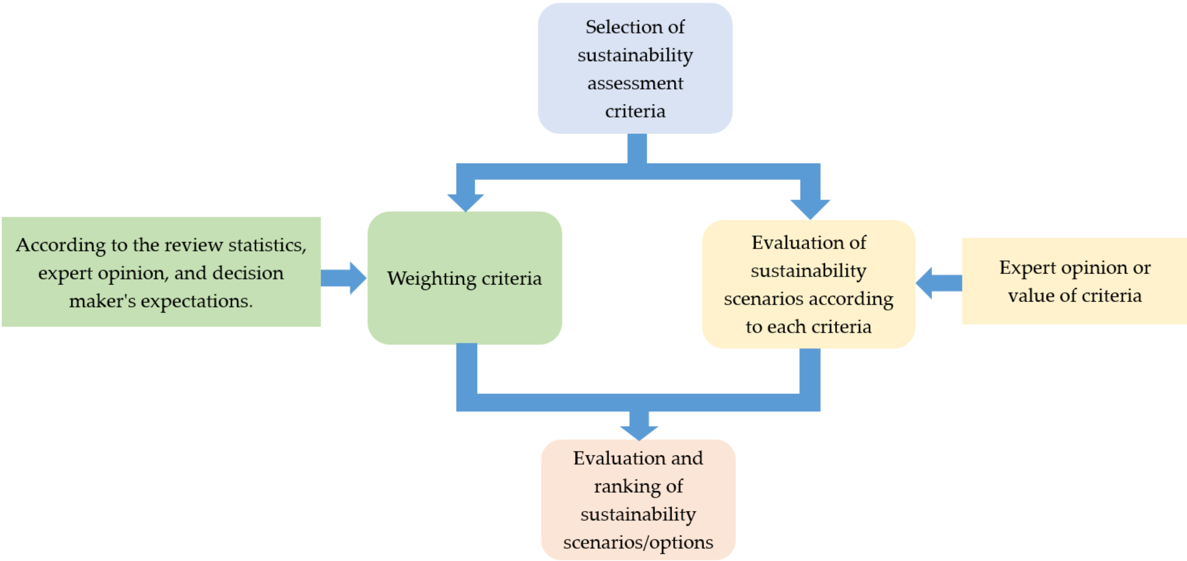


Figure 2. Decision support system stages in the sustainability context

The studies synthesized for this framework, along with their primary methodologies, are listed in Table 1.

Table 1. Methodology of DSS in case studies

No	Paper	Methodology
1	[20], [35], [36], [19], [21]	AHP method
2	[22], [18]	Fuzzy AHP method
3	[37], [26], [38], [39]	PROMETHEE method
4	[23], [24]	Fuzzy TOPSIS method
5	[40]	ANP method
6	[27]	Fuzzy VIKOR method
7	[41]	AHP - VIKOR method
8	[28]	Fuzzy AHP method, fuzzy TOPSIS
9	[29]	TOPSIS method, Fuzzy AHP
10	[30]	Fuzzy AHP and fuzzy multi-objective linear programming
11	[42]	AHP method, LCA method
12	[43]	TOPSIS and VIKOR method
13	[44]	TOPSIS-based fuzzy goal programming
14	[45]	AHP, DELTA, Promethee II, and NAIADE method
15	[46]	Rainfall run-off model
16	[47]	Fuzzy ε-constraint method
17	[48]	The sustainability index methodology
18	[49]	Mathematical method and a matrix method

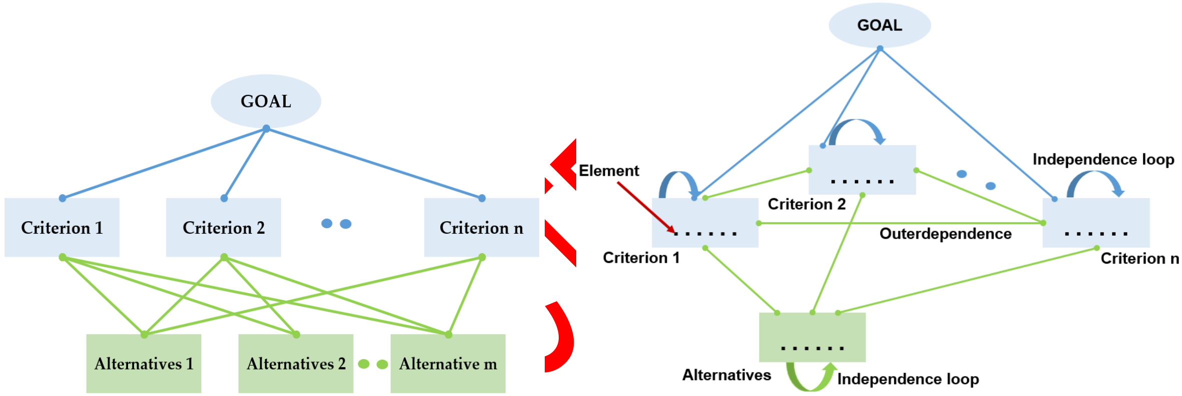
No	Paper	Methodology
19	[50]	Fuzzy best-worst (FBW) method

Core multi-criteria decision-making approaches in sustainability

In the context of DSS frameworks for sustainability, several MCDM methods are widely adopted due to their unique features and suitability for complex evaluation tasks. This subsection describes the core approaches such as AHP, ANP, PROMETHEE, TOPSIS, and VIKOR, each offering different advantages depending on the structure and requirements of the decision-making problem.

Analytical hierarchy process method

The AHP and Fuzzy AHP (FAHP) are quantitative methods used to sort decision alternatives and select an option that satisfies given criteria based on the pairwise comparison principle [21], [36]. This is the best choice that meets the decision maker's criteria by comparing pairs of options and a specific calculation mechanism [51]. By employing the relative scale measurement, a set of pairwise comparison matrices for each of the lower levels, with one matrix for each element in the level, is generated. Pairwise comparisons are made regarding which element is preferred over the other [21]. The model of the AHP method is presented in Figure 3a.



a. AHP method **b.** ANP method

Figure 3. The decision-making model of the pairwise comparison and hierarchy approach

Analytical network process method

The ANP method is a network analysis method that considers the hierarchy and the interaction between the criteria in the system [25], [40], [51], [52], [53]. In practice, ANP is a combination of two parts: one is a network of standards and criteria, and the other is a network of influences between factors and criteria clusters [25]. The model of the ANP method is presented in Figure 3b [52].

Preference ranking organization method for enrichment evaluations method

The PROMETHEE is an outranking method for ranking a finite set of alternative actions when multiple criteria are often conflicting and various decision-makers are involved [54]. PROMETHEE uses partial aggregation, and pairwise comparison of alternative actions allows one to verify whether, under specific conditions, one step outranks or not the others [26], [37], [38], [39], [55], [56], [57], [58]. The model of the PROMETHEE method is shown in Figure 4.

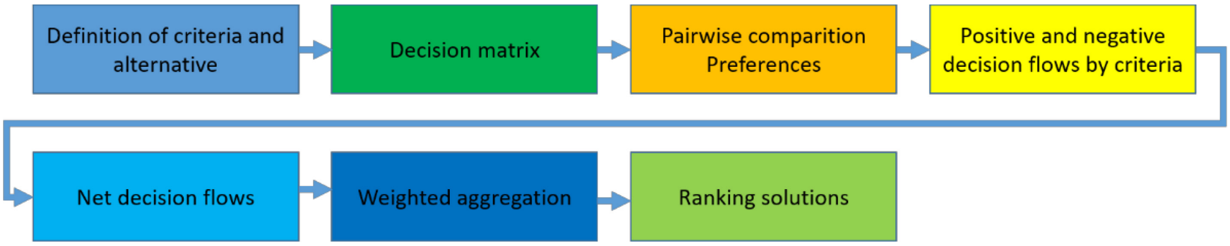


Figure 4. The model of the PROMETHEE method [57]

Technique for order preference by similarity to ideal solution method

TOPSIS, which is one of methods of the multi-criteria decision making, is founded on the fundamental premise that the best solution has the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution as shown in [23], [24], [28], [29], [43], [55], [59], [60], [61]. Therefore, alternatives are evaluated using a global index based on their distance from the optimal solutions [61]. The model of the TOPSIS method is shown in Figure 5.

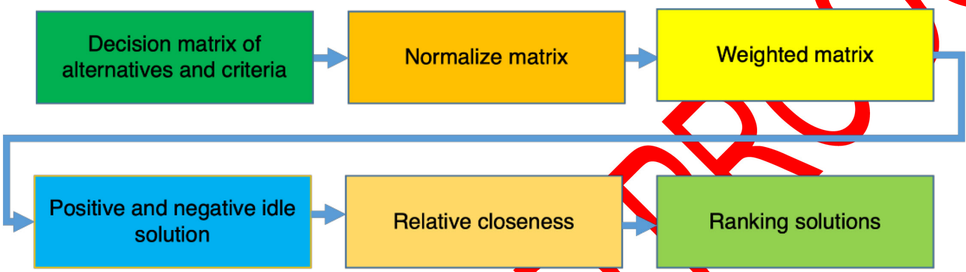


Figure 5. The model of the TOPSIS method [52], [60]

Vise kriterijumska optimizacija i kompromisno resenje method

This method evaluates the solutions based on their distance to ideal and anti-real points [62]. For individual decision-making variants, the weighted average distance from the ideal solution, the maximum weighted distance from this point, and the so-called comprehensive criteria are determined [27], [43], [60], [63]. The model of the VIKOR method is shown in Figure 6.

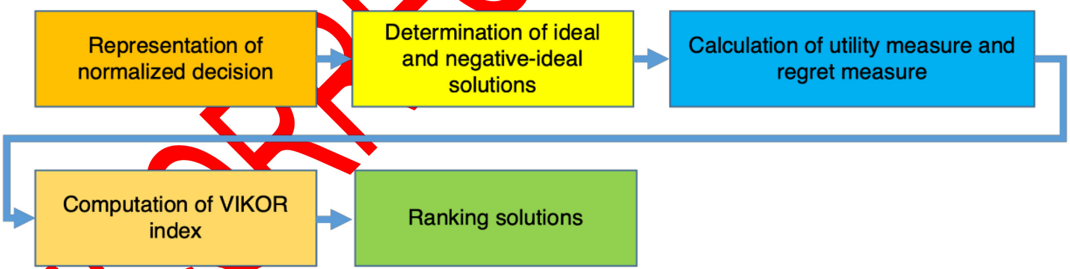


Figure 6. The model of the VIKOR method [52], [60]

The strength and weaknesses of the multi-criteria decision-making methods

The major MCDM methods are broadly classified as follows: VIKOR and TOPSIS are reference point approaches [64], [65], while PROMETHEE is a higher ranking approach [66]. ANP and AHP are pairwise comparison and hierarchical approaches [51]

Analysis shows that these MCDM methods are suitable for designing and developing DSSs in a sustainable context. AHP and ANP are suitable for hierarchical sustainable decision problems, with ANP being more applicable for complex systems with interdependencies [67]. PROMETHEE focuses on outranking sustainable alternatives based on clear preferences, while TOPSIS and VIKOR aim to identify the best sustainable alternative using different approaches to evaluate distances from the ideal and anti-ideal solutions [68].

The inherent characteristics of each method provide distinct advantages and limitations when applied to sustainability challenges. For example, AHP, despite its simplicity and ability to handle both quantitative and qualitative data, suffers from limitations when handling large numbers of criteria due to the exponential increase in pairwise comparisons required [28], [41], [42]. The assumption of criterion independence can also be a drawback in highly interconnected sustainable systems. ANP, an extension of AHP, addresses these interdependencies, providing a more precise analysis and a more explicit method for assessing criterion weights [25]. However, the increased complexity of this method requires significant expertise and can be computationally intensive [40]. In addition, Taherdoost and Madanchian (2023) presented a comprehensive review of the Analytic Network Process (ANP), highlighting its strength in handling complex, interrelated decision-making problems across various domains, while also discussing its methodological advantages and practical limitations [69].

PROMETHEE is recognized for its simple ranking and the use of preference functions that reflect the decision maker's specific bias, making it transparent and intuitive for higher rankings [56]. However, a notable challenge is that the method lacks an inherent weighting mechanism, often requiring external sources, which can lead to subjectivity. The method also requires careful definition of preference functions and can be sensitive to changes in weights or criteria scores [70].

TOPSIS and VIKOR are both reference point methods that reduce subjectivity by evaluating alternatives based on their proximity to ideal and anti-ideal solutions [71]. TOPSIS provides a direct ranking, while VIKOR focuses on the compromise solution by considering both utility and regret. While generally easy to apply, common weaknesses of both are their reliance on external weighting criteria and their sensitivity to data normalization and input variations. Both can struggle with computational complexity for very large problems and may assume linear relationships that do not always hold in real-world sustainability problems. VIKOR's assumption of an ideal solution may not always be feasible.

Error! Reference source not found. Table 2 presents the strengths and weaknesses of the MCDM methods in the sustainability context.

Table 2. Strengths and weaknesses of methods in the sustainability context

Method	Strength	Weakness	Remarkable	Paper
AHP	Simple, easy to understand and advantageous in applying with a small number of criteria and alternatives. Allowing pairwise comparisons of criteria and alternatives. Can handle both quantitative and qualitative data. Easy integration with another method. Increasing decision confidence by using fuzzy logic.	Limited by the consistency ratio - if not consistent, results may be unreliable. Requiring many comparisons between criteria and alternatives in each criterion. The pairs of comparison increase quickly when the number of criteria increases. Value of comparison pair effects to the accuracy of decisions. Assuming criteria independence, which may not always be true. The result of the decision may be	Hierarchical decision-making problems where criteria can be organised into levels and sub-levels.	[18], [19], [20], [21], [22], [28], [29], [30], [35], [36], [41], [42], [67], [72], [73]

Method	Strength	Weakness	Remarkable	Paper
		changed if adding or reducing one alternative.		
ANP	An extension of AHP that accommodates interdependencies among criteria and alternatives. Handles both quantitative and qualitative data. Less dependent on consistency ratio than AHP. Increasing decision confidence by using fuzzy logic.	More complex than AHP and may be harder to understand. Requires additional judgment to determine interdependencies among criteria.	This method is suitable for complex decision sustainable issues with multiple layers and interdependent criteria.	[25], [40]
PROMETHEE	Straightforward ranking of alternatives; Considers preference functions for each criterion, reflecting decision-makers preferences. Transparent and visual approach for outranking. Increasing decision confidence by using fuzzy logic.	Using weighting criteria from another source, so it makes the decision more subjective and less accurate. Require more effort to define appropriate preference functions (It has six preference functions). Sensitive changes in weights or criteria scores.	This method is suitable for decision problems where decision-makers want to outrank alternatives based on clear preferences.	[26], [38], [39]
VIKOR	Considers both utility and regret in decision-making. Balances compromise and dominance concepts. Provides a ranking of alternatives and a compromise solution. Relatively simple to apply. Increasing decision confidence by using fuzzy logic.	Using weighting criteria from another source. Requiring normalisation of data. It may be sensitive to changes in weights or criteria scores.	This method is suitable for decision problems with conflicting and trade-off criteria, where a balance between the best possible outcomes and minimising potential losses is desired.	[27], [41], [43]
TOPSIS	Identifies ideal and anti-ideal solutions. Ranks alternatives based on their proximity to the ideal	Using weighting criteria from another source. Requiring normalisation of data.	This method is suitable for decision problems with multiple	[23], [24], [28], [29], [43], [44].

Method	Strength	Weakness	Remarkable	Paper
	solution and distance from the anti-ideal solution. Relatively simple to apply. Provides a straightforward ranking of alternatives. Increasing decision confidence by using fuzzy logic.	Sensitive changes in weights or criteria scores.	criteria and a large number of alternatives, where an ideal solution is sought.	

Integration potential and fuzzy approaches

Different MCDM methods could be combined to fully exploit the effectiveness of both methods, for example, AHP with TOPSIS [28], [29] TOPSIS and VIKOR [27]and AHP with VIKOR [41]. These integrations improve the accuracy of decisions, reduce the number of calculations and make them more objective and less dependent on expert judgement. Furthermore, the integrated methods improve the efficiency of the DSSs concerning uncertain criteria [18], [22], [23], [29].

These MCDM methods are combined with fuzzy logic when users seek to develop a tool for evaluating intricate objects encompassing both quantitative and qualitative criteria. It is important to note that DSS frameworks, designed for specific audiences, should only be applied within those target groups. In DSS frameworks utilizing expert opinions for assessment, the evaluation quality is highly dependent on the expertise of the involved stakeholders. Fuzzy logic presents an alternative solution, aiding decision-makers in selecting the best option with minimal reliance on experts.

One disadvantage of these integrated methods is their complex structure. Moreover, they require users to be familiar with a wide range of computational methods. It is a challenge for users to assess sustainability. As a result, these methods are not generally explored and utilized, even though they can produce high-quality evaluation outcomes. The choice of either individual and specific method, or integrated methods depends on the problem that needs decisions and the advantages that the methods bring to the decision-makers.

PRACTICAL APPLICATIONS OF MULTI-CRITERIA DECISION-MAKING METHODS IN SUSTAINABILITY CONTEXTS

MCDM methods have been widely applied in many areas related to sustainability. These applications illustrate how MCDM frameworks support the formulation of complex decisions involving multiple, often conflicting sustainability criteria. This section summarizes key case studies and elaborates on the use of specific methods in real-world contexts.

Overview of reviewed case studies

Table 3 summarizes the applications of these methodologies in various case studies.

Table 3. Application of methodologies in some case studies

Methodology framework	Application	Reference
AHP method	Selection of Urban Sustainability Scenarios.	[20]
	Selection of renewable energy sources.	[19] [36]

Methodology framework	Application	Reference
	Ranking and comparing regions in terms of environmental sustainability.	[21]
	Determining the sustainability of a public transport system.	[35]
	Cage aquaculture managers.	[41]
	Calculating the weights of the Sustainable Supplier Selection main dimensions, criteria, and sub-criteria.	[42]
	Choosing the better energy generation options among a range of many feasible solutions.	
Fuzzy AHP method (FAHP)	Quantification and ranking of five critical sustainability project criteria.	[18]
	Selection of relevant sustainability issues.	[22]
	Weighting criteria in selecting sustainable energy alternatives.	[29]
	Weighting the sustainability criteria in the selection of energy technologies.	[28]
	Analyzing the weights of the multiple factors for supplier selection and quota allocation.	[30]
PROMETHEE Method	Manufacturing company by changing and prioritizing material, product, and process orientations.	[38]
	Ranking alternatives in sustainable urban mobility planning.	[26]
	Ranking agricultural systems in coastal Bangladesh.	[39]
Fuzzy TOPSIS method	Ranking renewable energy supply systems.	[24]
	Selecting the right sustainable supplier.	[23]
	Selecting the best energy technology alternative.	[28]
	Selecting sustainable energy alternatives.	[29]
	Evaluating the level of sustainable development of EU countries.	[43]
	Selecting sustainable project.	[44]
Analytic Network Process (ANP)	Management tool for organizational sustainability.	[40]
	The sustainability of touristic strategies for coastal national parks of Venezuela.	[25]
VIKOR method	Fashion company to deploy green raw materials.	[27]
	Selection of the sustainable supplier.	[41]
	Evaluating the level of sustainable development of EU countries.	[43]
Other methodologies	Setting up micro-hydro power (MHP) plants.	[46]
		[47]

Methodology framework	Application	Reference
	Optimizing multi technology, multi product supply chains and co-modal transportation networks for biomass-based.	[48]
	Assessing water distribution systems.	[49]
	Choosing the design option of Ultimate Pit Limit.	[50]
	Selecting sustainable supplier.	

Detailed applications of multi-criteria decision-making methods

The versatility of MCDM methods is evident in their diverse applications in a variety of sustainability contexts. In the following subsections, specific implementations of each method are explored, highlighting real-world decision-making situations where each technique has been used effectively.

Analytical Hierarchy Process applications

The AHP is also one of the most popular methods to assess sustainability in the field. For example, Cellura et al. (2002) used AHP to calculate the weights in the mathematical model to evaluate the whole environmental performance of urban systems and control the developing sustainability trends due to different human management scenarios for Palermo City in Italy [20]. Halide et al. applied AHP to evaluate the best site from several alternatives to assist cage aquaculture managers based on the holding density, cage volume, the survival rate of fish seed, mean fish weight at harvest, feed conversion ratio, cost of seed, the interest rate on borrowed funds, etc. Yağmur Kara & Aylin Çiğdem Köne (2012) presented a multi-criteria decision-making model that applied the AHP method to rank and compare regions regarding environmental sustainability [36]. The AHP method was also used by Kumar et al. (2015) to determine the sustainability of a public transport system, including pedestrian and transit services in the South Delhi region, India [21], and by Alabrese et al. (2018) to select the most relevant sustainability issues to create common value for both business and society [22]. The AHP method is combined with the Strong Sustainability Model (SSP-AHP) to develop a structured assessment framework for the social sustainability of health systems, thereby supporting transparent assessment, cross-system comparison, and effective policy decision-making [73].

Analytical Network Process applications

The ANP method, well-suited for complex decision-making problems with interdependencies, has also seen significant applications. Fikret K. Turan et al. (2009) proposed software based on the ANP method to calculate sustainability [40]. This research presented a supporting tool built on the foundation of the ANP method called the Benefits, Opportunities, Costs and Risks (BOCR) model. Under each node of the BOCR model, three subnets are delineated - economic, environmental, and social. The decision-maker makes a series of pairwise comparisons. Using the summation formula to combine the four control values, the absolute priorities of the five project alternatives are inferred. García-Melón et al. (2010) evaluated the sustainability of touristic strategies for coastal national parks of Venezuela [25]. The ANP technique was proposed to help managers make decisions about this sustainability. Saputro et al. 2023 applied the ANP method to determine the priority order of sustainable rural tourism development strategies, based on sensitive attributes identified from MDS analysis, helping to ensure a balance between ecological, economic and social criteria [74].

Preference Ranking Organization Method for Enrichment Evaluation applications

Karolina Ogrodnik (2017) selected a multi-criteria analysis method for Polish cities based on sustainable development goals [37]. The PROMETHEE method was used to rank top cities in the social, economic, environmental, and political sectors. Four cities (Bialystok, Lublin, Chorzow, and Czestochowa) were selected based on 66 sustainability indicators. Morfoulaki and Papathanasiou (2021) applied the PROMETHEE method to rank criteria and mobility measures in Sustainable Urban Mobility Plan (SUMP) [26]. SUMP's 15 targets and five difficulty levels are covered. Ten experts were selected to share their experiences and feedback on this framework's proper development and testing. Calculation results show that "Redesign of the existing public transport system" ranks highest and "Development of a shared system of electric and conventional bicycles as well as small-capacity electric cars" ranks lowest. Vinodh & Jeya Girubha (2012) used the PROMETHEE method as a computationally and cost-effective selection method that has been used to improve sustainability in a manufacturing company by changing and prioritizing material, product, and process orientations [38]. Talukder & W. Hipel (2018) referred to the PROMETHEE method applied to five different types of agricultural systems in coastal Bangladesh to rank alternatives from best to worst according to a series of indicators of sustainability [39]. The PROMETHEE method was also applied to cluster and rank suppliers in the supply chain based on criteria for creating sustainable shared value, thereby supporting strategic decision making [70]. Using PROMETHEE helps businesses effectively evaluate suppliers not only based on economic performance but also on the level of contribution to social responsibility and sustainable development.

Technique for Order Performance by Similarity to Ideal Solution applications

The TOPSIS method was commonly employed for ranking and selecting sustainable options. It is usually utilized to create DSS by integrating with other methods, such as AHP and VIKOR, to assess alternative sustainability scenarios with unclear information and challenging-to-define criteria such as flexible working arrangements [23] or social acceptability criteria [24]. Memari et al. (2018) presented an intuitionistic fuzzy TOPSIS method to select the most sustainable supplier, concerning nine criteria such as cost, quality of products, service performance, environmental efficiency, green image, pollution reduction, green competencies, safety and health, employment practices, and 30 sub-criteria for an automotive spare parts manufacturer [23]. Three suppliers (a), (b) and (c) who provide cast iron parts to a manufacturing company are considered for evaluation. The authors developed intuitionistic fuzzy-TOPSIS to evaluate each supplier. First, three suppliers were ranked on the expert basis, according to nine criteria. After that, this expert based result was compared with the result calculated by the fuzzy TOPSIS method. The comparison results show that the supplier (a) is the best choice for sustainability in both approaches. S¸ engül et al. (2015) developed the multi-criteria decision support framework for Turkey's ranking renewable energy supply systems [24]. The weights of each criterion are calculated using Fuzzy Shannon's Entropy. After that, Fuzzy TOPSIS is utilized to rank the alternatives. The results showed that the first criterion in preference ranking of renewable energy sources in Turkey is the Amount of Energy Produced, followed by the ranking systems Land use, Operation and maintenance cost, Installed Capacity, Efficiency, Payback period, Investment cost, Job creation, and Value of CO2 emission. This study showed that the Hydro Power Station is the best (or the most sustainable) renewable energy supply system in Turkey [24].

Vise Kriterijumska Optimizacija I Kompromisno Resenje applications

The VIKOR method is used to solve complex decision-making problems with clear values. One case used it to choose a sustainable supplier [41] and assess the sustainability ratings of the supplier’s country [43]. Zhang & Xing (2017) examined a practical use of the Fuzzy - VIKOR method regarding selecting the appropriate period for a fashion company to deploy green raw materials [27]. The newly developed probabilistic language VIKOR technique has been applied to calculating weighted criteria and alternative ratings. The results of calculating the weights of the criteria show that the criterion "Marketing" has the highest weight (0.305), and the criterion "Logistics" has the lowest weight (0.148). The ranking of alternatives shows that eight months of green raw material implementation is appropriate for the fashion company and should be recommended out of the four possible periods. The combination of fuzzy logic and VIKOR would increase the method's efficiency to give high-quality decisions in conditions with unclearly sustainability criteria. The VIKOR method is also applied to rank and select optimal sustainable suppliers in the supply chain, based on the balance between economic, social and environmental criteria [64]. Combined with DANP, VIKOR helps to effectively evaluate options under conditions of interdependence of criteria, thereby supporting comprehensive decision making in line with sustainable development goals.

Other methodologies

Beyond the widely used methods, various other approaches have been developed for specific situations. Buchholz et al. (2009) assessed the potential of Multi-Criteria Analysis (MCA) to facilitate the design and implementation of sustainable bioenergy projects [45]. These MCA tools use four methods AHP, Delta, PROMETHEE II, and Novel Approach to Imprecise Assessment and Decision Environments (NAIADE), for sustainability assessment. Research results show that different tools can give different results. Shaw et al. (2012) presented an integrated approach to select the appropriate supplier in the supply chain, addressing carbon emissions, using fuzzy AHP and multi-objective linear programming [75]. In this model, fuzzy AHP was first used to calculate the criteria weights, and then fuzzy linear programming was used to find the optimal solution to the problem. Khalili-Damghani & Sadi-Nezhad (2013) developed a DSS using TOPSIS-based fuzzy goal programming (FGP) to solve sustainable Multi-Objective Project Selection problems with Multi-Period Planning Horizon (MOPS-MPPH) [76]. Mattiussi et al. (2014) presented a framework for an energy supply DSS based on the AHP method for sustainable plant design and production, utilizing an innovative use of multi-objective and multi-attribute decision-making (MODM, MADM) modelling together with impact assessment of the emission outputs [77]. Other methodologies were explored by Aydin et al. (2015) [78]; Afsordegan et al. (2016) [79]; Luthra et al. (2016); Rahmanpour & Osanloo (2017) [80]; Balaman et al. (2018) [81]; Mateusz et al. (2018) [82]; Alavi et al. (2021) [83].

SUSTAINABILITY CRITERIA AND SCALES OF DECISION SUPPORT SYSTEM APPLICATION

To ensure effective implementation of DSS in a sustainable development context, it is important to establish clear sustainability criteria and understand the different scales of application of these systems. This section presents key criteria drawn from the literature and case studies, followed by an analysis of how DSS frameworks are applied at both the enterprise and regional/national levels.

Sustainability criteria and sub-criteria

Pavlovskaia asserted that sustainability criteria and their content should be linked to the concept of sustainable development and sustainability [84]. Pavlovskaia described sustainability criteria as requirements for a product's sustainable quality and its sustainable production process, which must be satisfied to achieve sustainable status or certification [85]. Zink posited that these criteria are applied to assess opportunities and risks arising from economic, environmental, and social sustainability facets [86]. Meanwhile, Koplin et al. (2007) emphasized that environmental sustainability criteria establish requirements for suppliers, aiming to reduce natural resource inputs and mitigate environmental risks through enhanced supplier efficiency [87].

Sustainability criteria play a crucial role in incorporating a sustainability perspective effectively [88]. These criteria support long-term sustainability assurance, investment protection, and measurement of decision-makers expectations. The criteria create a standard framework for sustainability to guide development for businesses and for a country. The present review indicates that the selected sustainability criteria in the case studies are based on four pillars:

- Technology - as considered in [19], [24], [28], [29].
- Economy - reflected in [19], [21], [23], [24], [28], [29], [41].
- Environment - addressed in [19], [21], [23], [24], [28], [29], [41].
- Society - evaluated in [19], [21], [23], [24], [28], [29], [41].

In 29 reviewed papers, 14 studies considered the hierarchy of sustainability assessment criteria, including criteria and sub-criteria. These studies are identified as follows: [19], [20], [21], [22], [23], [24], [27], [28], [29], [35], [39], [40], [41], [42]. For example, Ahmad & Tahar et al. (2014) used four criteria (technical, economic, social, and environmental criteria) and 12 sub-criteria to select renewable energy sources [19]. Three criteria (Technical, Economic and Environmental criteria) with 24 sub-criteria were considered in Mattiussi et al. (2014) paper [42]. Besides, Luthra et al. (2016) employed 22 sub-criteria and divided them into three criteria economic, environmental and social [41]. In these studies, 7/9 cases used economic, environmental, and social pillars as criteria. The 2/9 remaining cases employed other criteria, such as productivity, stability, efficiency, durability, compatibility, and equity, for assessing sustainability in agriculture [39]. In addition, four out of nine cases considered technology as an additional sustainability criterion. The criteria were also divided into qualitative and quantitative criteria. For example, social acceptability was used as a qualitative criterion [29], whilst transportation cost and CO_2 emission were quantitative. Besides that, the criteria were used at different scales of countries or an enterprise. For example, Mateusz et al. (2018) used 14 SDGs to evaluate the level of sustainable development of EU countries, while Shaw et al. used specific criteria for supplier selection [43]. The number of criteria was different in studies. García-Melón et al. (2010) used 13 criteria [25], while there were 16 criteria in S. Vinodh & R. Jeya Girubha (2012) [38]. The weighting of criteria in the DSSs can vary depending on the specific case studies and relevant context.

The aggregated criteria and sub-criteria used to assess and select options at the company level are shown in Figure 7.

Figure 7. Main sustainable criteria and sub-criteria from the literature

Scale of application

The scales of the DSSs in the sustainability context could be divided into two main categories: the enterprise level, and the regional and national levels [89].

At the enterprise level, DSSs have been employed in numerous research for a broad range of applications. Four studies employed DSSs to help enterprises choose the best supplier [23], [30], [41], [50]. DSS was employed in two studies to select the design of the energy systems [45], [46]. In the other research, DSSs were used for selecting design options [49], identifying development strategy [18], and evaluating sustainability projects [40]. Two studies utilized DSSs to define the significant criteria and essential factors for sustainable development [18], [38]. Furthermore, DSSs have been employed to select plans for utilizing green materials [27], identify key development strategy goals [22], and manage cage aquaculture by assisting with site classification, selection, holding capacity determination, and economic appraisal [35].

At the regional and national levels, DSSs were used in four studies to select the best options for energy and renewable energy development [19], [24], [42], [47]. DSSs were considered in one study as a tool to help managers evaluate alternatives in urban planning and city development planning, such as assessing sustainable residential development in terms of culture and life [26]. There were three cases employing DSSs to evaluate the sustainability of cities as a primary planning future development policy [20] and rank cities according to the criteria of sustainability [37]. Kumar et al. (2015) considered the DSS as a tool to help Indian managers develop a strategy for a sustainable transport system [21]. Talukder & W. Hipel (2018) employed the DSS to select sustainable agricultural development plans for localities [39]. Another study used DSS to help managers evaluate the effectiveness of tourism planning and development [25]. Additionally, two other studies utilized DSS to assess the sustainability ratings of different regions and cities and identify areas that need special attention to achieve common sustainable development goals [36], [37]. Lastly, one study used the DSS to evaluate countries' sustainability ratings against each other [43], which was the basis for assessing the effectiveness of countries' sustainability policy implementation.

The divisions of the DSS applications by scale are presented in Figure 8.

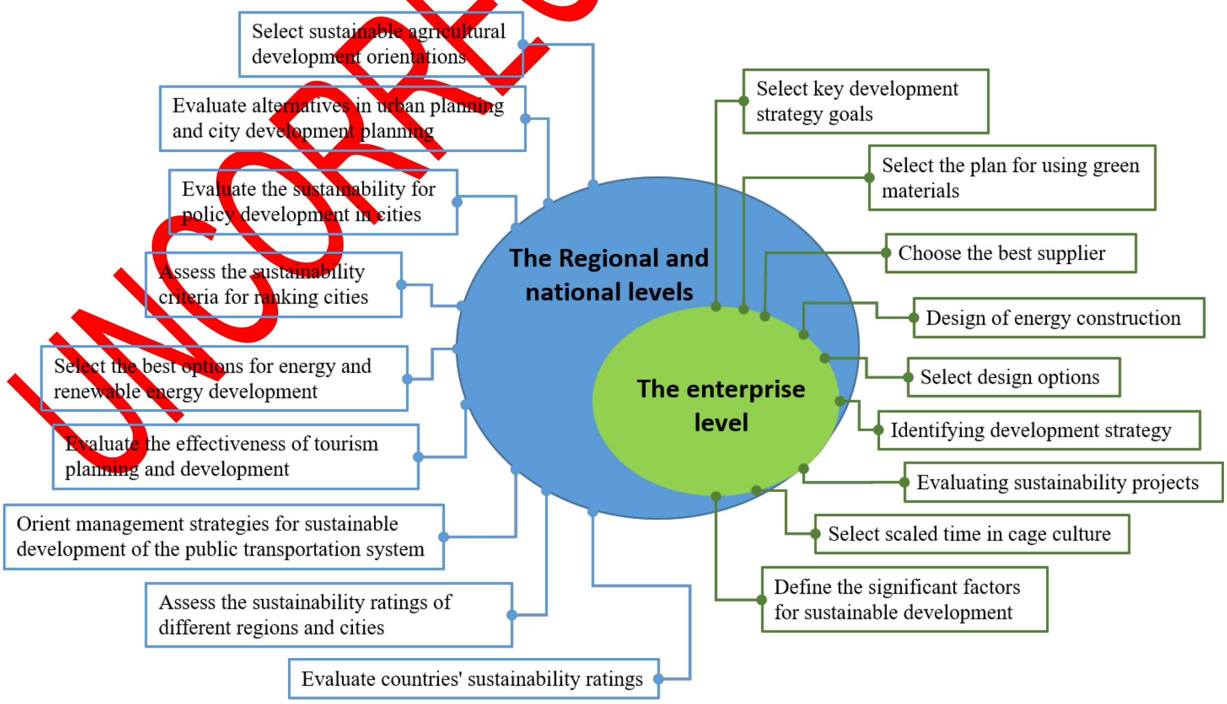


Figure 8. Divisions of the DSS applications by scale

Broader benefits

Beyond the enterprise and regional/national scales, MCDM methods—especially AHP, TOPSIS, VIKOR, and their fuzzy or hybrid forms—have been extensively applied across a multitude of sustainability-related fields, providing a structured framework for evaluating complex problems involving multiple, often conflicting, criteria.

In municipal solid waste management, MCDM has been used to compare landfill, incineration, and recycling technologies using criteria such as cost, greenhouse gas emissions, and local feasibility [90], [91], [92], [93]. For example, MCDM is applied to evaluate and select sustainable urban solid waste treatment technologies, based on 12 criteria in three groups: economic, social and environmental [91]. The use of MCDM allows for a systematic comparison between technologies, thereby determining the optimal solution – in this case, waste-to-energy incineration technology – suitable for the practical context of Ho Chi Minh City.

In sustainable agriculture, MCDA assists in crop selection, irrigation strategies, and soil nutrient management [94], [95], [96]. According to Heiba et al. (2023) MCDM method is a useful tool to solve complex problems involving many factors acting simultaneously, such as in agricultural land potential assessment. By integrating climate, soil, topography and social factors, MCDM – combined with AHP – helps determine the suitability of land for farming, supporting strategic decision making on efficient land use and sustainable agricultural development.

In sustainable transportation, MCDA supports the assessment of public transport systems, infrastructure upgrades, and emission reduction strategies [97], [98]. Khakbazan et al. (2025) applied the AHP method to evaluate and rank cities in Iran for metro system development, based on various criteria such as population, air pollution, and traffic congestion [97]. The use of AHP within the MCDM framework provides a structured and data-driven method to support metro investment decisions, while providing a basis for sustainable urban policy. Tirkolaee and Aydin (2022) proposed a fuzzy bi-level decision support system integrating supply chain and transportation network design for perishable products, using multi-objective MILP models and fuzzy weighted goal programming to address uncertainty, perishability, and sustainability in large-scale logistics systems [99].

For renewable energy planning, MCDM methods are used to compare solar, wind and biomass options [100], [101], [102]. MCDM allows for the assessment of investment costs, energy potential, environmental impacts and policy incentives. MCDM is also effective in climate change adaptation. Teng et al . (2025) used AHP within the MCDM framework to evaluate and rank coastal adaptation strategies, considering criteria such as environmental impact, cost-effectiveness, social acceptability, and long-term sustainability [103] .

In water resource management, MCDA has been applied to water allocation strategies, wastewater treatment options, and investment priorities. For example, Fathi et al. (2025) applied the TOPSIS method within the MCDM framework to evaluate and select the optimal water resources management strategy for the Dehgolan Delta, Iran, based on 12 important indicators and scenarios simulated by the WEAP model [104]. Fetanat and Tayebi (2022) developed a novel picture fuzzy set-based decision support system to prioritize petroleum refinery effluent treatment technologies, integrating sustainability and circularity criteria to support a circular water economy transition in the oil and gas sector [105].

For low-carbon technology evaluation, MCDM was used to balance cost, efficiency, and environmental impacts [106]. For example, Esangbedo & Tang (2023) applied the grey-MEREC-MAIRCA hybrid MCDM method to evaluate the carbon emission reduction strategies of six Chinese enterprises, thereby identifying direct emission control and energy saving efficiency as the top priorities [106].

In the context of a circular economy, MCDM supports decisions regarding material selection, recycling technology and reverse logistics [107], [108]. Filho et al. highlighted the integration of MCDM methods with artificial intelligence (AI) is opening up a new approach to reverse solid waste (RSCSW) supply chain management according to the circular economy model, helping to automate decision making, reduce costs and increase waste traceability. Finally, the emerging combination of MCDM and AI enhances the ability to automate decisions and data processing [109].

Key benefits and effectiveness enhancements of decision support systems

DSSs offer significant advantages in navigating the complexities of sustainability decision-making. Even when some sustainability criteria are qualitative and inherently difficult to quantify, DSSs can effectively assist decision-makers in making optimal selections. Five studies applied judgment integration support tools to assess qualitative and uncertainty criteria [18], [23], [29], [40]. Furthermore, to enhance objectivity or address situations with limited expert availability, fuzzy methods have been widely adopted in seven studies for ranking or assessing sustainability [18], [22], [23], [24], [28], [29], [30]. Besides that, six cases used integrated methods in the DSSs to make the decision more accurately [28], [29], [30], [41], [43], [49]. Half of these cases used the AHP method to rank the criteria [28], [29], [41], while the other method was employed to rank alternatives. The comprehensive benefits derived from applying DSSs, as detailed in the literature, are summarized in Table 4.

Table 4. The scale and benefits of applying DSS from the literature

Scale	Paper	Benefits
National	[24]	Defining the most significant criterion in preference ranking of renewable energy sources in and the best renewable energy supply system in Turkey.
	[19]	Identifying the most important economic and technological criteria as well as priorized energy sources for Malaysia.
	[29]	Allowing the evaluation of alternatives in energy planning without the need for precise variable values.
	[47]	Allowing users to select the design of full or separately supply chain and transportation network. To define the configuration of the supply chain or give the configuration to plan the transportation network.
	[43]	Assessing the sustainability of the EU country suitable with the real condition.
	[37]	Assessing the sustainability of cities and building on other well-known concepts.
Regional	[20]	Allowing decision makers to choose the best option based on user-oriented and indicators.
	[36]	Showing the strengths and weaknesses of sustainability for a region.
	[42]	Identifying the best alternative from the point of view of the economy - technology, decision-maker, and equal weight for energy plant designs.
	[25]	Determining the highest and lowest criteria in the sustainable assessment of the coastal National Park "Los Roques".
	[21]	Identifying the most influential parameters to sustainability in transportation.

Scale	Paper	Benefits
	[39]	Allowing analysts and decision makers to provide methodological advice for agricultural sustainability assessments.
	[26]	Allowing decision-makers to rank the highest and lowest alternative in the sustainability of Greek city mobility.
Company	[45]	Assisting decision makers to choose the best option based on social criteria.
	[46]	Supporting in selecting the appropriate technology for sustainable development.
	[35]	Assisting users in selecting the ideal website in accordance with their preferences.
	[40]	verifying by mapping the model with practical applications.
	[28]	Selecting the best energy technology based on quantitative and qualitative criteria.
	[38]	Selecting the material that responds to mechanical, environmental, and economic factors for sustainability.
	[30]	Proposing a very useful decision-making tool for mitigating environmental challenges according to the manager's requirements.
	[44]	Determining a set of four different investment chances with the priority of effectively achieving a certain level of fuzzy goals. Generating high-quality solutions in the sense of sustainability.
	[48]	Defining threshold points of technical parameters to ensure sustainability in the water supply system.
	[41]	Helping business managers and professionals distinguish essential supplier selection criteria and evaluate the most effective supplier in terms of sustainability within the supply chain while remaining competitive in the marketplace.
	[49]	Determining UPL alternative based on the calculated UPL sustainability score.
	[27]	Selecting the appropriate time frame for the implementation of green raw materials in a fashion retail company.
	[22]	Permiting the company to incorporate the sustainability approach into its strategic management, identify the areas of reciprocal influence between the company and society.
	[23]	Allowing more accuracy in result calculation due to using intuitive fuzzy for weighting criteria and ranking of alternatives.
	[18]	Allowing project managers and decision-makers to identify selection criteria with higher weights.
	[50]	Allowing users to use historical data on suppliers for selection and define the importance of chosen criteria.

CONCLUSION AND FUTURE WORK

This paper provides a comprehensive review of the DSS frameworks which are being applied in the sustainability context. By synthesising 29 case studies, the paper highlights the widespread application of MCDM methods—namely AHP, ANP, PROMETHEE, TOPSIS, and VIKOR. These methods have been used in sustainability decision-making processes to evaluate environmental performance, select suppliers, and assess various renewable energy systems, which are presented and discussed.

Each method has its advantages and limitations, and their suitability depends on the specific decision-making context and available data. In most applications, sustainability is assessed using four basic pillars: technological, economic, environmental, and social. DSS frameworks also vary in their scale of use, from enterprise-level decisions to regional and national planning.

While this review outlines the capabilities of current DSS approaches, it also identifies several research gaps. First, many systems are still limited in their ability to handle large-scale stakeholder engagement or dynamic, real-time data. Second, most case studies rely on traditional MCDM tools that do not fully exploit emerging technologies.

Future research should focus on improving the effectiveness of DSS in the context of sustainable development by integrating AI and machine learning to support real-time adaptation and data-driven decision making. Developing participatory DSS platforms is also essential to better engage stakeholders and incorporate their diverse values in a transparent manner. Furthermore, applying DSS frameworks in emerging areas such as climate adaptation, urban resilience, and cross-sectoral sustainable development can test their versatility and applicability to real-world challenges. Finally, improving the ability of DSS to handle uncertainty and complexity through the development of hybrid models—especially those that combine MCDM techniques with fuzzy logic—can increase the robustness and reliability of sustainability assessments.

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