

Decision making support tool for renewable energy prioritization to achieve sustainable development goals (SDGs): Conceptual framework



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ABSTRACT

Renewable energy adoption is pivotal for achieving Sustainable Development Goals (SDGs), yet selecting suitable renewable energy systems involves complex decision-making processes. This study reviews the existing body of knowledge on decision-making methodologies for renewable energy systems in relation to SDGs and proposes a conceptual framework grounded in the findings of a systematic literature review (SLR) and bibliometric analysis of 43 peer-reviewed articles.

The analysis reveals the dominance of MCDM techniques particularly the Analytic Hierarchy Process (AHP) and the prevalence of technical, economic, and environmental criteria, while regulatory, policy, and geographical dimensions remain underrepresented. Furthermore, the literature's reliance on static, one-time evaluation models highlights a critical gap—namely, the lack of decision-making support tools that accommodate evolving priorities and stakeholder input.

To address these limitations, a conceptual framework for renewable energy prioritization decision-making support tool is proposed to enable a more context-sensitive, inclusive, and iterative decision-making approach. The proposed framework consists of five interlinked stages: (1) identifying key decision factors, (2) weighting and balancing priorities using Multi-Criteria Decision-Making (MCDM) methods, (3) comparing renewable energy alternatives, (4) generating tailored recommendations, and (5) incorporating stakeholder feedback for continuous refinement. A feedback loop ensures an iterative refinement process, adaptability to evolving conditions and continuous improvement of the decision-making tool. Altogether, the framework promotes a transparent, inclusive, and responsive approach to renewable energy prioritization and supports long-term sustainability transitions.

1. Introduction

The pursuit of sustainable development has emerged as a critical global challenge in the 21st century. At the heart of this challenge lies the essential transition from traditional fossil fuel-based energy systems to renewable sources such as wind, solar, hydro, and biomass. This shift is vital not only for reducing greenhouse gas emissions and combating climate change but also for ensuring long-term energy security, fostering social equity through a just transition, and supporting inclusive economic growth worldwide (UNDP [1], World Bank [2]). The United Nations' (UN) Sustainable Development Goals (SDGs), and in particular Goal 7 on Affordable and Clean Energy, aim to ensure that everyone has access to affordable, reliable, sustainable, and modern energy services by 2030 (UN [3]). In this context, Kumar et al. [4] highlight the decisive role of surplus energy in supporting economic growth and the

attainment of development goals in developing countries.

Mateo [5] documents substantial advancements in energy planning methodologies from straightforward, single-objective approaches to more sophisticated frameworks incorporating multiple criteria and stakeholders. These developments, however, have also introduced greater complexity. The current energy planning landscape is marked by an increasing number of objectives, definitions, and evaluation criteria, a complexity that often hampers the realization of systems truly aligned with sustainability goals. This growing intricacy underscores the need for decision-making tools capable of systematically addressing and reconciling competing priorities. As Diakoulaki and Karangelis [6] point out, the process of selecting the most appropriate renewable energy system for a given region or project is inherently fraught with difficulty, as it requires balancing diverse and sometimes conflicting technical, economic, environmental, and social factors. In this context,

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multi-criteria analysis serves as an effective tool to integrate and evaluate these diverse perspectives by linking relevant alternatives with the influencing factors. As Cavallaro [7] notes, it offers a scientifically grounded decision-support mechanism capable of providing clear and consistent justifications for choices within the renewable energy sector.

Köksalan et al. [8] argue that Multi-Criteria Decision Making (MCDM), rooted in operations research, offers a robust and versatile framework whose methodological diversity enables it to address complex decision problems involving multiple, often conflicting, criteria across various disciplines. In complementary view, Majumder [9] highlights that a core advantage of MCDM is its focus on incorporating the preferences of decision-makers, given that most real-world problems do not yield a single optimal solution. This argument underscores the importance of balancing conflicting objectives and making rational choices based on a comprehensive evaluation of alternatives. In the context of energy supply systems, this flexibility is often viewed as essential for achieving sustainable development outcomes. Pohekar and Ramachandran [10] further contend that MCDM techniques are effective in handling both quantitative and qualitative criteria, particularly when analysing conflicts not only among criteria but also among different stakeholders. They position MCDM as an indispensable tool for selecting appropriate renewable energy technologies, given its ability to structure complex decisions and facilitate transparent comparison of alternatives.

D'Adamo and Gastaldi [11] present a transparent Multi Criteria Decision Analysis (MCDA) framework for mapping regional SDG progress in Italy, but its limited set of targets constrains the comprehensiveness and adaptability of the assessment for policy development. Mardani et al. [12] suggest a comprehensive synthesis of MCDM techniques applied to sustainable and renewable energy systems by highlighting the growing use of hybrid and fuzzy MCDM approaches but it lacks critical analysis of methodological limitations or inconsistencies across the reviewed studies. While, Sugumar and Anglani [13] conducting structured framework for renewable energy site selection by integrating Analytic Hierarchy Process (AHP) with resilience considerations and Sustainable Development Goals (SDGs) and propose future integration of a ranking method like Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) into their AHP-based renewable energy site selection framework, but its absence in the current study leaves the decision-support system incomplete for practical application.

Maceiras et al. [14] apply AHP to evaluate alternative fuels for the Spanish Navy, offering a focused sectoral application. Yet, the absence of sensitivity analysis in their study limits the credibility of their ranking, particularly in scenarios where emission-reduction priorities may shift. A comparable limitation is evident in Elavarasan et al. [15], who integrate AHP with Shannon's Entropy to select clean energy sources in Australia. While their approach adds weighting objectivity, it overlooks socio-political indicators despite well-documented evidence, such as AlArjani et al. [16], showing governance structures as pivotal in energy transition outcomes.

Concerns around methodological subjectivity also persist in fuzzy-logic applications. Ezbakhe and Pérez-Foguet [17] argue that calibrating membership functions often lacks transparency and may amplify bias in the absence of strong expert consensus. While spatially integrated AHP applications by Kamati et al. [18] and Richards et al. [19] offer valuable geospatial perspectives for renewable energy site selection, they do not address the complexities of multi-criteria integration aligned with the SDGs. Conversely, although Büyükköçkan et al. [20] introduce an SDG-oriented hesitant fuzzy MCDM model, its application is limited to a single country and does not consider interdependencies among criteria, underscoring the need for approaches that are both contextually adaptable and methodologically comprehensive. Collectively, these studies reflect both the utility and the limitations of widely used MCDM approaches in renewable energy planning. To address the complexities of renewable energy system selection and its alignment with sustainability goals, this study conducts a review the existing body of

knowledge on decision-making methodologies for renewable energy system in relation to SDGs and develop conceptual framework based on the finding from literature review. By systematically mapping the MCDM research in this field, this study seeks to identify key trends and research gaps that need further exploration which then will be used as empirical base to develop conceptual framework. The bibliometric analysis will provide quantitative insights into emerging trends through, while the systematic review will synthesize qualitative insights to highlight commonly used methodologies and selection criteria in the literature.

This paper will begin with a systematic literature review, analysing existing studies on MCDM applications for renewable energy system and its alignment with SDGs. Following the systematic literature review, a bibliometric analysis will be conducted using scientometric techniques such as keyword mapping to uncover research clusters and emerging trends in this field. By combining qualitative evaluation of methodological use with quantitative scientometric insights, this study will map the landscape of decision-making methodologies approaches for renewable energy in relation to the SDGs, thereby identifying gaps and informs the development of a conceptual framework designed to enhance coherence with SDGs and effectively guide sustainable energy transitions.

2. Methodology

This paper carried out a literature review in accordance with the latest PRISMA statement guidelines. According to PRISMA, systematic literature review involves four stages: identification, screening, eligibility assessment, and inclusion of relevant papers (Page et al. [21]). Scopus and Google Scholar were selected for this study, as Scopus is widely recognized as the most used database for defining a research field through academic citations (Strozzi et al. [22]) and Google Scholar additionally uncovered a considerable number of unique citations not present in the other databases (Martin-Martin et al. [23]). Scopus offers approximately 20 % broader coverage compared to WOS (Aghaei et al. [24]). Scopus is currently the largest multidisciplinary database, indexing 40,562 peer-reviewed journals, whereas Web of Science (WoS) includes 24,831 journals (Carrera-Rivera et al. [25]). Google Scholar's inclusive indexing uncovers both well-known and previously hidden scholarly sources, aiding literature searches and research impact assessments (Yang et al. [26]).

As shown in Fig. 1, PRISMA process begins with the identification phase where there were 708 articles initially found on Scopus and Google Scholar by utilizing keywords such as “decision” AND “making” AND “renewable” AND “energy” AND “SDGs” OR “sustainable” AND “development” AND “goals”. Rayyan AI was utilized to identified duplicate records, as result 21 duplicate records was removed, leading to next stage which is screening. Rayyan AI is a web-based tool that streamlines the screening and selection process for systematic reviews by enabling duplicate detection, and collaborative article screening using AI-assisted features. In the second phase, 687 papers were evaluated based on inclusion and exclusion criteria set by the researchers. This phase involved the exclusion of book chapter, book, html, editorial, non-peer reviewed articles. We screened the title, abstract, and keywords of each article to ensure relevance. Additionally, only English-language papers published between 2004 and 2025 were considered, based on these criteria, 559 publications were excluded.

In the eligibility phase, 128 full-text articles were assessed for relevance. To ensure methodological consistency, articles were included only if they (1) were peer-reviewed journal publications, (2) explicitly applied decision-making methodologies to renewable energy systems, and (3) demonstrated direct relevance to SDGs through either criteria alignment or evaluative focus. Articles were excluded if SDGs were only mentioned in passing, if the study focused solely on fossil energy transition, or if the decision-making framework was unrelated to renewable energy prioritization. This process resulted in 43 articles meeting the

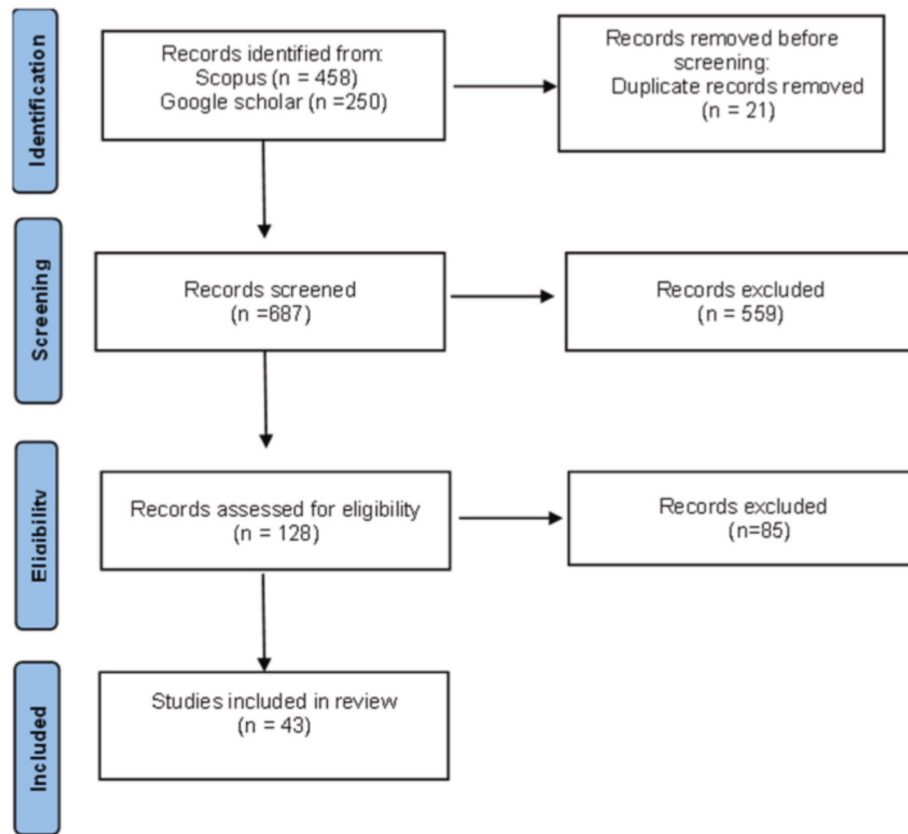


Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram.

final inclusion criteria. This inclusion process follow established approaches for enhancing transparency in renewable energy reviews, as demonstrated by Abdullayev et al. [70] and further exemplified by Hussein and Basel [76], who explicitly detailed their selection logic to strengthen replicability in case-based analyses.

This study also employs bibliometric analysis to systematically examine and identify both prominent and underrepresented research themes in decision making for renewable energy systems in relation to the SDGs using key word co-occurrence. Bibliometric analysis provides a robust method for reviewing and mapping the scope and evolution of existing literature, particularly by highlighting key concepts and thematic trends (Donthu et al. [27]; Mukherjee et al. [28]). As such, bibliometric analysis not only supports the systematic literature review but also guides future research directions by uncovering overlooked areas and contextualizing the study's contributions within the broader academic landscape (Gureyev & Mazov [29]; Khan et al. [30]).

To contextualize the use of bibliometric analysis in informing framework development, this study builds on the precedent set by Aljanabi [74], who conducted a comprehensive bibliometric exploration of decision-making research within civil engineering. The study demonstrated how keyword networks and evolving research topics can illuminate knowledge gaps and guide conceptual model development. Similarly, our bibliometric mapping of renewable energy and sustainable development literature informs the foundation and structure of the proposed decision-making framework, ensuring it is grounded in current scholarly discourse and research needs.

VOSviewer, a scientific mapping tool based on Visualization of Similarities (VOS) technology, was employed to conduct keyword co-occurrence analysis. This study leveraged VOSviewer's co-occurrence tool to identify and cluster frequently occurring terms. One of the key advantages of VOSviewer is its ability to visually represent maps containing many elements more effectively than alternative tools (van Eck

& Waltman [31]). The visualization map from VOSviewer generates nodes for keyword, which are organized into multiple color-coded clusters. The varying thickness of the links and nodes reflects the strength of their connections, allowing one to interpret the relationships among these elements (Orduña-Malea & Costas [32], van Eck & Waltman [31,33]).

In this study, bibliometric analysis served to affirm the prevailing decision-making methods identified in the systematic literature review, these combined insights from both the SLR and bibliometric analysis informed the development of a conceptual framework to address the identified research gaps.

3. Finding

3.1. Systematic literature review

The Systematic Literature Review (SLR) categorized the papers into two main categories: (1) the methodologies used for decision-making, and (2) the criteria used for decision making process. This categorization provides a structured approach to understanding the existing body of knowledge in renewable energy decision-making research. Methodology classification provides insights into the various decision-support techniques employed, including MCDM methods (AHP, TOPSIS, Elimination and Choice Translating Reality (ELECTRE), Preference Ranking Organization Method for Enriched Evaluation (PROMETHEE)), hybrid decision-making frameworks, fuzzy logic, Geographic Information System (GIS) based approaches, and other advanced computational. The criteria-based classification categorizes studies based on the factors influencing decision-making, including economic, environmental, technical, social, political & regulatory, and geographical considerations. This categorization enables to evaluate and identify gap in existing research that future studies can address.

3.1.1. Distribution of methodologies

Fig. 2 illustrates the distribution of methodology categories used in the research. Each section represents a different methodological approach and its corresponding percentage in the study.

The finding reveals that the AHP and its variants are the most widely used methods, accounting for 15.8 % of the total studies. This reflects the method's flexibility, ease of use, and strong acceptance in energy-related multi-criteria decision analysis. AHP-based hybrid approaches (such as AHP-Fuzzy, AHP-VIKOR, and AHP-GIS) are also prominently featured, each constituting a significant share of the methodological landscape. These hybrid methods are often employed to enhance the handling of uncertainty, integrate spatial data, or combine ranking and weighting procedures demonstrating the adaptability of AHP to more complex or context-specific requirements.

Other MCDA techniques such as ELECTRE, generic MCDM frameworks, Fuzzy methods, VIKOR, TOPSIS, The Complex Proportional Assessment (COPRAS), and others appear with lower frequencies, each comprising around 2–8 % of the studies. This suggests that while a variety of approaches are available and have been utilized, the field is heavily dominated by AHP-centric methodologies.

Overall, these findings indicate a clear methodological preference for AHP and its hybrids among scholars conducting sustainability assessments and renewable energy planning, with other MCDM methods playing more specialized or supplementary roles. This trend underscores the importance of AHP in facilitating structured, transparent, and participatory decision-making processes in complex, multi-criteria contexts.

3.1.2. Distribution of Research by criteria

Fig. 3 illustrates the distribution of the main criteria groups utilized in the reviewed literature for sustainable energy decision-making. As depicted in the chart, the most commonly considered criteria are Economic, Technical, Environmental, and Social factors, which together represent the overwhelming majority of the criteria identified across studies. Technical and Economic criteria (22.8 %) represent the largest individual category. Technical criteria encompassing factors such as technical specifications, system performance, reliability, efficiency, and technological maturity. This highlights the central importance placed on the feasibility and performance aspects of sustainable energy solutions. Economic Criteria are equally prominent, reflecting a strong focus on cost-related considerations. These criteria include investment costs,

financial viability, operational expenses, economic growth, and payback periods underscoring the necessity for projects to be both technologically sound and economically viable.

Environmental Criteria (21.1 %) follow closely, indicating the continued emphasis on ecological impacts. These criteria address greenhouse gas emissions, resource use, pollution, renewable energy adoption, and broader environmental consequences of energy choices.

Social Criteria (19.9 %) represent factors related to societal impacts and community acceptance, such as employment generation, public perception, health and welfare, social equity, and cultural dimensions. The frequent inclusion of social aspects demonstrates an awareness of the need for energy solutions to align with community values and public well-being.

This strong emphasis on these four domains reflects a holistic approach in the field, where economic viability, technical feasibility, environmental sustainability, and social acceptability are viewed as equally critical for decision-making in energy and sustainability contexts. The frequent integration of these criteria suggests that researchers and practitioners are increasingly aware of the need to balance technical performance and cost-effectiveness with environmental protection and societal well-being.

In addition to the main four, Policy/Regulatory criteria were also included in several studies (7.6 %), highlighting the growing recognition of governance, regulatory frameworks, and policy alignment in the evaluation process. Land Use/Geography (4.7 %) appears primarily in studies addressing site selection or spatial planning. Criteria classified as SDG/General or Other were rare, indicating that most studies opt for more conventional or discipline-specific evaluation frameworks. The results demonstrate that economic, technical, environmental, and social considerations are at the core of multi-criteria decision analysis in sustainable energy research, with policy and spatial dimensions serving as important, though less frequently emphasized, complements.

3.2. Bibliometric analysis

3.2.1. Key words Co-occurrence

Key words co-occurrence analysis is used to identify which key words frequently appear in the literature. Fig. 4 displays an overlay visualization of keyword co-occurrence in the reviewed literature, produced using VOSviewer. In this network, each node represents a keyword, with node size indicating its frequency, and the connections (edges)

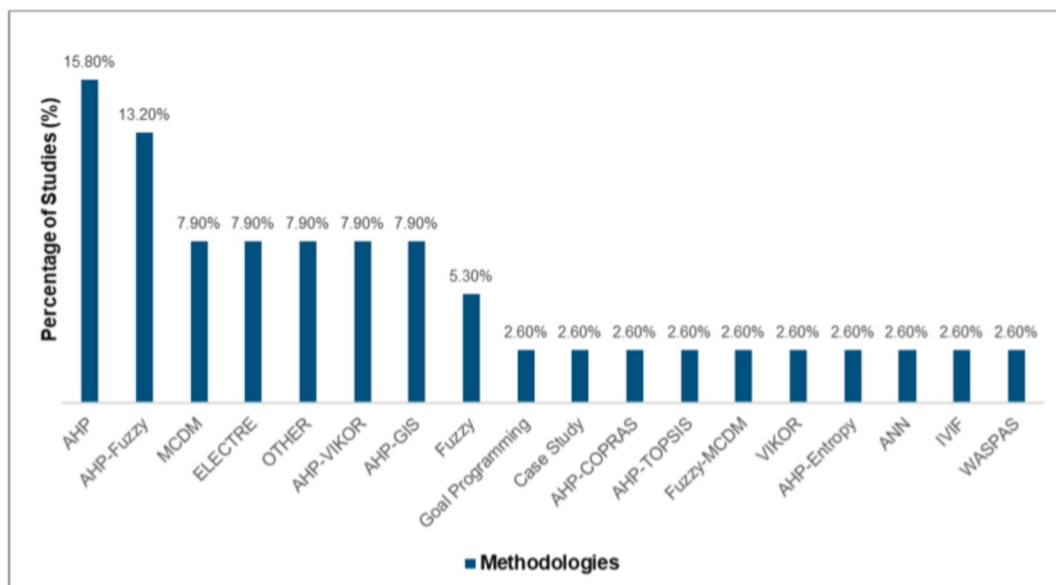


Fig. 2. Distribution of methodologies used in reviewed studies.

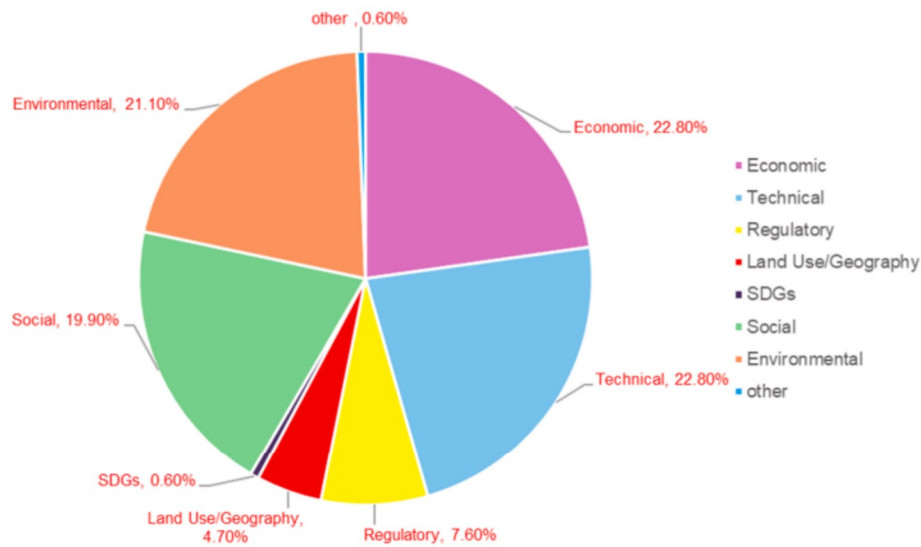


Fig. 3. Distribution of research by criteria used in reviewed studies.

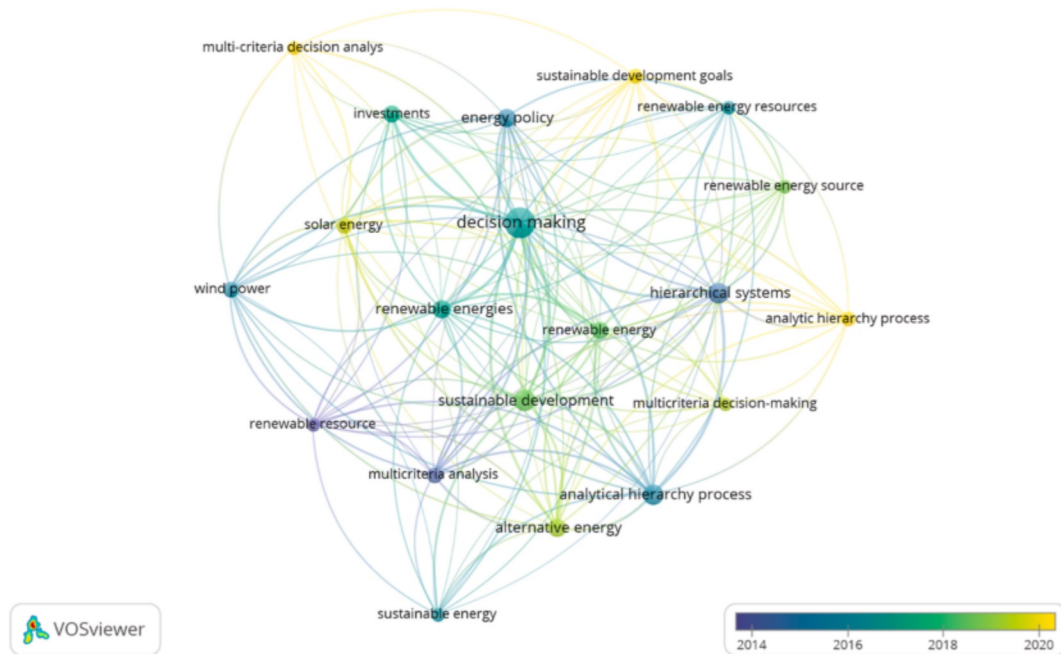


Fig. 4. Mapping of keywords co-occurrence.

representing the strength of co-occurrence between keywords. The selection criterion applied is a minimum keyword co-occurrence of 5, resulting in 20 keywords emerging from an initial set of 560. “decision making” is identified as the most frequently occurring keyword, appearing 24 times with a total link strength (TLS) of 92. While “analytical hierarchy process” followed with 11 times occurrence and TLS 67. The unique feature of this visualization is the use of a color gradient to reflect the average publication year associated with each keyword: darker colors (purple/blue) represent earlier years (2014–2016), while lighter colors (green/yellow) indicate more recent years (2018–2020).

The central keyword “decision making” remains highly prominent and well-connected throughout the timeline, acting as a persistent hub for research activity in this area. Several key terms such as “sustainable development,” “alternative energy,” “multicriteria analysis,” “analytical hierarchy process,” and “sustainable energy” are shown in darker hues.

This suggests these topics formed the core foundation of the literature in the earlier years of the review period, indicating early scholarly attention to foundational concepts and methods.

In contrast, keywords shaded in lighter colors, such as “multi-criteria decision analysis,” “sustainable development goals,” “analytic hierarchy process,” and “energy policy,” reflect newer trends and areas of emerging research interest from 2018 onward. This indicates a growing integration of specific methodologies (e.g., AHP/MCDA) and a shift towards alignment with global sustainability frameworks (e.g., SDGs) and policy perspectives in recent years. The evolution of color across the network reveals that while the field’s central methodological and thematic constructs have remained stable, there is increasing attention to policy-related, goal-driven, and multi-criteria frameworks in the most recent literature.

The dense interconnections and gradual progression in color tones also highlight the increasing interdisciplinarity and convergence of

themes over time. This temporal co-occurrence map shows a clear progression from fundamental methodological and sustainability topics toward more specialized, policy-oriented, and globally relevant research areas, reflecting the dynamic and evolving nature of decision-making studies in the context of renewable energy and sustainable development.

4. Decision making for renewable energy

An extensive body of research has employed MCDM methodologies to support renewable energy planning, often using techniques such as AHP, VIKOR, ELECTRE, and various fuzzy or hybrid approaches. Despite the growing sophistication of these tools, several patterns and limitations persist across the literature. A dominant trend is the reliance on structured techniques like AHP and its hybrids, particularly in studies such as Hauger et al. [34], Flora [35], and Richards et al. [19], where GIS and AHP are used to identify optimal locations for renewable infrastructure. These studies offer strong methodological structure but frequently underplay social acceptance and local stakeholder dynamics. This gap is echoed in Shenouda [36] and Aras [37], which also emphasize technical and environmental criteria but miss local perspectives essential for implementation.

By contrast, Dinçer et al. [38] offer a more socially attuned approach by incorporating governance and CSR considerations in their hybrid MCDM framework. However, the added complexity may hinder replicability and broader application. Similarly, Elavarasan et al. [15] present a technically robust hybrid model (Fuzzy AHP and Shannon's Entropy), though socio-cultural dimensions remain underexplored. This tension between methodological advancement and contextual sensitivity is a recurring issue.

The reviewed studies illustrate the growing sophistication of MCDM techniques in renewable energy planning, yet reveal important inconsistencies and gaps. Ighravwe et al. [63] use HOMER-WASPAS to optimize hybrid energy systems for rural healthcare but fall short in addressing social and institutional dimensions, a gap partially filled by Jansa et al. [68], whose MCDA framework incorporates broader criteria to align low-carbon technology choices with Thailand's carbon neutrality targets but lack the iterative feedback mechanisms essential for long-term adaptability, an issue similarly observed in Cutz et al. [66], who focus on biomass energy options in Central America using fuzzy MCDM but underrepresent stakeholder or governance considerations.

Zhang and Yuan [65] demonstrate the utility of ELECTRE III in power distribution system planning, though their exclusion of participatory inputs undermines the robustness of results. In contrast, Løken [67] offers a methodological overview that sets a strong theoretical foundation but lacks of stakeholder involvement, limiting its utility for decision-makers. While Rojas-Zerpa and Yusta [61] apply various MCDM methods like ELECTRE and AHP to help plan electricity supply in rural areas, but their approach stays general and does not go deep into comparing specific technologies.

On the other hand, Azzopardi [62] focus more narrowly on choosing the best photovoltaic (PV) technology using ELECTRE III and gives detailed comparisons and includes economic, technical and environmental aspects, but it mainly fits countries where energy markets are not affected by government subsidies. In contrast, Tahri et al. [59] use a GIS-AHP method to identify suitable locations for solar farms, combining spatial and environmental data, but their approach is limited by a narrow focus on site selection without considering economic or social criteria. Taken together, while these studies highlight the versatility of MCDM tools, they collectively underscore a critical need for frameworks that are not only methodologically sound but also adaptive, participatory, and context-sensitive particularly as countries pursue energy transitions aligned with sustainability goals.

Other studies attempt to balance technical rigor with broader impacts. Talinli et al. [39], for example, justify wind energy planning with strong environmental and social rationale, but their data is dated. Kim et al. [40] and Wang et al. [41] deliver economic assessments of

hydrogen and microgrid systems, respectively, yet fail to capture geopolitical and infrastructural disparities. These oversights can weaken real-world applicability, particularly in diverse regional settings.

In terms of methodological coverage, some works integrate novel tools or combinations of MCDM with AI, such as Ghosh et al. [42] with Artificial Neural Network model (ANN), or Ying-yu and De-jian [43] using fuzzy VIKOR. Despite innovative approaches, these studies often suffer from a lack of empirical validation or scenario testing. Rana et al. [44], Yazdi et al. [45], and Li et al. [46] also venture into advanced hybrid territory but neglect implementation logistics or ecological depth.

Several papers focus on ranking technologies or energy systems. For example, Wang et al. [47], Matulaitis et al. [48], Ezbakhe and Pérez-Foguet [17], and San Cristóbal [49] all use MCDM variants to evaluate and prioritize renewable options. While analytically sound, most studies lack a feedback mechanism, resulting in static outputs that don't evolve with policy or stakeholder input.

In the area of policy alignment and SDG assessment, works like Castor et al. [50], AlArjani et al. [16], D'Adamo and Gastaldi [11], and Meyar-Naimi and Vaez-Zadeh [51] adopt evaluative frameworks, yet often miss full integration of contextual indicators. Siksneilyte et al. [52] and Mardani et al. [12] provide broader MCDM reviews but avoid in-depth critique of method limitations or sectoral fit.

Additionally, several studies lack comparative depth or cross-technology insight. Sindhu et al. [53] and Toosi et al. [54] address regulatory and socio-technical challenges but treat them in isolation. Similarly, Janjic et al. [55], Barin et al. [56], and Ali et al. [57] target specific systems or goals without mapping broader trade-offs. Marzouki et al. [58] uniquely apply social media analytics for SDG tracking, but do not integrate this with structured decision-making.

Overall, existing studies employ MCDM as a static evaluation tool typically for one-off prioritization or site selection without incorporating mechanisms for adaptability, real-time feedback, or iterative refinement. Table 1 summarizes MCDM methodologies and their respective purposes in the current literature.

5. Discussion

This study presents review state of the art of decision-making methodologies for renewable energy systems aimed at achieving the Sustainable Development Goals (SDGs) from literature. By integrating both qualitative and quantitative perspectives, the review enhances our understanding of how decision-making processes shape renewable energy selection and implementation.

5.1. Synthesis of systematic literature review and bibliometric analysis findings

The systematic literature review revealed two major themes: decision-making methodologies and decision criteria. Methodologically, Multi-Criteria Decision-Making (MCDM) approaches are highly prevalent the Analytical Hierarchy Process (AHP) alone accounts for 15.8 % of reviewed studies, with its hybrid forms such as AHP-Fuzzy (13.2 %) and AHP-VIKOR also widely adopted. The widespread use of AHP and its variants highlights their value in systematically addressing the inherent complexity and conflicting objectives in renewable energy planning. Notably, many studies employ AHP for weighting criteria, often pairing it with other techniques to tailor the decision process to specific research or policy goals. However, despite its extensive application for criteria weighting, the actual prioritization and ranking of renewable energy alternatives remains less thoroughly explored, indicating an area for further investigation.

The bibliometric analysis reinforces these findings, identifying "decision making" and "analytical hierarchy process" as central and highly connected keywords within the literature. The keyword network demonstrates that AHP serves as a methodological anchor, enjoying both

Table 1
Review of MCDM methodology use and purpose in renewable energy and sustainability research.

No	Category	Articles (Author, Year)	Objective
1	Renewable Energy Site Selection/ Location Suitability	Tahri et al. (2015) [59], Richards et al. (2025) [19], Richards et al. (2024) [60], Hauger et al. (2025) [34], Flora (2025) [35], Shenouda et al. (2024) [36], Aras et al. (2004) [37], Sugumar & Anglani (2025) [13], Dinçer et al. (2023) [38], Ghosh et al. (2016) [42]	Weighted criteria for identifying and ranking suitable locations for renewable energy projects
2	Technology/Project Prioritization and Ranking	Ezbakhe & Pérez-Foguet (2020) [17], Wang et al. (2019) [47], Matulaitis et al. (2016) [48], Rojas-Zerpa & Yusta (2015) [61], San Cristóbal (2011) [49], Janjic et al. (2012) [55], Büyükoçkan et al. (2018) [20], Elavarasan et al. (2024) [15], Rana et al. (2024) [44], Azzopardi et al. (2013) [62], Li et al. (2025) [46], Ali et al. (2020) [57], Mardani et al. (2015) [12], Toossi et al. (2013) [54], Zhang & Yuan (2005) [65], Jansa et al. (2024) [68], Talinli et al. (2010) [39]	Weighting criteria and ranking renewable energy technologies/projects based on multiple criteria
3	Policy/Sustainability Assessment and SDG Analysis	D'Adamo & Gastaldi (2022) [11], Castor et al. (2020) [50], Meyar-Naimi & Vaez-Zadeh (2012) [51], AlArjani et al. (2021) [16]	Aggregating sustainability and SDG indicators for policy evaluation and guidance
4	Energy Production/Economic Evaluation & Optimization	Wang et al. (2020) [41], Kim et al. (2025) [40], Onar et al. (2015) [64], Sindhu et al. (2016) [53], Ighravwe et al. (2018) [63], Cutz et al. (2016) [66], Yazdi et al. (2025) [45]	Economic and techno-economic evaluation, optimization of renewable energy systems
5	Methodological Reviews and Comparisons of MCDM	Løken (2007) [67], Siksnyte et al. (2018) [52], Mardani et al. (2015) [9]	Review and critique of MCDM methods for energy/sustainability applications
6	Hybrid/Fuzzy or Advanced MCDM for Complex Decision Making	Ying-yu & De-jian (2011) [43]	Use of hybrid/fuzzy MCDM methods to handle uncertainty and complexity
7	Social Media Analytics for Decision Making Policy	Marzouki et al. (2021) [58]	Using social media data analytics (engagement, trends, insights) to inform urban/energy decisions making policy.

widespread adoption and intense scholarly debate, as evidenced by its high link strength and frequent co-citation. In contrast, keywords associated with fuzzy methods appear more dispersed, suggesting a lack of consensus in how uncertainty is managed across studies. The temporal overlay of keyword usage further reveals an evolution from foundational

topics such as sustainable development and multicriteria analysis toward more recent emphasis on policy, SDGs, and advanced MCDA techniques.

While the Analytic Hierarchy Process (AHP) remains widely utilized, it can be limited by its static approach, making it less suitable for highly dynamic contexts where real-time adjustments and evolving stakeholder input are critical. Mohammed et al. [72] highlight that traditional MCDM methods have limitations when dealing with complex real-world problems, advocating for hybrid models and adaptability in decision-support tools. The study demonstrates how MCDM techniques such as AHP, TOPSIS, ELECTRE, and fuzzy logic are increasingly operationalized within computational environments to improve flexibility and scalability. Drawing from these insights, the proposed framework can be extended into a web-based decision-support tool that leverages these digital methodologies. This would facilitate real-time analysis, enhance transparency, and support iterative stakeholder engagement, thereby improving the responsiveness and contextual relevance of renewable energy planning processes. To enhance the practical utility of the proposed decision-support framework, future development could benefit from integrating insights from the software engineering domain, particularly regarding digital implementation.

Criteria analysis shows a strong focus on Technical and Economic (22.8 %), Environmental (21.1 %), and Social (19.9 %) dimensions. Technical criteria, such as reliability, efficiency, and technological maturity, are the most frequently emphasized, underscoring the primacy of technological feasibility in renewable energy project evaluation. Environmental criteria remain highly significant, highlighting the sector's commitment to reducing ecological impacts and supporting the transition to cleaner energy sources. Economic criteria such as investment, financial viability, and cost-effectiveness are equally central, reflecting the critical importance of economic sustainability in energy transitions. Social criteria, while slightly less frequent, play a crucial role by encompassing employment, public acceptance, and broader social benefits.

Less frequently considered are Policy & Regulatory (7.6 %) and Geographical & Land Use (4.7 %) criteria. The relative underrepresentation of these factors signals important gaps, as regulatory environments, institutional frameworks, and location-specific variables often shape the real-world feasibility of renewable energy adoption. The findings suggest that future research and practice would benefit from more robust integration of these contextual and governance-related dimensions.

The review of MCDM methodologies use and purpose across various thematic areas in renewable energy and sustainability research are organized into seven broad categories, ranging from site selection and technology prioritization to economic evaluation, sustainability assessment, and advanced hybrid decision models. Most existing MCDM applications tend to focus narrowly on specific objectives such as site selection, economic efficiency, or sustainability rankings while treating these dimensions in isolation. For instance, studies categorized under renewable energy site selection heavily utilize GIS-based AHP models, but often ignore institutional, political, or socio-cultural dynamics that affect implementation. Similarly, technology prioritization studies generally emphasize technical and economic indicators while underplaying contextual and regional-specific concerns. While these studies contribute valuable insights, they often frame MCDM as a technical ranking mechanism rather than as part of an ongoing decision-making support system that responds to evolving needs and stakeholder contexts.

A key limitation across much of the literature is that decision-making is treated as a linear, one-time process. Once criteria are weighted and alternatives are ranked, the process is considered complete. This approach overlooks the iterative nature of real-world planning, where decisions often need to be revisited, refined, and adjusted based on new data, stakeholder input, or changing policy environments. Additionally, few models support structured feedback loops or allow decision-makers

to reassess and re-balance priorities over time. Moreover, across all categories, there is limited integration of feedback mechanisms, iterative refinement, or stakeholder input after initial analysis. Many decision-support tools end at the recommendation phase without enabling further user engagement or reflection, leading to static outputs that may lose relevance over time.

A critical gap in the existing literature is the absence of adaptive decision-making framework as opposed to static evaluative models that effectively integrates contextual complexity with ongoing stakeholder input and responsiveness. Most MCDM applications remain fragmented and linear, offering one-time rankings or site assessments without mechanisms for feedback, refinement, or alignment with changing real-world conditions. Yet renewable energy planning is inherently dynamic, requiring tools that can respond to shifting policy landscapes, evolving priorities, and diverse stakeholder perspectives needs that are rarely addressed in current MCDM research.

5.2. Rationale of proposed conceptual framework

The proposed conceptual framework addresses this limitation by offering more user-centred approach decision-making support tool. It incorporates flexible criteria selection, user-driven prioritization, context-specific evaluation of renewable energy options, and feedback loops that support continuous improvement. Rather than ending with a final ranked output, the framework supports an ongoing, reflective process where decision-makers can reassess trade-offs, adjust inputs, and enhance the relevance and effectiveness of decisions over time.

This makes the framework fundamentally different from much of the existing literature. Rather than treating MCDM as an isolated technical exercise, it positions it as part of a continuous and context-sensitive decision support system. It also aligns more closely with the complex realities of energy planning, where diverse stakeholders, shifting priorities, and policy uncertainties all play a role. The framework provides a more practical, inclusive, and adaptive foundation for renewable energy prioritization. In doing so, it contributes a novel approach that bridges the gap between theoretical models and real-world decision-making needs.

The next stage of this study is the development of conceptual framework for renewable energy prioritization decision-making support tool that addresses current methodological and contextual gaps. The conceptual framework is designed to provide a systematic approach for prioritizing renewable energy alternatives by integrating context-specific criteria into the decision-making process. The proposed conceptual framework introduces a multi-stage adaptive decision support process for renewable energy prioritization by embedding responsiveness within the MCDM process, the framework directly responds to the limitations identified in the literature. It bridges the gap between technical optimization and real-world applicability, supporting practical and more sustainable renewable energy decisions.

Al Barazanchi and Rasheed [75] highlighted how the integration of adaptable green technologies such as renewable energy systems, carbon capture, and digital monitoring can significantly enhance sustainability outcomes in carbon-intensive sectors. This underscores the importance of developing decision-making frameworks that not only address technical and economic priorities but also evolve in response to changing environmental and policy contexts. Aligning with this perspective, our proposed framework advances beyond static MCDM models by incorporating iterative stakeholder input, adaptive weighting mechanisms, and context-sensitive criteria, thereby enhancing its applicability for real-world renewable energy planning.

This framework will serve as reference to assist policymakers, planners, and other stakeholders in evaluating and prioritizing renewable energy options. By considering a comprehensive set of criteria and tailoring recommendations to specific regional and national contexts, the framework aims to ensure that renewable energy decisions are analytically sound, context-sensitive, and aligned with both local

realities and broader sustainability objectives. Ultimately, it aspires to support effective and inclusive renewable energy adoption, providing clear, evidence-based recommendations to accelerate progress toward achieving the Sustainable Development Goals (SDGs).

6. Conceptual framework for renewable energy prioritization decision making support tool

The transition to renewable energy is essential for addressing climate change, promoting economic growth, and achieving the United Nations' Sustainable Development Goals (SDGs). However, choosing the best renewable energy options for a particular country, region, or project is a complex process, involving many factors such as technology, costs, environmental impact, community needs, and policy considerations.

To address this complexity, the proposed framework adopts an adaptive and context-sensitive approach, allowing expert decision-makers and policymakers the flexibility to tailor criteria based on situational needs. Recognizing the importance of social equity in renewable energy transitions, the proposed framework is designed with adaptability in mind, allowing expert decision-makers and policymakers the flexibility to include equity-related considerations as part of the decision-making criteria when deemed relevant. Drawing insights from Jiao and Tan [73], potential social dimensions such as affordability, accessibility, distributive impacts on vulnerable populations, employment opportunities, and gender considerations can be incorporated based on contextual priorities and local conditions. Furthermore, social equity is closely intertwined with policy design and geographic accessibility, particularly in underserved regions. These insights reinforce the need for decision-making tools that are sensitive not only to social but also to regulatory, institutional, and spatial factors. Accordingly, the proposed framework enables the inclusion of policy and geographical dimensions such as regulatory readiness, land use constraints, and infrastructure access into the evaluation process, thereby enhancing its relevance for diverse real-world contexts. During the weighing and prioritization stages, decision-makers can emphasize these contextual factors to ensure that renewable energy decisions remain both equitable and grounded in practical implementation realities. During the weighting and prioritization stages, decision-makers have the flexibility to emphasize these equity-oriented factors, thus ensuring renewable energy decisions are adaptable to encompass broader social and equity objectives alongside technical and economic factors.

To help with this challenge, our study proposes conceptual framework for a decision-making support tool that offers a clear, step-by-step approach for prioritizing renewable energy solutions. This conceptual framework is designed to help policymakers, planners, and stakeholders make informed choices that support sustainable development. The conceptual framework is organized into sequential, interlinked phases that are built on one another. Although various MCDM methods exist, the fundamental steps common to any MCDM process are: (1) defining the relevant criteria and potential alternatives; (2) establishing the relative importance of each criterion and evaluating the impacts of the alternatives; and (3) analyzing the performance of these alternatives using an appropriate MCDM approach Triantaphyllou [69]. As shown in Fig. 5, the conceptual framework for web-based decision-making support unfolds in five stages.

1 Identifying Key Factors

The first phase of the framework focuses on identifying and selecting the most relevant decision criteria. This stage ensures that decision-making processes are more inclusive, context sensitive, and adaptive to evolving local conditions and stakeholder needs.

2 Weighting and Balancing Priorities

After criteria are selected, the framework applies MCDM techniques

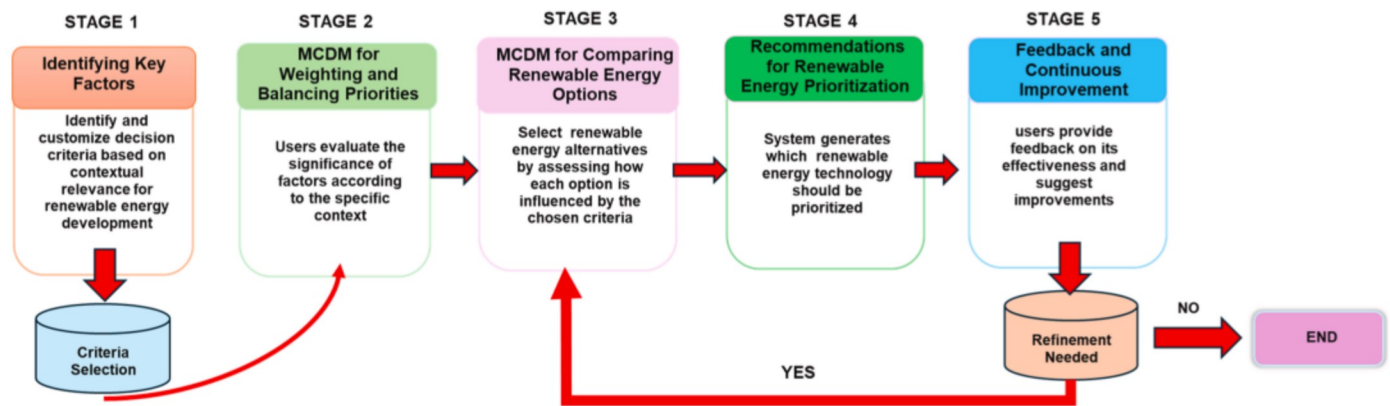


Fig. 5. Conceptual framework for decision making support tool for renewable energy prioritization.

to determine the relative importance of each criterion. This step ensures that the weightings reflect the priorities of stakeholders and the unique context of the decision environment, rather than relying on generic or externally imposed values. Recognizing that every context is unique, users reflect on which factors are most significant for their region or community. For instance, some areas may prioritize job creation, while others may emphasize environmental protection or energy costs. This stage ensures that the prioritization process is tailored to local needs and values.

3 Comparing Renewable Energy Options

In the next phase, alternative renewable energy technologies are evaluated against the weighted criteria using MCDM methods. This systematic comparison allows for transparent and evidence-based ranking of options, ensuring that recommendations are robust and tailored to local needs. Users select renewable energy alternatives by assessing how each option is influenced by the chosen criteria. This step helps users see the impact of each criterion on different renewable energy technologies, supporting an informed and context-sensitive comparison.

4 Providing Recommendations for Renewable Energy Prioritization

Based on the evaluation against the selected criteria, the system generates recommendations indicating which renewable energy technology should be prioritized. This allows decision-makers to focus on options that best meet local needs and support sustainable development goals. This stage is critical for aligning decisions with both local priorities and the overarching SDGs.

5 Feedback and Continuous Improvement

A distinguishing feature of this framework is its feedback mechanism. Stakeholders are invited to provide input on the effectiveness and practicality of the recommendations. If feedback indicates the need for refinement, the process loops back to earlier stages, enabling continuous learning and adaptation. This iterative loop ensures the framework remains relevant and responsive as contexts and priorities evolve.

The proposed conceptual framework distinguishes itself by incorporating an iterative feedback loop that allows stakeholder perspectives and dynamic contextual data to shape renewable energy planning over time. This stakeholder-inclusive and adaptive approach addresses the limitations of static decision models that fail to evolve with changing socio-technical conditions. A similar philosophy is evident in Yang et al. [71], who developed a deep learning-based crop monitoring system capable of adapting to evolving environmental inputs and user feedback. Their system highlights the value of embedding continuous feedback

and participatory insights in decision-making, principles that align closely with the cyclical nature of our proposed renewable energy planning framework.

The framework considers a range of contextual factors in renewable energy decision-making. It includes a feedback mechanism that encourages ongoing stakeholder engagement and allows for continuous refinement, helping the approach remain responsive to changing needs and circumstances. Aligning decision-making processes with both local priorities and the Sustainable Development Goals (SDGs), the framework aims to support the development of effective and contextually relevant strategies for sustainable energy transitions. With this approach, policymakers are expected to make smarter and more sustainable choices about which renewable energy projects to pursue. The process helps ensure that energy decisions are not only technically sound and economically viable, but also socially responsible and aligned with national and global sustainability goals.

7. Hypothetical use case

To demonstrate the practical application of the proposed framework, a hypothetical use case was developed for a mid-sized province in Indonesia seeking to prioritize renewable energy investments. The example reflects commonly used criteria in renewable energy planning, such as cost, emissions, and socio-economic impact (e.g., Sugumar & Anglani [13]; Elavarasan et al. [15]). Local stakeholders identified key decision criteria: levelized cost of energy (LCOE), CO₂ emissions reduction potential, job creation, land availability, and policy support. Using AHP, stakeholders assigned weights to each criterion reflecting local priorities, with job creation and cost given the highest importance. Five renewable energy options: (1) solar, (2) wind, (3) bioenergy, (4) geothermal, and (5) hydro were evaluated based on hypothetical performance scores. The framework processed these inputs to generate a ranked recommendation, prioritizing solar and bioenergy as the most suitable technologies. Stakeholder feedback suggested adjustments to the environmental weighting, prompting an iterative re-evaluation. This hypothetical walkthrough illustrates how the framework enables transparent, adaptive, and SDG-aligned decision-making even in data-scarce or rapidly evolving policy environments. Table 2 illustrates a hypothetical application of the proposed framework, demonstrating how renewable energy options can be evaluated and prioritized based on context-specific criteria, stakeholder-assigned weights, and iterative feedback in a decision-making scenario for an Indonesian province.

In contrast to previous literature where MCDM methods were primarily used for static evaluations, the proposed framework incorporates a feedback loop and contextual weighting that would allow for iterative refinement and alignment with evolving policy conditions.

Table 2

Hypothetical application of the proposed framework for renewable energy prioritization in an Indonesian province.

Stage	Description	Illustrative Input/Output
1	Identifying Key Factors	Criteria: LCOE, CO ₂ reduction, Job creation, Land availability, Policy support
2	Weighting Priorities (AHP)	Weights: Job creation (0.30), LCOE (0.25), CO ₂ reduction (0.20), Policy (0.15), Land (0.10)
3	Evaluating Alternatives	Technologies evaluated: Solar, Wind, Bioenergy, Geothermal, Hydro Sample scores (1–5 scale): e.g., Solar scores 5 in LCOE and 4 in Job creation
4	Generating Recommendations	TOPSIS or weighted scoring output ranks: 1) Solar, 2) Bioenergy, 3) Wind, 4) Geothermal, 5) Hydro
5	Feedback & Refinement	Stakeholders suggest increasing weight on CO ₂ reduction leads to updated rankings on re-evaluation which might change the ranking output

8. Conclusion

This paper provides insights into the decision-making methodologies applied in renewable energy system selection, particularly in the context of achieving Sustainable Development Goals (SDGs). The findings indicate that AHP is widely utilized for evaluating renewable energy projects. Review of 43 peer-reviewed articles on renewable-energy decision-making, adhering to PRISMA guidelines, to map out the landscape of multi-criteria approaches and their alignment with the SDGs. We found that while the previous studies are increasingly adopting frameworks such as AHP, fuzzy logic, and hybrid MCDM methods, most studies remain narrowly focused on technical and economic dimensions, often overlooking context-specific factors that can significantly influence the success of renewable energy projects such as institutional regulatory factors. Based on the review of existing literature there is research gap in the absence of decision-making support tool that can effectively integrate contextual complexity with ongoing stakeholder input and responsiveness.

In response to these findings, this study proposes a conceptual framework for a decision-making support tool that is adaptive, context-sensitive, and grounded in continuous feedback. The framework is designed to guide the prioritization of renewable energy technologies by integrating local conditions, societal values, and policy dynamics with technical, economic, and environmental criteria. Unlike rigid, one-size-fits-all models, this approach incorporates mechanisms for stakeholder input and iterative learning, allowing the framework to evolve based on changing needs and feedback from users. This enables policymakers to evaluate renewable energy options systematically while ensuring the decisions reflect the real-world complexities and aspirations of the communities they aim to serve. By integrating these dimensions into a structured MCDM model, the framework aims to empower policymakers to make choices that are both sustainable and well-suited to local circumstances. This approach enhances the practical relevance of decision-support tools and ensures that renewable energy investments are more likely to gain community acceptance and deliver meaningful, long-term benefits. This conceptual framework will guide policy makers in systematically evaluating the performance of different type of renewable energy technologies based on these criteria in alignment with SDGs and provides a foundation for more inclusive, context-aware, and effective renewable energy planning.

To illustrate the practical utility of the proposed framework, a hypothetical use case was developed for a mid-sized province in Indonesia. Local stakeholders were involved in identifying decision criteria such as Levelized Cost of Energy (LCOE), CO₂ reduction, job creation, land availability, and policy support. AHP was used to assign weights based on local priorities, and five renewable energy options such as solar, wind, bioenergy, geothermal, and hydro were evaluated. The results

prioritized solar and bioenergy based on the composite performance and local preferences. Importantly, stakeholder feedback prompted adjustments to environmental weightings, demonstrating the framework's capacity for adaptive, transparent, and context-aware decision-making. This scenario shows how the framework functions even in data-scarce or rapidly evolving environments and strengthens SDG alignment through grounded community input.

This study contributes to academic literature by identifying critical gaps in current renewable energy decision-making approaches, particularly the lack of context-specific analysis and the absence of continuous feedback mechanisms within MCDM frameworks. By introducing a region-specific contextual dimension aligned with the evaluation structure of the SDGs, this research advances a more nuanced and context-sensitive analytical approach. For policymakers, the conceptual decision support tool offers a practical pathway to systematically compare renewable energy technologies and develop strategies that align with national and global sustainability targets, thereby directly supporting progress toward national and global SDG targets such as SDG 7 (Affordable and Clean Energy).

CRedit authorship contribution statement

Karmila Seran: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **James Rotimi:** Supervision. **An Le:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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