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Review article

Decision support systems for waste-to-energy technologies: A systematic literature review of methods and future directions for sustainable implementation in Ghana

Theophilus Frimpong Adu [a,b,d,*], Lena Dzifa Mensah [a], Mizpah Ama Dziedzorm Rockson [c], Francis Kemausuor [d]

[a] Department of Mechanical Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
[b] Department of Renewable Energy Technology, Cape Coast Technical University, Cape Coast, Ghana
[c] Department of Chemical Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
[d] Energy Centre, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

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ABSTRACT

Waste-to-energy (WtE) technologies play a crucial role in sustainable waste management and energy production. Decision-making in this context requires a comprehensive and structured approach to balance the environmental, socio-economic, and technical dimensions. This systematic literature review aims to provide an overview of the applications of Decision Support Systems (DSS) in the field of WtE, identify key trends, and outline future research directions. The study utilized the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach in analyzing and synthesizing a diverse range of studies to identify key observations, trends, and a pathway for future research. The study has addressed its primary objectives through a rigorous analysis of existing scholarship, identification of essential decision-making criteria, assessment of DSS methodologies' efficacy, and identification of knowledge gaps and future research directions. The review reveals that DSS methodologies, particularly Multi-Criteria Decision Analysis (MCDA), Geographic Information Systems (GIS), and Life Cycle Assessment (LCA), have significantly contributed to enhancing decision-making processes in the WtE sector globally. These tools have demonstrated their effectiveness in handling the complex, multi-faceted nature of WtE technology selection and implementation, addressing issues ranging from site selection to technology ranking based on multiple criteria. The research identifies key criteria for WtE technology selection in Ghana, including technical feasibility, environmental impact, economic viability, social acceptability, and energy efficiency. The study also highlights significant gaps in the current application of DSS to WtE technologies, particularly in the context of developing nations like Ghana. Many existing DSS approaches fail to adequately account for local socio-economic factors, rely on static data, and do not fully incorporate diverse stakeholder perspectives. Adapting global DSS applications to the Ghanaian context requires careful consideration of local priorities, data availability, and the role of the informal waste sector. The review proposes a holistic approach to DSS development, emphasizing the need for context-specific, dynamic, and inclusive methodologies. Future research directions identified by this study include the development of Ghana-specific DSS models, integration of real-time data collection methodologies, creation of user-friendly interfaces for local decision-makers, and exploration of emerging

* Corresponding author. Department of Mechanical Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.
E-mail address: du.frimpong@cctu.edu.gh (T.F. Adu).

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technologies such as blockchain and IoT or Machine learning (ML) for enhancing DSS in WtE management.

1. Introduction

1.1. Background

The global municipal solid waste (MSW) production stands beyond 2 billion tons annually with a projection of 3.4 billion tons by 2050 [35]. The rise in MSW generation in Africa coupled with ineffective waste management systems can cause significant global health and environmental impacts [115]. For instance, the disposal and burning of solid waste in open landfills results in the emission of high amounts of greenhouse gases (GHG), as well as air and water pollution. Besides, the scarcity of suitable land for new landfill facilities makes this type of waste management unsustainable for Developing Countries in Africa [111]. The rising rate of MSW generation in Ghana is a growing concern, driven by population growth, urbanization, and socio-economic factors ([93,95,99]). Similar studies shows that a significant portion of the municipal solid waste generated in Ghana is organic, contributing to environmental issues like air pollution, water contamination, and the spread of diseases ([99,105,112]).

Waste management in Ghana faces a multitude of challenges arising from a complex interplay of regulatory frameworks, socio-economic factors, and other issues. Despite the decentralization of waste management through the Local Government Act of 1993, waste management challenges persist. Local authorities often lack effective strategies and regulatory enforcement ([99,107]), resulting in inefficiencies in waste collection and disposal. A substantial portion of daily waste generation remains uncollected, exacerbating the problem [42]. The absence of proper waste segregation at the source of generation hampers the acquisition of reliable waste data ([60,102,121]). Complex interactions among the stakeholders have led to disparities in waste collection fees [63]. Citizens' behaviors, attitudes, and education levels also contribute to indiscriminate dumping of waste, while the lack of sanctions for non-compliance with local authorities' by-laws on solid waste management further complicates the issue [64]. Moreover, the absence of appropriate cost recovery strategies for low-income groups hampers effective waste management [42].

The Renewable Energy Master Plan (REMP) for Ghana presents significant potential for WtE conversion. However, regulatory and operational challenges have hindered its realization [100]. Although some municipalities have initiated waste recycling efforts, these programs remain limited in scope, with a focus primarily on plastics and metals, neglecting organic waste recycling. Despite favorable provisions for renewable energy technologies adoption in the Renewable Energy Act, 2011 (Act 832), the implementation of WtE technologies remains limited in Ghana due to low government commitment (and an unclear pathway for WtE adoption), excess electricity capacity, and unfavorable perceptions of technologies such as incineration. Several WtE plants in Ghana have faced failure due to issues such as low feed-in tariffs and challenges related to obtaining Power Purchase Agreements (PPAs) [107]. Effective waste management planning and policy development are essential for addressing these challenges.

The incorporation of Decision Support Systems (DSS) within Waste-to-Energy (WtE) technologies in Ghana remains in its formative phase, characterized by several significant knowledge gaps that hinder extensive implementation. Rectifying these deficiencies is imperative for maximizing the efficacy of WtE technologies in advancing sustainable development objectives (SDGs) in Ghana. The identified gaps include: the availability and quality of data, the contextual adaptation of DSS models, the integration of socio-environmental factors, as well as the support from policy and regulatory frameworks. A principal constraint is the absence of high-caliber, real-time data concerning waste generation, composition, and energy potential. The existing datasets in Ghana frequently present fragmentation, obsolescence, or inaccessibility, thereby obstructing the formulation of robust DSS instruments that necessitate dependable input data [81]. Additionally, numerous existing DSS frameworks for WtE technologies are conceived in environments that may not correspond directly with the socio-economic and environmental contexts of Ghana. For instance, financial and technical premises within these models frequently neglect the distinctive challenges posed by informal waste management practices and the inadequate infrastructure prevalent in Ghana [59]. Moreover, current DSS tools for WtE technologies predominantly emphasize technical and economic feasibility, with insufficient attention directed towards socio-cultural acceptance and environmental trade-offs. This deficiency is of considerable significance, as community engagement and compliance with environmental regulations are essential for the successful implementation of WtE initiatives in Ghana [82]. Furthermore, there exists a notable insufficiency in the integration of DSS tools into policy frameworks that would assist decision-makers in the sustainable selection and execution of WtE technologies. This gap constrains stakeholders' capacity to effectively assess competing WtE alternatives amidst varying regulatory and economic landscapes.

A systematic literature review approach is appropriate for mapping of available evidence due to the broad and complex field of sustainable WtE area [73]. This approach allows for an assessment of how research on WtE technologies and decision support systems has been conducted. By systematically reviewing the literature, a scoping review can highlight areas where research is lacking, particularly in the context of Ghana.

1.2. Objectives of the systematic literature review

Literature search reveals numerous published data on waste-to-energy technologies [2]. Nevertheless, information on the decision support systems as a strategic tool for the implementation waste-to-energy technologies in the developing countries are yet to be synthesized. It has then become necessary to conduct a systematic literature review to systematically gather studies and evaluate to

produce synthesized knowledge that can serve as a guide for further studies. Systematic literature review is employed in this study to aggregate critical information for decision-making and to efficiently move from knowledge discovery to implementation of waste to energy technologies in developing countries. Many authors have made an effort to apply systematic literature review in the waste management sector ([25,50,74,86]). For instance Refs. [28,30], used systematic literature review to investigate the urban waste challenges and the environment treat associated with solid waste [46]. adopted a systematic literature review to explore social dimensions of municipal solid waste management around the globe [49]. also conducted a systematic literature review of the research studies on electronic-waste management in Sub-Saharan Africa in 2020 [65]. used systematic literature review approach to synthesize knowledge on the benefits, challenges and critical factors of success for zero waste implementation [22]. also conducted a similar study to investigate the social dimension of municipal solid waste management systems through life cycle evaluation. Lastly [47,55], employed systematic literature review approach to investigate the application of internet of things (IoT) and artificial intelligent techniques in solid waste management.

Also, efforts have been made by some authors to apply systematic review in the waste to energy conversion studies. For instance Ref. [31], adopted a systematic literature review to synthesize knowledge on sustainable food waste management and to explore the factors that contribute to the adoption waste to energy technologies in managing in food waste [16]. investigated the adoption of municipal solid waste treatment technologies through the lens of circular economy using both systematic and bibliometric approach [13]. conducted a systematic literature review on the adaptation of waste-to-energy technologies for renewable energy generation [88]. adopted systematic literature review approach to synthesize research knowledge on the status and future directions food waste-to-energy conversion technologies [23]. employed systematic literature review approach to investigate on the life cycle assessment of different waste to energy valorization technologies [85]. performed systematic review of scientific publications on the technological development and decision support systems to aid solid-waste management. Similarly [14], used systematic review to knowledge on the progress of studies on decision support tools for the assessment circular biowaste management systems [23]. adopted a systematic literature review on life cycle assessment of different waste to energy valorization technologies.

Decision Support Systems (DSS) have been employed in various studies to address waste disposal siting challenges and evaluate waste treatment methods. For instance Ref. [92], effectively used GIS techniques for regional bioenergy sources and organic waste management. Similarly [41], employed multiple DSS methodologies to assess potential waste disposal sites, while [11] used GIS-based MCDA for radioactive waste site selection [101]. combined GIS and Hesitant Fuzzy Linguistic Term Sets (HFLTS) for landfill site assessment [96]. also combined Single Valued Neutrosophic Sets (SVNSs), Decision-Making Trial and Evaluation Laboratory-Analytical Network Process (DANP), and GIS for WtE plant site selection [71]. used GIS and MCDA techniques to arrive at suitable landfill sites in Ghana. Though these and other studies have touched upon some decision support systems for waste to energy technologies implementation, this study specifically aims to synthesize key decision-making criteria and strategies for selection and implementation of optimum WtE for energy access in Ghana, which may not have been meticulously addressed in previous literature reviews. The primary research questions the need to be answered by the systematic review include: How can DSS be effectively utilized to optimize the selection and implementation of WtE technologies for sustainable waste management and energy access in Ghana? The secondary research questions include: i). What are the fundamental criteria and methodologies for decision-making pertaining to the selection and execution of Waste-to-Energy (WtE) technologies? ii). In what ways have diverse DSS methodologies, such as GIS, and MCDA, been utilized in the global selection and implementation of WtE technologies? iii). What are the significant deficiencies in the present utilization of DSS for WtE technologies? iv). In what manner can the insights acquired from international DSS applications in WtE be tailored to fit the specific context of Ghana? Therefore, the objectives of this study are: i). To conduct a comprehensive synthesis and critical analysis of the existing scholarship regarding the application of Decision Support Systems (DSS) in the selection and implementation of WtE technologies. ii). To identify the essential decision-making criteria and strategies that are pertinent to the Ghanaian context, aimed at achieving optimal selection of WtE technologies. iii). To assess the efficacy of various DSS methodologies in addressing the challenges associated with WtE technologies within developing nations. iv). To pinpoint existing knowledge gaps and identify prospective avenues for future research concerning the application of DSS in relation to WtE technologies in Ghana. This study thus, aims to aggregate critical information for decision-making and to efficiently move from knowledge discovery to implementation of waste to energy technologies in Ghana.

The results of this study have important applied implications for sustainable waste management and policy-making in developing countries. This study can serve as a guide for stakeholders and researchers on the most relevant and influential research in the field of waste management. The subsequent sections of this manuscript are organized in the following manner. Section 2 presents an outline of the methodology, detailing the process of data collection, data extraction, screening, quality assessment and systematic review approach used in this study. Section 3 delves into the results, synthesizes the discoveries and puts forward potential avenues for future research. Lastly, Section 4 wraps up the study by concisely summarizing the essential insights and underscoring the importance of this study regarding the adoption of WtE technology in Ghana.

2. Methodology

The study employed the systematic review approach to guarantee the thoroughness and replicability of the review process. To encompass a broad range of relevant studies for inclusion in the review, a comprehensive search strategy was formulated. The study employed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach, which consists of guidelines that furnish a checklist to ensure the quality and replicability of the review procedure. The PRISMA approach contributes to upholding consistency and transparency in the review process. The study devised a systematic process that outlined the criteria for selecting articles, the systematic approach for data query (literature search), and the strategies used for data extraction and analysis. Different

sections of the study adhered to the PRISMA approach to guarantee the quality and replicability of the systematic review.

2.1. Literature search

To identify relevant studies for our research, we conducted a comprehensive search across various electronic databases, academic journals, conference proceedings, and reputable sources. The selected electronic databases included Google Scholar, Scopus, and Web of Science. The interface used for the literature search for database include: Google Scholar - Google Scholar web interface (scholar.google.com), Scopus - Elsevier Scopus web interface (www.scopus.com), and Web of Science - Clarivate Web of Science web interface (www.webofscience.com). We used a well-defined set of keywords and search strings related to WtE technologies and decision support systems. Keywords related to WtE Technologies include: Waste-to-Energy, Energy Recovery from Waste, Waste Incineration, Anaerobic Digestion, Pyrolysis, Gasification, MSW, Renewable Energy from Waste, and Thermal Conversion of Waste. Keywords related to Decision Support Systems include: Decision Support Systems, Decision Making, Decision Analysis, Multi-Criteria Decision Analysis (MCDA), Multi-Objective Optimization, Decision Support Tools, Decision Support Models, Policy Decision Support, and Environmental Decision Support Systems.

For Scopus and Web of Science databases, the search strings used were: ("Waste-to-Energy" OR "Energy Recovery from Waste" OR "Waste Incineration" OR "Anaerobic Digestion" OR "Gasification" OR "Pyrolysis" OR "Biomass Energy" OR "Renewable Energy from Waste" OR "Thermal Conversion of Waste") and ("Municipal Solid Waste") and("Decision Support Systems" OR "Decision Making" OR "Decision Analysis" OR "Multi-Criteria Decision Analysis" OR "Multi-Objective Optimization" OR "Decision Support Tools" OR "Decision Support Models" OR "Environmental Decision Support Systems" OR "Policy Decision Support"). A search validation procedure was designed to ensure that the literature review captures the most relevant and important papers in the field of Decision Support Systems for Waste-to-Energy technologies. The search validation procedure include: i). Using a set of known, highly relevant papers as a benchmark, ii). Iterative refinement of the search strategy based on initial results, iii). Supplementary strategies to capture any papers that might be missed by database searches alone, iv). Thorough documentation of the process for transparency and reproducibility. This approach helps to lessen the risk of missing crucial literature, and provide a systematic and transparent method for developing and refining the search strategy.

2.1.1. Inclusion and exclusion criteria

To refine our search results, we established inclusion and exclusion criteria, as outlined in Table 1. These criteria were applied to determine which studies were relevant for our review.

We excluded review papers, editorials, book chapters, grey literature, preprints, and unpublished studies to ensure the elimination of bias and data duplication. However, reviews were used initially for reference chaining to identify relevant primary research papers. The search was conducted from 2010 to 2023, and the initial search was performed on October 24, 2023. The potential explanatory variables for which data was sought for WtE DSS Outcomes in Ghana is presented in Table 2.

2.2. Data extraction, screening, and study selection

The initial search yielded a total of 1816 literature sources, with 583 in Web of Science, 163 in Scopus, 644 in Google Scholar, and additional 426 records from other registered sources. Records from Web of Science, and Scopus were extracted in RIS text files, while those from Google Scholar and other sources were downloaded directly for screening in Rayyan systematic review software. Screening was first conducted based on the literature titles and abstracts to select related or relevant studies. Afterward, the full texts of these relevant studies were reviewed to determine if they met the set inclusion criteria. This process resulted in the creation of a final list of studies to be included in the review.

We used the Rayyan systematic review platform for de-duplication and study selection, and the full-text assessment and review was done manually. We followed the PRISMA Systematic Review flowchart to report both retained and excluded articles, along with reasons for their inclusion or exclusion, as illustrated in Fig. 1.

Table 1
Inclusion and exclusion criteria.

Inclusion criteria	Indicator for selection
Search strategy	keywords and abstracts
Time period	Between 2010 and 2023
Language	English
Document type	Peer-reviewed articles, theses and dissertations, technical reports, Conference papers were considered.
Exclusion criteria	**Indicator for rejection**
Field of study	Studies unrelated to or lacking a clear link to WtE conversion technologies
Accessibility	Articles with missing bibliometric data and those without full text access
Deletion	Duplicate records, reviews, editorials, book chapters, grey literature, preprints, unpublished studies

Table 2
List and description all variables for which data were sought.

Variable	Description Variables
Characteristics of Decision Support Systems (DSS)	Type of DSS methodology used (e.g., GIS, MCDA, AHP, TOPSIS) Integration of multiple DSS methods
Waste-to-Energy (WtE) Technology Factors	Type of WtE technology considered Technological maturity
Socio-economic Factors	Economic development level for WtE adoption Social acceptance
Stakeholder Engagement	Degree of community involvement in decision-making Partnerships between public and private sectors
Technical Capacity	Availability of skilled labor for WtE operations Local technical expertise in DSS and WtE technologies Access to technology and maintenance support
Environmental Considerations	Local environmental regulations and standards Baseline environmental quality (air, water, soil) Climate change mitigation goals
Data Availability and Quality	Availability of accurate waste data Quality and comprehensiveness of geographical data Accessibility of socio-economic and environmental data

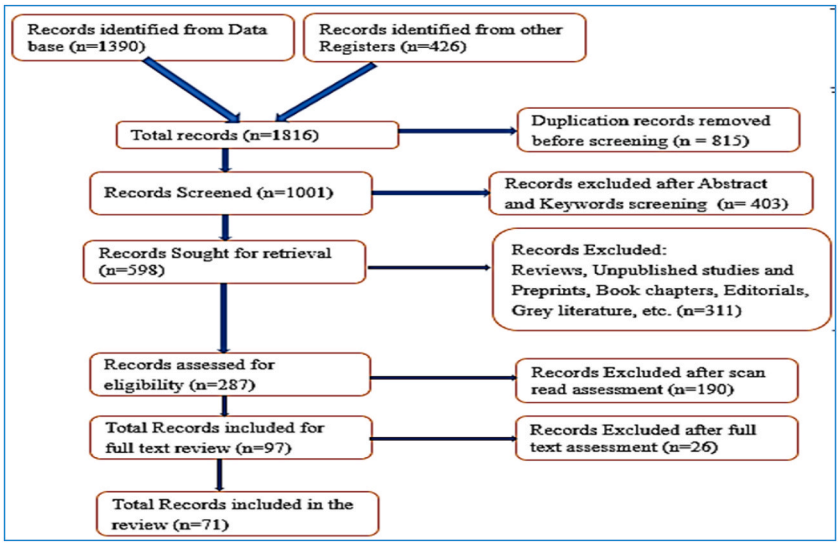

Fig. 1. Literature search and selection flow chart adopted from PRISMA.

2.3. Data extraction, data charting method and quality assessment

The process of data charting for this scoping review adheres to the framework articulated by Ref. [8], which has been modified to align with the specific context of Decision Support Systems (DSS) pertinent to Waste-to-Energy (WtE) technologies within the Ghanaian setting. This methodology guarantees a systematic and exhaustive extraction of pertinent information from the sources of evidence that have been incorporated. A standardized data charting instrument was developed through an iterative process undertaken by the research team. The initial iteration of this instrument was grounded in the research inquiries and objectives of the review, integrating key variables identified during the preliminary scoping of the literature. This preliminary form was subsequently piloted by two members of the team independently on a varied sample of studies selected from the literature. The outcomes of this pilot study were compared and deliberated upon among the entire research team, culminating in enhancements to both the structure and content of the instrument. This iterative process was conducted until the team achieved a consensus regarding the comprehensiveness and usability of the instrument.

The finalized data charting instrument encompasses fields pertaining to: Study characteristics (e.g., authors, publication year, geographical focus), types of DSS employed, and methodological approaches, WtE technologies evaluated, essential decision-making criteria, significant findings and outcomes, limitations, and prospective research directions. In accordance with the Arksey and O'Malley framework, the data charting was executed in duplicate by two independent reviewers (registered in Rayyan) for each study included in the review. This methodological approach serves to mitigate bias and ensures the integrity of the extracted data [57]. The two reviewers utilized the calibrated data charting instrument to extract relevant information independently from each study. Regular

meetings of the research team were convened to discuss advancements and to address any challenges or discrepancies that arose during the charting process. In instances where the two reviewers reached differing conclusions regarding the extracted data, a third team member was consulted to mediate and render a final judgment. This process was meticulously documented to uphold transparency and reproducibility of the review. Once the data had been graphed, the research team applied both statistic and narrative techniques to merge the information they obtained [32]. The quantitative synthesis encompassed descriptive statistics regarding study characteristics and DSS methodologies, while the qualitative synthesis involved thematic analysis aimed at identifying key trends, gaps, and future research directions within the domain of DSS for WtE implementation.

3. Results and discussion

3.1. Frequency of use of various DSS methods

The frequency of use of various DSS methods suggests a comprehensive and systematic approach to the selection and implementation of WtE technologies. Researchers and Decision makers leverage on a variety of tools and techniques to address the multifaceted challenges and considerations associated with WtE technology projects. Table 3 demonstrates the use of DSS methods in studies related to WtE implementation included in this review. The table provides a comprehensive overview of various studies by: their objectives, types of DSS used and analytical method, and key findings related to WtE implementation. The Table demonstrates the versatility and significance of DSS in addressing a wide range of WtE challenges.

It is obvious that most of the studies demonstrate high methodological rigor in the context of the research question, with some exceptions that need more clarity or validation of their methodologies in the WtE context. In order to understand the dominance use of theses DSS tools by Researchers in the waste sector, their frequency of use was analyzed bases categories. Fig. 2 shows the frequency of the category of DSS tools used by different authors in the selected studies. While some authors used one DSS tool for their analysis most authors however used more than one DSS tools in a particular study.

3.2. Evaluation of methods for selecting waste-to-energy technology

The literatures considered under the study generally suggest that selecting the optimal waste-to-energy (WtE) technology requires a context-specific and data-driven approach that considers project objectives and stakeholder perspectives. While quantitative methods provide valuable data, incorporating qualitative factors and engaging stakeholders ensures a robust decision-making process. Continuously validating models and updating data based on changing conditions is crucial for long-term success. The specific inputs required for selecting suitable technologies will vary depending on the chosen method, project details, available data, and geographic location. Combining quantitative data, expert opinions, and stakeholder perspectives often leads to the most comprehensive decisions. Regardless of the chosen approach, validating inputs and continuously updating data are essential for ensuring the reliability of results and long-term effectiveness.

Table 4 presents an evaluation of different methods for selecting WtE technology, highlighting key factors to consider for each. This information can guide decision-makers in selecting the approach best suited to their specific context and needs.

3.3. Discussion

This section discusses the contributions of DSS methodologies to the WtE sector. It identifies ways to address existing gaps and provides insights to the Ghanaian context through evaluation of DSS methods, highlights knowledge gaps and future research directions. The systematic review of studies reveals significant insights and patterns regarding the utilization of Decision Support Systems (DSS) in the adoption of Waste-to-Energy (WtE) technologies. Decision Support Systems (DSS) methodologies have contributed to the WtE sector in multiple ways. And diverse array of DSS tools and methodologies employed across various studies reflects a deliberate alignment of approaches with specific research objectives. For instance, Geographic Information Systems (GIS) have been instrumental in site selection processes, considering geographical constraints, proximity to waste sources, and environmental sensitivity ([11,12,41]). Multi-Criteria Decision Analysis (MCDA) has been employed to rank and select WtE technologies based on multiple criteria, often incorporating stakeholder preferences ([2,33,117]). Fuzzy Logic has been applied to handle uncertainties inherent in decision-making processes ([54,92]). Life Cycle Assessment (LCA) has been utilized for evaluation of the environmental impacts of different WtE technologies [36]. Additionally, integrated approaches combining multiple DSS tools (e.g., GIS-MCDA) have been adopted to provide more comprehensive decision-making frameworks ([21,29,92]). The review identified several fundamental criteria for decision-making pertaining to the selection and execution of WtE technologies. These include technical feasibility considering local infrastructure, environmental impact (particularly waste reduction and emissions), economic viability (including job creation potential), social acceptability and cultural appropriateness, energy efficiency and contribution to energy access, and waste reduction potential ([1,6]).

Decision Support Systems (DSS) methodologies have demonstrated efficacy in addressing challenges associated with WtE technologies in developing nations by handling complex, multi-criteria decisions, addressing geographical constraints, evaluating environmental impacts, and incorporating stakeholder perspectives [48]. Life Cycle Assessment (LCA), Safety Health Environmental (SHE) index, and comprehensive stakeholder analyses offer complementary perspectives [18]. However, despite these contributions, several significant gaps exist in the present utilization of DSS for WtE technologies. Many studies inadequately consider specific socio-economic and cultural factors in developing countries like Ghana ([13,83]). Also, most DSS tools rely on static data, limiting their

Table 3
Critical appraisal of selected studies that relates to DSS in WtE technologies.

Author	Study objectives	Types of DSS used,	Key findings
[41]	To determine appropriate locations in Peninsular Malaysia for the establishment of a repository for the disposal of sealed radioactive sources (DSRS) and to implement a permanent disposal facility.	GIS-based Weight Linear Combination (WLC) analysis, improved AHP, and TOPSIS	The top five potential sites are ranked, with Jerantut & Ulu Lepar, Bandar Tun Razak, Tanjung Ipoh, Labis, and Simpang Pertang emerging as leading candidates. The paper emphasizes the importance of these methodologies in radioactive waste management and highlights the need for considering critical factors like hydrogeology, seismicity, and lithology in future site selection projects.
[11]	To select suitable sites for the disposal of radioactive waste generated by the Akkuyu Nuclear Power Plant in Turkey using GIS-based Multi-Criteria Decision Making (MCDM) methodologies.	GIS-based MCDM	It effectively showcases the utility of GIS-based MCDM as an evaluative instrument in the process of RWDF site selection. The investigation employs a total of 12 data layers encompassing geodetic, geological, geophysical, hydrological, chemical, and mechanical factors to ascertain the most suitable locations for RWDF
[5]	To choose a suitable WtE technology while considering both the subjective perspective of decision-makers and the objective evaluation of performance metrics for each alternative.	Fuzzy-AHP and Fuzzy-MULTIMOORA	The findings rank anaerobic digestion as the ideal WtE technology for implementation in Cape Town, followed by gasification, pyrolysis, and incineration. The study suggests the promotion of integrating anaerobic digestion and gasification for a well-balanced WtE technology.
[45]	To comprehensively analyze the strengths, weaknesses, opportunities, and threats (SWOT) factors related to the implementation of WtE (WtE) in Pakistan and develop strategic plans based on these factors.	MCDM with fuzzy set and grey system theories	The identification of 28 SWOT sub-factors, the formulation of 12 SWOT strategies, and the prioritization of strategies based on their quantitative significance. The study reveals the importance of considering opportunities and renewable energy generation in the context of sustainable WtE in Pakistan, with a focus on enforcing a fixed share of WtE feed into the national energy mix.
[61]	To assess landfill locations using GIS and MCDA techniques.	GIS, HFLTS and TOPSIS	the identification of 12 alternative landfill site locations, with environmental criteria exhibiting superior outcomes. The Atakum and Canik areas in Samsun city were determined to be highly suitable areas for landfill locations. The study underscores the importance of considering constraints for unsuitable landfill areas and generating conformity maps through overlay analysis.
[101]	To ascertain the primary determinants that affect the potential ecological consequences of various WtE (WtE) technologies, which encompass incineration, pyrolysis, gasification, and gasification combined with ash melting	LCA	Factors influencing environmental impacts include energy recovery efficiency, feedstock variability, emissions at the stack, metal recycling, and operating conditions like air pollution control and management of by-products. Model assumptions, such as alternative energy sources, choice of functional unit, and operating time, significantly affect environmental performance.
[39]	To establish a quantitative index for the evaluation of WtE technologies, with a specific focus on safety, health, and environmental factors.	Safety Health Environmental (SHE) index	The authors propose that future research should incorporate additional assessments to comprehensively analyze WtE technologies in terms of their technological aspects, feedstock considerations, environmental impacts, and societal implications.
[79]	To propose an improved fuzzy TOPSIS methodology for selecting a suitable approach and site for MSW disposal.	fuzzy MCA and fuzzy pairwise comparison matrices derived from the AHP	While the study focuses on MSW disposal method and site selection, it does not address other aspects of solid waste management or potential sources of uncertainty. Further research is needed to validate the methodology in different contexts, integrate additional waste management aspects, evaluate long-term impacts, and assess economic feasibility.
[37]	To present a MCDA methodology for determining hazardous waste landfill sites in the Western region of Ghana.	Geo-environmental, economic, and social factors, during the site selection process.	The study emphasizes the need for further in situ studies to make the final site selection. While the paper does not explicitly mention limitations, it implies the need for additional data and

(*continued on next page*)

Table 3 (*continued*)

Author	Study objectives	Types of DSS used,	Key findings
			stakeholder engagement. Potential research gaps may include evaluating long-term environmental and social impacts, exploring alternative waste management strategies, and comparing the effectiveness of the MCDA approach to other methodologies.
[75]	To employ MCDA to select the most suitable WtE (WTE) technology for Moscow, aiming to reduce GHG emissions and the use of landfills.	AHP and expert opinions	A sensitivity analysis reveals the responsiveness of rankings to environmental and technical criteria. The paper offers decision-makers in Moscow a tool for informed WTE technology selection
[34]	To develop a GIS-based multi-criteria fuzzy approach for decision-makers with a comprehensive standard for selecting the optimal site for a WtE plant or a landfill.	GIS-based multi-criteria fuzzy approach	It provides decision-makers with a comprehensive standard for selecting the optimal power plant or landfill sites, considering multiple criteria and incorporating flexibility in the decision-making process.
[71]	To assess the involvement of identified stakeholders in solid waste management (SWM) and examine their interests, importance, and influence in SWM.	Interviews, focus group discussions, observation, stakeholder engagement and SWOT analyses	low stakeholder engagement in SWM despite composting and recycling opportunities. Recommendations included stakeholder consultation, integration of scavengers, and public education.
[110]	To create a structured approach to the decision-making process for landfill site selection.	Integrates fuzzy-AHP and geoinformation techniques.	The paper underscores the potential benefits of combining GIS and MCDA techniques to enhance public engagement in waste facility location decisions. It stresses the importance of inclusivity, transparency, and the development of user-friendly tools to facilitate meaningful public participation.
[97]	To evaluate and compare the sustainability of different PET waste treatment methods against twelve distinct performance criteria, which represent the three pillars of sustainability: environmental, economic, and social.	TOPSIS-AHP and TOPSIS-COV approaches.	Based on the findings obtained from both the TOPSIS-AHP and TOPSIS-COV approaches, the paper identifies closed-loop recycling as the most optimal method for treating PET waste bottles. Furthermore, the paper emphasizes the comparability of the weights obtained through the COV and AHP approaches. However, certain performance indicators, such as cost, photochemical oxidant potential, and human toxicity, exhibit discrepancies
[118]	To establish a hierarchy among various waste treatment options in MSW management based on technological, ecological, and environmental criteria.	Integrated q-rung orthopair fuzzy based SWARA-COPRAS model to rank waste treatment methods.	The order of the waste treatment alternatives is as follows: upcycling is ranked highest, followed by recycling, pyrolysis, hydrolysis, biotechnological, core plasma pyrolysis, incineration, composting, gasification, and landfilling. Through sensitivity analysis, it is evident that the ranking results are significantly affected by changes in criteria weights, highlighting the importance of accurately estimating the weights select the overall ranking of the alternatives. The COPRAS method, which is utilized in the proposed model, is easily applicable and comprehensible, making it suitable for various decision-making problems in engineering fields
[96]	The study aims to determine an appropriate WtE technology for Chittagong City with an emphasis on cleaner technology. It seeks to identify criteria and options for selecting WtE technologies, taking into account various factors.	Analytical Hierarchy Process (AHP)	Stakeholders' preferences led to anaerobic digestion (AD) being identified as the most suitable WtE technology for Chittagong City, with a significance weight of 38 %. Landfill gas (LFG) recovery ranked second with a weight of 27 %, followed by gasification (21 %) and incineration (14 %). The study found that the inclination towards AD was influenced by economic criteria, while LFG gained preference when economic criteria were prioritized.
[51]	The paper aims to develop a model for selecting WtE plant sites that considers technical, environmental, economic, and social factors. The research contributes to the sustainable development and integration of WtE plants into urban energy structures.	SVNSs, DANP and GIS	The model successfully selects optimal WtE plant sites in Beijing, China. SVNSs help address the uncertainty and fuzziness of criteria. Geographic data collected through GIS reduces subjective biases in site selection. The paper demonstrates the stability and feasibility of the model through

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Table 3 (*continued*)

Author	Study objectives	Types of DSS used,	Key findings
			testing. The research contributes to sustainable waste management and energy production.
[68]	The primary goal is to improve the efficiency of solid waste management in Manila City. The study employs MCDA, specifically AHP, to evaluate and prioritize WTE technologies based on environmental, economic, technical, and sociocultural criteria. The paper considers anaerobic digestion, incineration, and pyrolysis as potential WTE technologies. An estimate of biogas production using anaerobic digestion within a 21-day timeframe is provided.	AHP	Anaerobic digestion (AD) is identified as the most appropriate WTE technology for Manila City, Philippines. The estimated biogas production using AD over 21 days is 249,318 cubic meters. The paper recommends implementing anaerobic digestion as the WTE technology of choice. Prioritize environmental considerations in WTE technology selection. Implement a comprehensive solid waste management program in line with relevant legislation. Focus on waste reduction, reuse, recycling, and explore alternatives to landfilling for non-reusable waste.
[91]	The study aims to examine the dimensions, location, and economic viability of municipal-owned biogas plants for organic waste management. The goal is to develop a DSS at the local level in Turkey for utilizing regional bioenergy sources and managing organic waste.	GIS techniques	The study contributes to the development of a local DSS in Turkey for efficient bioenergy utilization and organic waste management. It emphasizes the importance of minimizing transfer distances and optimizing the siting and sizing of waste resource recovery facilities for sustainable organic waste management. The study utilizes a unique approach involving scenario modeling based on cluster analysis.
[92]	The primary goal is to create a framework for identifying appropriate locations for MSW management facilities, with a focus on incineration plants. The study combines MCDA techniques with a GIS to develop a fuzzy AHP model.	Fuzzy AHP model integrated with GIS	The study identifies four potential sites for incineration technologies in the Izmir Metropolitan Municipality based on environmental and economic factors. It estimates that an incineration plants with an overall capacity of 117 MWe could be developed to produce energy from 5649 tons of MSW generated daily.
[104]	To broaden the application of the 3T approach in the context of WtE technologies and biorefineries, facilitated by the utilization of multicriteria analysis as a decision-making tool.	The 3T Method were integrated in a MCDA tool based on the PROMETHEE-GAIA methods and five WtE plants were analyzed.	The methodology based on multicriteria analysis (MCA) that is proposed is utilized to examine and assess the performance of five WtE (WtE) plants, with a specific focus on biorefineries. The proposed methodology surpasses the limitations of the R1 and 3T methods and can be deemed an exceedingly valuable instrument in comparative assessments and in validating the results of other assessment methods.
[11]	To accomplish appropriate site selection to be used as containment of radioactive wastes generated by Nuclear Power Plant in Turkey utilizing GIS-based MCDA methodologies.	GIS and MCDA	The altitude of the study area was regarded as a vital criterion in the exploration of suitable sites for RWDFs. Areas in close proximity to sea level were not favored in the selection procedure of RWDF sites due to the potential contamination of pristine water resources and issues pertaining to drainage.
[56]	To examine the crucial criteria for the precise selection of new projects for the secure disposal of MSW, while also identifying and evaluating the risk factors that impact the performance of these projects.	R-TOPSIS, R-VIKOR, R-MARCOS and R-MULTIMOOSRAL	The findings of the study demonstrate the superiority of the plasma pyrolysis plant in comparison to alternative projects, such as power plants based on landfill usage, plasma gasification, and waste pyrolysis plants. These conclusions have been derived through the application of the R-TODIM method. The risk evaluation of the plasma pyrolysis system emphasizes the significance of various risk factors, including access to technology, laboratory equipment, and modern scientific resources.
[36]	The objective of the study was to assess the potential for recovering energy and the environmental consequences of various WtE options, based on the characteristics and composition of the waste to aid relevant authorities in making informed decisions regarding waste management in Dhanbad, India	LCA)	Six different scenarios were formulated and compared based on the potential for energy recovery and environmental impacts. The scenario involving the mass incineration of combustible portions of waste and the subsequent landfilling of the remaining waste exhibited the highest potential for energy recovery, amounting to 602 kWh/tonne of dry waste. Through sensitivity analysis, it was determined that the

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Author	Study objectives	Types of DSS used,	Key findings
			efficiency of collecting LFG for electricity production significantly influenced the magnitude of both global warming and the creation of photochemical ozone.
[40]	The primary objective is to construct an innovative model for multi-objective programming that can aid in making optimal decisions by simultaneously considering system profit, greenhouse gas emissions, and energy recovery.	Interval-valued fuzzy numbers (I-VFN) MCDM approach.	The investigation suggests that sustainable waste management heavily relies on the implementation of appropriate government subsidies and the active participation of the public in waste source separation. The withdrawal of subsidies would lead to a decrease in overall profit, carbon emissions, and energy recovery. WtE technologies, particularly anaerobic digestion which receives higher subsidies, would be more affected by this policy.
[79]	To formulate a methodology of MCDA in order to choose hazardous waste landfill sites in the western region of Ghana.	General MCDA	By applying criteria of optimality, it was determined that 5 % of the selected study area was the most appropriate for locating landfill sites. The study emphasized the necessity of conducting further on-site studies in order to make a final decision regarding the selection of landfill sites. The methodology provided a well-established approach for selecting landfill sites, which can be utilized by decision-makers in the Western region of Ghana.
[19]	This study focuses on finding the best ways to manage daily MSW, considering both avoiding waste in the first place and cleaning up after its created. The ultimate goal is to minimize environmental harm and keep people healthy.	General MCDA approach.	Incineration with pollution control was explored as a possible solution, but the study stressed that any chosen technology needs to be well-understood. They also found that planning and investment are crucial for success. The best approach may involve sorting trash first, then using a combination of separating recyclables (triage), composting food scraps, and incineration with advanced pollution control. The study linked positive public perception of MSW management to public awareness and good management of incineration plants.
[125]	This study is looking for the best way to turn trash into useable energy at small military bases (FOBs) in remote locations. They consider different technologies (like pyrolysis and gasification) and weigh factors like health, pollution, and power generation to pick the best option for different base sizes.	Multi-step structured decision making (SDM).	This study compared ways to turn WtE at remote military bases. They considered health, pollution, waste reduction, and power generation. The best technology depended on the base size and what was most important (e.g., health or easy transport). Two technologies (gasification G1 and pyrolysis P1) were generally best, but for very small bases, burning trash in open pits was most suitable (because it's easiest to move). This study provides a way to choose the best WtE option for remote locations.
[126]	To investigate the variables that establish a fitting WtE technology in order to enhance waste management in rural areas of Ghana.	Generic MCDA approach	The study found that a landfill with gas capture would be the best option because it's affordable and can grow bigger as needed. They also mentioned that different areas might need different solutions, and that for food scraps, special machines that break them down could be a good option. Overall, this approach could provide clean energy, improve waste management, and reduce diseases.
[88]	This study wants to see how government policies affect the development and spread of technology that burns trash to create energy.	System dynamics modeling approach	This study found that government policies helping develop and spread waste incineration power technology were effective. Specifically, a policy guaranteeing payment for the electricity produced (feed-in tariff) was more effective at increasing the amount of waste incineration power capacity compared to a policy that supports research and development. Overall, these policies helped reduce the cost of building these power plants by encouraging innovation.
[69]	This study compared three ways to turn WtE in Iran (landfill gas, incineration, and digestion) to	A combination of well-defined economic analysis techniques and a specific software tool (LandGEM)	This study in Iran compared ways to turn WtE (landfill gas, incineration, and digestion). They found that over time, a special digester (anaerobic

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Table 3 (*continued*)

Author	Study objectives	Types of DSS used,	Key findings
	see which option generates the most electricity and makes the most money.		digestion) could produce the most energy (7.27 GW-hours per year) and make the most money (almost $5 million profit) at a lower cost (5 cents per kilowatt-hour) compared to the other options. Burning trash (incineration) was not profitable.
[58]	To assess and compare the life cycle sustainability of different WtE technologies for generating electricity from MSW in Lagos and Abuja, Nigeria.	Multidimensional Life Cycle Sustainability Assessment (LCSA), MCDA with Multi-Attribute Value Theory (MAVT)	Both LCSA ranking and MCDA analysis indicated that WtE technologies provide sustainability benefits for both cities, with a slight advantage for Lagos. The study highlights the importance of considering trade-offs between environmental, economic, and social factors during WtE technology selection. Decision-makers should consider stakeholder priorities when choosing the most suitable WtE option for their specific context.
[127]	Develop a new approach for landfill suitability analysis using a Multi-Criteria Spatial DSS (MC-SDSS).	GIS, AHP, TOPSIS and Ideal Point Methods	A case study demonstrates the application in the Thrace region of Greece. The study compares four models based on different distance metrics used in the compromise programming methods: Euclidean distance, Manhattan distance, TOPSIS, Chebychev distance The results suggest that Euclidean distance and TOPSIS methods show strong similarities. Also TOPSIS results are closer to Manhattan distance compared to Euclidean distance. Chebychev distance, being a non-compensatory approach, yields significantly different results from the other methods.
[4]	Select the most suitable WtE technology for electricity generation in Lagos, Nigeria.	TOPSIS	A hybrid system combining AD, and pyrolysis, and landfill gas recovery, yielded the most promising results in terms of Environmental benefits, electricity generation potential The study discourages incineration due to high investment and operational costs Negative environmental impact while the case study focuses on Lagos, the methodology can be applied to other cities globally.
[1]	To establish a decision support framework that can be used to identify the most suitable WtE technology in South Africa, with a specific focus on the Western Cape municipality and other urban regions.	Analytical Hierarchy Process (AHP).	The findings of the investigation demonstrate that Anaerobic Digestion (AD) is the optimal technology for converting waste into energy for the selected city in South Africa. This conclusion is supported by a score of 57 % in relation to its positive influence on the environment.
[7]	To apply a multi-criteria analysis (MCA) in order to assess WTE technologies and ascertain limitations when considering the location of a WTE facility.	Multi-criteria analysis (MCA).	The study's findings reveal that pyrolysis emerges as the favored choice across all scenarios for both developed and developing nations, given its manifold advantages in terms of environmental impact, societal implications, associated risks, and waste management.
[62]	The primary aim of this study is to delineate the composition of MSW in Ahmedabad, India and identify a suitable waste management technology that ensures sustainable processing and secure disposal of MSW.	Comparative evaluation framework based on the waste characterization data	The findings of the investigation demonstrate that the implementation of controlled combustion-based WTE technology is a viable and efficient approach for the treatment of waste in Ahmedabad. This technology significantly diminishes the amount of waste by 75 % and substitutes 417 tons of coal on a daily basis, leading to a decline in GHGs and the production of electricity.
[70]	The primary aim of this study is to construct an environmental DSS for waste management and decision-making processes, utilizing Volunteered Geographic Information (VGI).	Volunteered Geographic Information (VGI) data gathering Geographic Information System (GIS), with MCDA	The findings of this investigation exhibit the pragmatic viability and relevance of the constructed VGI-based environmental DSS for decision analyses concerning pollution. The system enables the active participation of the general populace in the production of waste pollution data, while also delivering suitable GIS and MCDA tools for analysis.
[76]	To develop a decision-making framework for the purpose of selecting an environmentally friendly	LCSA and game theory MCDA.	The findings of the investigation illustrate that the suggested decision framework has the ability to

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Author	Study objectives	Types of DSS used,	Key findings
	WtE technology, specifically designed for the treatment of MSW.		assist individuals with a vested interest in reaching a common and practical resolution for the selection of WtE technology. The examination carried out in Vancouver, located in Canada, reveals that both the cement industry and the local governing body can derive mutual advantages from utilizing refuse-derived fuel, provided that the industry compensates the municipality for the privilege of acquiring the necessary quantity of solid waste.
[2]	To evaluate the techno-economic viability of WtE approaches for potential investment in Ghana while also determining the most beneficial alternative.	Fuzzy TOPSIS	The findings of the investigation reveal that gasification is the most viable technology for WtE investment in Ghana. This is followed by AD, pyrolysis, and plasma arc gasification. The annual energy generation and initial investment are identified as the most influential technical and economic factors, respectively. It is suggested that the integration of anaerobic digestion and gasification represents a well-balanced option for WtE technology.
[66]	The primary aim of this study is to identify a suitable WTE conversion technique for the disposal of domestic waste in the Dhaka-Mirpur Cantonment region of Bangladesh.	Analytic hierarchy process (AHP) model.	The findings of the examination demonstrate that plasma gasification (PG) is the utmost fitting conversion technology for WTE in the residential waste context of the Dhaka-Mirpur Cantonment area. PG exhibits a compact spatial requirement, possesses the capability to process unsorted waste, and is capable of generating synthetic gas of commendable quality while avoiding the production of highly hazardous waste by-products.
[128]	The primary goal of the study is to put forward an optimal WtE methodology for the management of MSW in the Sultanate of Oman.	Analytical Hierarchy Process (AHP)	The study's findings establish that, according to the identified criteria, AD, followed by fermentation and incineration, emerges as the most suitable WtE technology for the state, Oman. This particular technological approach will contribute to the reduction of waste production, greenhouse gas discharges, and landfill expenses.
[48]	To develop a DSS tool for public authorities and industries to evaluate the sustainable exploitation of extractive waste facilities.	Decision Support Tool (DST) was developed.	This research offers a valuable tool for decision-makers considering the extraction of raw materials from waste facilities. By using the DST, authorities and industries can make more informed choices that promote resource recovery while considering potential social and environmental implications.
[53]	The primary aim of this study is to put forth an optimal WtE methodology for the management of MSW in the Sultanate of Oman.	Analytical Hierarchy Process (AHP)	The investigation concludes that, considering the established criteria, AD followed by fermentation and incineration is the most appropriate WtE technology for the country of Oman. This technological approach will contribute to the reduction of waste production, emissions of greenhouse gases, and expenses associated with landfills.
[122]	To develop a method for optimizing systems that consider the water-energy-waste nexus (WEW nexus).	Multi-objective framework and Fuzzy C-means clustering	Fuzzy C-means clustering helps identify different levels of synergy among various optimal solutions. Solutions within a cluster share similar trade-off characteristics, indicating a level of synergy in how they address the WEW nexus
[94]	To develop a sustainable energy management system for the textile industry by utilizing cotton crop waste as a biomass energy source.	Integrated Decision Model	This research offers a promising approach for the textile industry to achieve a more sustainable energy system by utilizing readily available cotton waste as a biomass source. The study also identifies challenges and potential solutions to overcome them.
[113]	To develop a novel method for evaluating critical factors and suitable technologies for sustainable management of tannery solid waste (TSW) in developing countries, considering uncertainties.	Interval Type-2 Trapezoidal Fuzzy Sets (IT2TrFSs) based Delphi Technique, and Extended Weighted Influence Non-linear Gauge System (WINGS).	By applying the model to a real-world case study, the research finds that Environmental policies for TSW management is identified as the most critical factor for successful sustainable TSW management. Gasification is determined to be the most favorable valorization technology for TSW,

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Table 3 (*continued*)

Author	Study objectives	Types of DSS used,	Key findings
			considering various factors like environmental impact and efficiency.
[103]	To select the most suitable technology for producing biogas from chicken manure in rural Iran, promoting a circular carbon economy and low-carbon energy production.	Complex Spherical Fuzzy Set (CSFS)-based TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution).	By applying this method, the study ranks the four technologies, Pragati technology emerges as the most suitable option for biogas generation from manure in the given context. The order of preference from most to least preferred is: Pragati, Deenbandhu, Janata, and KVIC technology.
[51]	To develop a two-stage model for selecting optimal locations for WtE plants, considering various technical, environmental, economic, and social factors.	SVNSs, DANP, GIS and EDAS	The study proposes a novel model that incorporates fuzziness and uncertainties in decision-making criteria using SVNSs. The DANP method helps determine the relative importance of various criteria for WtE plant site selection. GIS facilitates the analysis of spatial data and identification of potential sites. The EDAS method, considering the SVNSs environment, ranks potential sites based on their overall performance across the established criteria.
[116]	To understand how waste treatment companies make decisions regarding the circular economy.	Semi-structured interviews, workshops, and focus groups	This study emphasizes the importance of considering the challenges faced by waste treatment companies when implementing a circular economy. By addressing competition, technological uncertainty, and regulatory needs, policymakers can create an environment that encourages a smoother transition towards a more sustainable waste management system.
[129]	To improve the efficiency of extracting new energy from agricultural waste (AW).	Fuzzy Neural Networks (FNN)	This research offers a novel approach to extracting new energy from agricultural waste by combining waste processing techniques with an adaptive decision model for team formation. The FNN-based model can potentially aid in selecting the most effective team structure to maximize resource utilization and project success.
[108]	To develop a decision support model for designing waste heat recovery systems in Data Centers (DCs) and High-Performance Computing (HPC) clusters.	DSS was developed	This research offers a valuable tool for designing energy-efficient data centers and HPC clusters. The decision support model helps select optimal configurations for waste heat recovery systems, considering factors like energy savings, cost reductions, and efficient use of resources. By promoting waste heat utilization for district heating, the model contributes to a more sustainable energy system.
[17]	To develop a novel DSS named Waste Utilization Decision Support System (WUDSS) for decentralized general waste management, focusing on promoting sustainable development for Small, Medium, and Micro Enterprises (SMMEs).	WUDSS framework	This research introduces a promising tool (WUDSS) for decentralized waste management. The WUDSS can support SMMEs by evaluating various waste processing options and their potential outputs. This can promote sustainable waste management practices and create business opportunities for SMMEs in South Africa.
[109]	To develop a framework and DSS for optimizing waste heat recovery in data centers.	Cost-Benefit and Environmental Analysis with DSS-based Optimization	This research offers a valuable framework and DSS for data centers to optimize waste heat recovery strategies. By improving energy efficiency and reducing reliance on traditional energy sources, this approach can contribute to a more sustainable data center industry.
[66]	To develop a decision support tool to optimize the economic and environmental performance of e-waste recycling businesses.	Comprehensive Manufacturing Assessment Tool (CMAT).	CMAT helps businesses make informed decisions about e-waste processing based on profitability simulations and worker allocation optimization. The open-source nature of CMAT allows for broader application in various recycling sectors, promoting more sustainable business practices.
[106]	To select the most suitable WtE technology for processing dumped plastic waste, considering environmental and economic factors	Stratified Fuzzy Multi-Criteria Decision Making (SFMCDM), Improved Intuitionistic Analytical Hierarchy Process (I-AHP) and WASPAS	This research introduces a valuable decision-making tool for selecting WtE technologies while considering uncertainties and complexities. The SFMCDM approach, with its improved I-AHP and WASPAS methods, can guide decision-makers in selecting environmentally and economically

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Author	Study objectives	Types of DSS used,	Key findings
			sustainable solutions for waste management, particularly for dumped plastic waste.
[98]	To develop a decision model for selecting new research and development (R&D) projects focused on safe and economical MSW disposal and energy conversion.	MCDA methods with R-numbers.	The fuzzy risk-based decision model helps assess both project potential and associated risks, leading to more informed investment decisions and potentially accelerating the establishment of sustainable waste management solutions.
[114]	To identify and analyze factors influencing construction waste generation in high-rise buildings using Design-Bid-Building (DBB) contracts. To assess the impact of these factors on different construction materials.	Grey Data Analysis	This research reveals that by understanding how design choices, procurement processes, and construction practices influence waste generation, stakeholders can develop strategies to minimize waste across different materials. This can lead to more sustainable and cost-effective construction practices.
[63]	To develop a web application that acts as a DSS for planning and managing MSW.	web-based Geographic Information System (GIS)	The web-based DSS offers a significant improvement over existing solutions by incorporating supply chain data into its analysis. The system allows exploration of factors influencing the waste supply chain.
[15]	To develop a DSS for policymakers to optimize the planning and management of the organic portion of MSW within a circular economy framework.	DSS based on Linear Programming (LP) techniques	The study introduces a valuable LP-based DSS for policymakers to make informed decisions regarding OFMSW management. By optimizing resource allocation and considering both economic and environmental factors, the DSS can help achieve sustainable and cost-effective solutions for organic waste treatment, promoting a circular economy approach.
[84]	To develop a data-driven DSS to aid decision-makers in the conceptual design phase of large-scale industrial heating networks.	data-driven DSS	This research introduces a valuable DSS for the conceptual design phase of large-scale industrial heating networks. By analyzing energy demand patterns and recommending suitable supply concepts, the DSS can support decision-makers in establishing more efficient and potentially decarbonized industrial heating systems.
[124]	To develop a model for optimizing the design and operation of a rural multi-energy system (W-RMES) that integrates WtE technologies with renewable energy sources (photovoltaic) and energy storage	Distributionally Robust Optimization (DRO)	This research introduces a promising optimization model for W-RMES design and operation. By integrating W2E technologies, renewable energy, and energy storage, W-RMES can provide rural areas with a sustainable, cost-effective, and environmentally friendly solution for their energy and waste management needs. The DRO approach ensures robustness in decision-making despite uncertainties in renewable energy generation.
[44]	To develop a robust and integrated approach for planning the location of WtE facilities in a large urban region, considering uncertainties in waste generation.	MCDA with Mixed-Integer Linear Programming (MILP)	This research offers a valuable framework for robust and integrated planning of WtE facilities. By considering multiple criteria, uncertainties, and a holistic exergy approach, the model can help decision-makers select the most sustainable and resilient WtE facility locations and configurations for managing waste in large urban areas.
[10]	To optimize the trade-off between cost savings and service quality in municipal waste management through the use of smart waste bin technology.	digital process twin	The model helps quantify the impact of cost savings on service quality reduction, allowing for informed decision-making. The concept of a digital process twin is introduced as a potential future tool for optimizing waste collection by learning from data and providing data-driven recommendations.
[123]	To investigate how agricultural waste management in Jiangxi Province, China, can be optimized for resource flow, greenhouse gas (GHG) mitigation, and sustainable waste utilization.	Material Flow Analysis (MFA), LCA and Objective Optimization Model	The study emphasizes the importance of synergistic waste disposal strategies across different sectors to ensure a sustainable agricultural waste management system. These findings can be applied to other regions with significant agricultural activities, providing a valuable reference for policymakers and stakeholders.

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Author	Study objectives	Types of DSS used,	Key findings
[38]	To develop an integrated DSS for planning a combined centralized-decentralized WtE Management System in large urban areas.	Multi-Criteria Sustainability Framework	This research introduces a valuable DSM for planning WtEMS in large urban areas. By combining MSW prediction, facility deployment optimization, and sustainability assessment, the proposed approach can help decision-makers design efficient, cost-effective, and environmentally friendly MSWM systems that leverage the benefits of both centralized and decentralized waste treatment facilities.
[120]	To assess the suitability of expert judgement as a data source for decision support in selecting mine waste valorization (reuse) technologies.	Multiple Criteria Decision Analysis (MCDA)	This research reveals the limitations of relying solely on expert judgement for selecting mine waste reuse technologies, especially when dealing with high uncertainty. While expert input can be valuable, it should be used cautiously and potentially combined with other data sources for more robust decision-making. The study also demonstrates the usefulness of distinguishability analysis for assessing the reliability of expert judgement data in decision support processes.

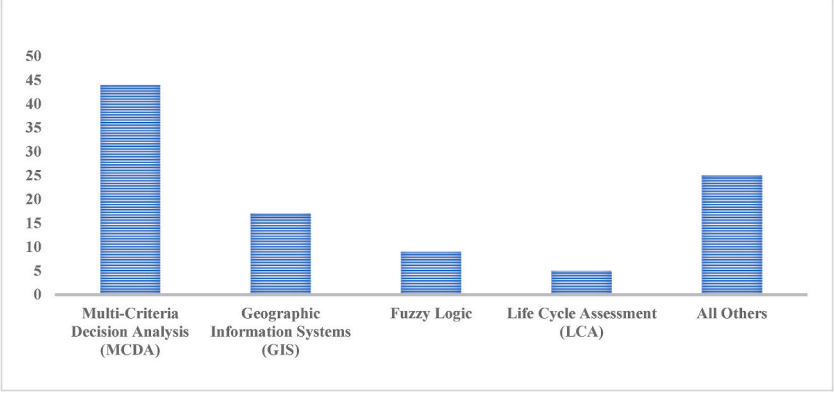

Fig. 2. The frequency of the category of DSS tools used by different Authors in the selected studies.

ability to adapt to changing conditions [40,90]). Furthermore, the complexity of advanced DSS tools may hinder practical implementation in resource-constrained settings, and some DSS models prioritize short-term gains over long-term environmental and social impacts [104]. It also requires involving local communities, government agencies, and industry experts in the decision-making process, developing user-friendly interfaces for DSS tools to enhance accessibility and integrating the role of the informal waste sector into DSS frameworks ([17,26,77]).

The integration of DSS in Ghana's WtE technologies sector requires a nuanced approach that addresses multiple systemic challenges. The existing gaps in DSS adoption in Ghana can be strategically addressed through an integrated methodological framework that combines multiple analytical approaches, each targeting specific limitations in current waste management decision-making processes [9]. The contextual adaptation challenge requires deep engagement with local stakeholders and understanding of waste management practices and socio-economic conditions. Strategies should focus on stakeholder engagement, capacity building for local operation and maintenance, integration with existing waste management systems, and consideration of both centralized and decentralized WtE solutions [2]. These methods enable decision-support systems to move beyond generic technological models, instead creating flexible frameworks that acknowledge the unique characteristics of informal waste management practices and infrastructure limitations prevalent in Ghana. Also, integrating socio-environmental considerations demands a holistic approach combining quantitative and qualitative methodologies.

Addressing the data availability and quality gap necessitates a multifaceted strategy leveraging GIS-based spatial analysis, Multi-Criteria Decision Making (MCDM), and fuzzy logic techniques. These methodologies can help transform fragmented and incomplete waste management data into comprehensive, actionable insights. By creating robust spatial databases, integrating disparate data sources, and employing fuzzy logic to manage uncertainties, decision-makers can develop more reliable and adaptive waste management strategies that reflect the complex realities of Ghana's waste ecosystem [87]. Again, bridging the policy and regulatory framework gap requires creating transparent, evidence-based decision-making tools [89].

The review identified several prospective avenues for future research concerning the application of DSS in relation to WtE technologies in Ghana. Future research must be geared towards the development of Ghana-specific DSS models incorporating local waste

Table 4
An evaluation of different methods for selecting WtE technology.

Approach	DSS Methods	Strengths	Weakness	Applicability in Waste management
GIS-Based Spatial Analysis	GIS-based Weight Linear Combination (WLC), GIS-based Multi-Criteria Decision Making (MCDM), GIS, HFLTS, and GIS-based Multi-Criteria Fuzzy Approach [67].	Enables spatial visualization and analysis, incorporates geospatial factors, provides insights into suitable locations [20]	Limited by data quality and availability, potential computational complexity, may require extensive geospatial data collection	Ideal for site selection of waste management facilities, landfill mapping, analyzing spatial distribution of waste generation and collection routes
Multi-Criteria Decision Making (MCDM)	Analysis Hierarchical Process (AHP), Fuzzy-AHP, MCDM with fuzzy set and grey system theories, COPRAS, SWARA, TOPSIS-AHP, and TOPSIS-COV.	Systematically considers multiple criteria, provides a structured decision-making framework [43].	Can be subjective due to expert judgment, time-consuming for complex decision problems, potential bias in criteria weighting	Useful for evaluating waste management technologies, facility location selection, comparing treatment methods, prioritizing waste management strategies
Fuzzy Logic and Fuzzy Sets	Fuzzy-AHP, fuzzy multiple criteria analysis (MCA), Modified Fuzzy TOPSIS.	Addresses uncertainty and vagueness in decision-making. Introduces flexibility in decision-making	Complexity in developing membership functions, potential interpretation challenges	Effective in handling imprecise data in waste management planning, risk assessment, technology selection, and performance evaluation
Life Cycle Assessment (LCA)	LCA	Evaluates environmental impacts throughout the life cycle of technologies [78].	Resource-intensive, requires comprehensive data, potential overgeneralization of environmental interactions.	Critical for assessing environmental sustainability of waste management technologies, comparing waste treatment methods
Other DSS methods:	Safety Health Environmental (SHE) index	Provides a quantitative measure for evaluation [3].	May not capture all qualitative aspects, limited to predefined metrics	Useful for risk assessment in waste management, evaluating workplace safety and environmental compliance
	Interviews, focus group discussions, and stakeholder and SWOT analyses	Captures qualitative insights, considers diverse perspectives.	Subjective, potential bias, limited generalizability [119].	Valuable for understanding stakeholder perspectives, identifying local challenges in waste management strategies
	Scenario modeling based on cluster analysis [24]	Considers various scenarios for decision-making.	Depends on historical data, may not account for unprecedented changes, computational complexity	Helpful in forecasting waste generation, planning future infrastructure, understanding potential future waste management scenarios

composition and energy needs, integration of informal sector dynamics into DSS frameworks, real-time data collection and integration methodologies for adaptive decision-making, and user-friendly DSS interfaces tailored for Ghanaian decision-makers ([15,27,52,63,72]. Employing advanced analytics, including big data and machine learning, can enhance the predictive accuracy and adaptability of DSS tools. These technologies can be leveraged to model complex waste streams and optimize energy recovery processes in dynamic environments. Future research should also focus on long-term sustainability assessment tools for WtE projects in Ghana, comparative studies of DSS efficacy in different regions of Ghana, integration of climate change resilience into WtE technology selection criteria, and exploration of blockchain and IoT technologies for enhancing DSS in WtE management ([80,84]). Furthermore, future research should prioritize creating DSS capable of managing dynamic data (e.g., changing waste composition, energy market prices) to enhance decision-making in real-life situations [10]. This approach could significantly improve the practical applicability of DSS in the rapidly evolving WtE sector. Several limitations of this review were acknowledged. The rapidly evolving nature of the field may lead to the review becoming quickly outdated, necessitating regular updates to keep pace with new developments. Language and publication biases could result in missing important insights, especially from local or regional sources not published in English or academic journals. The lack of stakeholder involvement in the review process might overlook practical, on-the-ground insights crucial for implementing DSS for WtE in Ghana. Lastly, the interdisciplinary nature of the topic could present challenges in synthesizing findings across different fields, each with its own terminology and methodological approaches.

4. Conclusion

This systematic literature review has comprehensively examined the application of Decision Support Systems (DSS) in the selection and implementation of Waste-to-Energy (WtE) technologies, with a particular focus on their potential adaptation to the Ghanaian context. The study has addressed its primary objectives through a rigorous analysis of existing scholarship, identification of essential decision-making criteria, assessment of DSS methodologies' efficacy, and identification of knowledge gaps and future research directions. The review reveals that DSS methodologies, particularly Multi-Criteria Decision Analysis (MCDA), Geographic Information Systems (GIS), and Life Cycle Assessment (LCA), have significantly contributed to enhancing decision-making processes in the WtE sector globally. These tools have demonstrated their effectiveness in handling the complex, multi-faceted nature of WtE technology selection and implementation, addressing issues ranging from site selection to technology ranking based on multiple criteria. However,

the study also highlights significant gaps in the current application of DSS to WtE technologies, particularly in the context of developing nations like Ghana. Many existing DSS approaches fail to adequately account for local socio-economic factors, rely on static data, and do not fully incorporate diverse stakeholder perspectives. These limitations underscore the need for more context-specific, dynamic, and inclusive DSS methodologies. The research identifies key criteria for WtE technology selection in Ghana, including technical feasibility, environmental impact, economic viability, social acceptability, and energy efficiency. These criteria, along with strategies focusing on stakeholder engagement, capacity building, and integration with existing systems, provide a foundation for developing Ghana-specific DSS frameworks.

The study reveals that while DSS methodologies have shown efficacy in addressing WtE challenges in developing nations, there remain significant opportunities for improvement. Adapting global DSS applications to the Ghanaian context requires careful consideration of local priorities, data availability, and the role of the informal waste sector. A recommended holistic DSS approach for Ghana would synergistically combine these methodological strengths, utilizing GIS for spatial insights, employing fuzzy MCDM to handle contextual uncertainties, conducting comprehensive Life Cycle Assessments, engaging stakeholders through targeted interviews, and developing predictive scenario models. This integrated strategy can transform current limitations into opportunities for developing more responsive, adaptive, and contextually relevant waste management solutions. Practical implementation of this approach requires strategic investments in local capacity building. This includes developing specialized data collection protocols, training local experts in advanced DSS methodologies, creating flexible decision-support frameworks, and establishing collaborative platforms that bridge academic research, policy development, and community engagement.

Future research on DSS for WtE technologies in Ghana should focus on developing locally relevant tools that account for the country's unique waste characteristics, the energy market and socio-economic conditions. Integrating advanced analytics, such as big data and machine learning, can improve the accuracy and adaptability of these tools for modeling complex waste streams and optimizing energy recovery processes. Incorporating participatory approaches that involve local communities, waste collectors, and policymakers will enhance the usability and acceptance of DSS tools by addressing socio-cultural and behavioral factors. Integrating life cycle assessment (LCA) methodologies will enable a comprehensive evaluation of the environmental and economic trade-offs of different WtE technologies. Additionally, scenario-based policy modeling should be employed to simulate the impacts of policy interventions, such as subsidies, carbon pricing, and public-private partnerships, on the financial and operational feasibility of WtE projects. Finally, exploring the dynamics of the informal waste management sector and its integration into formal WtE strategies will ensure more inclusive and sustainable implementation.

The limitations of this study, including potential language and publication biases and the rapidly evolving nature of the field, highlight the need for ongoing research and regular updates to keep pace with developments in both DSS methodologies and WtE technologies. The findings of this study have important implications for policymakers, researchers, and practitioners in the WtE sector, particularly in developing nations. They underscore the need for a holistic, interdisciplinary approach to WtE technology selection that considers technical, environmental, economic, and social factors. Future work should focus on translating these insights into practical, context-specific DSS tools that can effectively support sustainable WtE implementation in Ghana and similar developing nations.

CRediT authorship contribution statement

Theophilus Frimpong Adu: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Lena Dzifa Mensah:** Supervision. **Mizpah Ama Dziedzorm Rockson:** Supervision. **Francis Kemausuor:** Supervision.

Declaration of competing interest

I, Adu Theophilus Frimpong, (the author) have no conflicts of interest to declare. The co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report.

I certify that the submission is original work and is not under review at any other publication.

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