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Bibliometric analysis for sustainable food waste using multicriteria decision

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ABSTRACT

Sustainable food waste management is globally concerning, thus necessitating cutting-edge approaches and a thorough understanding. To address this complicated problem effectively, bibliometric analysis and multicriteria decision-making can be combined. Therefore, multicriteria decision-making methods have become critical tools for navigating the intricacies of sustainable solution development. This study explored the complex field of sustainable food waste management by conducting a comprehensive bibliometric analysis of multi-criteria decision uses in this field. Using bibliometric methods, a methodological examination of the scientific literature was performed to identify important trends, contributions, and gaps in research on sustainable food waste. Decision-makers can be further empowered by using multicriteria decision-making to assess interventions across various dimensions, including environmental effects, economic viability, and social acceptability, highlighting the interdisciplinary nature of this strategy and promoting interactions between researchers, decision-makers, and stakeholders. These guidelines directly followed the development of policies, business practices, and consumer behavior, indicating a more sustainable food system. The combination of bibliometric analysis and multicriteria decision-making offered a formidable instrument to reduce food waste, enhance resource efficiency, and spur progress in global sustainability initiatives in a world where sustainable behavior is crucial. The study results in decision-makers evaluating interventions and strategies holistically by concurrently considering the food waste dimension, a multicriteria model, economic factors, environmental factors, social factors, policy considerations, and technical feasibility are just some of the factors considered in this study. This analysis highlights the growing commitment to comprehensive solutions that focus not only on waste reduction but also on resource efficiency, environmental stewardship, and societal well-being as sustainable food waste management gains traction on global agendas.

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122	12	6

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INTRODUCTION

In the last decade, food waste has become a potential problem in achieving sustainable development goals of converting food waste into new usable and marketable products (Bilal and Iqbal, 2019; Zaman *et al.,* 2021; Weekes *et al.,* 2021; Charkhestani and Yousefi Kebria *et al.,* 2022). Food is discarded at many points in the food supply chain. Products that fail to fulfill aesthetic or quality criteria are frequently wasted on farms (Ortiz-Gonzalo *et al.*, 2021). Losses may also result from insect damage or overabundance of production. Offcuts, byproducts, and goods that do not fit the exact criteria add to the waste in processing and manufacturing. In retail settings, products not sold, outdated, or have slight flaws are regularly discarded. Plate waste, over preparation, and spoiling are sources of waste in restaurants, cafeterias, and catering industries. Furthermore, families play a significant role in the food waste problem owing to spoilage, underuse, and overbuying. Large amounts of edible food are discarded worldwide. Approximately one-third of the food manufactured for human consumption is never consumed (Williams and Rangel-Buitrago, 2022). This is equivalent to disposing of trillions of dollars' worth of food annually, or several billion tons (Tomaszewska *et al.*, 2022). This transformation is one of the crucial factors for the future of society and economies in various countries. To date, multiple studies have highlighted the increased investment in processing food waste, the price of essential ingredients, food insecurity, increased costs in the supply chain, and the resulting economic losses (Boyacı-Gündüz *et al.*, 2021). This is a compelling subject to researchers, as shown by the issue of food waste from various fields of science, as evidenced by the fact that the term food waste from Scopus, Science Direct, and Web of Science has up to 370,000 scientific papers on the economic impact of food waste, technical, regulatory food waste, social, renewable energy, and the impact on the environment (Chen *et al.*, 2014; Nouri, 2022). Researchers use various methods to achieve sustainable development supported by these various fields of knowledge. The initial discussion of "Estimating Food Losses from Field to Fork on a Global Scale," published in 2011 by the Food and Agriculture Organization (FAO) of the United Nations (UN), discusses global estimates of the amount and impact of food wastage at various stages of the food supply chain and technological advances developed in processing food waste into usable products for use and sale (Ghosh *et al.*, 2016). In addition, FAO has observed various approaches to food waste recovery that consider economic, environmental and social factors. Therefore, various technological options have been developed according to each region's needs and existing conditions to minimize environmental damage, public health, and economic benefits (Surendra *et al.*, 2014; Samimi and Shahriari Moghadam, 2018; Ehzari, *et al.,* 2022). Companies or parties that use products from food waste management in the form of fertilizer, electricity, and animal feed have examples of having a low environmental impact (lower consumption of fossil fuels, use of electricity, and generated pollution) and also fulfil social values, as well as consumer concern (Donner *et al.*, 2020; Nordahl *et al.*, 2020). In this scenario, stakeholders, researchers in each field, policymakers, governments in each region, and producers collaborate to choose various technologies and methods to achieve sustainable improvement by weighing factors such as technology, the economy, ecology, and society (Caputo *et al.*, 2023; Sachs, 2012; Solangi *et al.*, 2021). Thus, decision-makers must choose indicators and simultaneously make decisions with solid origins. Choosing the best sustainable option that may lessen the negative effects on the environment while bolstering the economy and society is challenging in the current setting. Various choices, viewpoints, and indicators hinder fast and precise selection. By comparing and summarizing the results of different choices, mathematical tools can aid in finding optimal solutions to organizational difficulties. Multicriteria Decision Making Aiding (MCDMA) is a commonly used approach that determines the criteria involved in selecting decisions, limiting choices to suggest priority choices that the decision-maker has predetermined (Bortoluzzi *et al.*, 2021). To comprehend research tendencies, contributions, and gaps in sustainable food waste management, the MCDMA concept was incorporated into the analysis in a methodological and structured manner (Fusté-Forné and Noguer-Juncà, 2023). To ensure consistency with the core concept of considering many decision-making criteria, articles were carefully selected that directly addressed the relationship between MCDM and sustainable food waste management. The selected papers were evaluated based on a set of established criteria. The use of MCDMA frameworks, the incorporation of environmental, economic, and social components, and the breadth of investigation into the complexity of food waste management were all considered as part of these requirements. When the selected papers were categorized and classified according to the specific MCDM methodologies or frameworks utilized, clear tendencies in the application of various techniques were apparent. A quantitative analysis plays a crucial role in explaining these tendencies by quantifying the use of different MCDMA techniques. This quantitative method helped highlight the prevalent MCDMA methodologies and highlighted industry norms. Moreover, the articles revealed overarching themes encompassing waste reduction techniques, resource allocation, stakeholder engagement, and policy formation, as observed through the MCDMA lens. The algorithms presented in the MCDMA model are useful tools for solving complex problems in the food waste field (Angelo *et al.*, 2017). Various methods have been applied to various cases that consider many perspectives and fields of science, economics, and society, such as China (Xi *et al.*, 2010), Singapore (De Clercq *et al.*, 2017), England (Iacovidou and Voulvoulis, 2018), and Indonesia (Yunus *et al.*, 2020). The relevance and weighting of the criteria are among the variables examined and provide information on the relative weights assigned to each criterion. Cost-benefit analyses examine the aspects of investment, operations, and income from an economic perspective. When combined, environmental impact parameters focus on resource utilization, emissions, and ecological footprint, highlighting the sustainability problem. The inclusion of risk and uncertainty parameters acknowledges the erratic character of outcomes, whereas social and ethical components gauge the influence on society and ensure that choices are consistent with moral principles (Ellestad and Winton, 2022). The all-inclusive evaluation strategy incorporates stakeholder priorities, quality measures, and regulatory conformity. Understanding the interplay of these variables is crucial and often necessitates the development of novel approaches. Moreover, in the quest for environmentally responsible food waste management, MCDMA strategies are crucial and provide essential direction. Waste management approaches can be compared using performance and utility scores, leading to decisions that more effectively reduce waste, conserve resources, and reduce environmental damage (Schmidt and Laner, 2023; Samimi and Mansouri, 2023). Economic considerations inform financial viability through a cost-benefit analysis, which directs resource allocation and justifies investments in waste-reduction technology and disposal strategies (Aithal and Aithal, 2023). Decisions guided by environmental impact criteria reduce emissions, save resources, such as water and energy, and save ecosystems (Drobyazko *et al.*, 2021; Moghadam and Samimi, 2022). Decisions that consider the community's welfare, food security, and moral principles are strengthened when social and ethical considerations are considered. Choosing strategies consistent with the current infrastructure is facilitated by conducting a technical feasibility evaluation. Therefore, sustainable technologies for food waste and MCDMA are relevant areas of study and have significant potential for progress (Bolaji *et al.*, 2021). Various literature reviews have highlighted the qualitative and theoretical research on food waste, management technologies, planning for sustainable systems, foresight, and supporting economic and policy decisions regarding food waste (Thyberg and Tonjes, 2015; Ghazali *et al.*, 2021). Previously cited research, however, has not yet addressed particular difficulties, such as the most frequently used performance metrics or MCDMA models for evaluating food waste. This represents an opportunity to explore subjects through bibliometric studies. Provided they can impartially recognize patterns in research, bibliometric studies offer the advantage of systematizing research topics carefully chosen by researchers (Verger *et al.*, 2019). Another notable contribution of this study is that by researching food waste, the application of the MCDMA model can be another direction, which still needs to be used. Therefore, this bibliometric technique is considered sufficient in identifying the characteristics of the research agenda on the theme of food waste and MCDMA (Bortoluzzi et al., 2021). Therefore, based on various aspects of sustainable food waste technology and methods, this study aimed to explore the complex field of sustainable food waste management by conducting a comprehensive bibliometric analysis of multi-criteria decision uses. Moreover, scientific literature was methodically examined using bibliometric methods to identify important trends, contributions, and gaps in research on sustainable food waste. Studies were conducted at Diponegoro University from January to August 2023 to segregate sustainable food.

Exploring food waste, MCDMA methods and criteria

This section briefly reviews various studies on alternative technologies and methods for food waste in implementing sustainable development, as well as the reasons for the MCDMA method and criteria used to study sustainable development through food waste.

Identification of sustainable food waste technology and method

Identifying technologies and methods for sustainable food waste involves considering various approaches that effectively reduce food waste, minimize negative environmental impacts, produce products with marketable and usable values, and promote resource efficiency to meet FAO and Environmental Protection Agency (EPA) goals. Additionally, alternative technologies should be as realistic as possible because of the socioenvironmental effects of energy generation and use (Taghikhah *et al.*, 2019; Pouran *et al.*, 2022). Simultaneously, the limitations of selection for implementation are various indicators and the impact of various technologies on the environment and society. According to Ma and Liu (2019), sustainable food waste technology has a low cost, small impact, and produces no residue that cannot be reused (Wojnowska-Baryła *et al.*, 2020). Food waste can be analyzed from a sustainability perspective as well as from its technical characteristics (Han *et al.*, 2022). Consequently, the quantity required to satisfy market demand and its technical characteristics, such as integration with other sources, must be considered (Lee *et al.*, 2020), and the economic feasibility of energy efficiency and operational costs are crucial factors in considering the selection of products (Hoang and Nguyen, 2021). Several studies have analyzed food waste sustainably. However, gaps result from studies analyzing variables such as geography, awareness and behavior change, equity and social sustainability, infrastructure, and accessibility to make the right choices when applying food waste technologies (Bachmann *et al.*, 2022; Rejeb *et al.*, 2021). Consequently, various options are available from various sources (new technologies arise to enhance the efficacy of existing sources). The following is a list of many sustainable technologies and approaches found in the literature review to help choose each solution with increased clarity.

1. Intelligent monitoring and tracking systems and precision agriculture are based on newly developed sensors (García *et al.*, 2020). Real-time monitoring with this technology and data analytics can be used to monitor and identify waste points, improve efficiency, and reduce overall food waste (Kayikci *et al.*, 2022). Precision agriculture uses drones and data analytics to increase agricultural efficiency, reduce food waste at the production level, and optimize the use of resources in the form of water and fertilizer (Monteiro *et al.*, 2021; Raj *et al.*, 2022). These technologies use the principle of preventing food waste generation, which has the highest hierarchy in food waste technology and methods.

2. Food redistribution involves the principle of food reuse. This method involves collecting and redistributing edible foods from surplus restaurants, supermarkets, or households. Food banks are allocated to those in need for distribution to charitable institutions.

3. Insect-based conversion involves living organisms in the form of insects, such as Black Soldier Flies (BSF) or mealworm beetles, converting food waste into a high-quality protein source (Mannaa *et al.*, 2023; Varelas, 2019). The intended conversion is in the type of insects used to consume food waste, convert insects into animal feed, and produce fertilizers used in plants (Ojha *et al.*, 2020; Samimi *et al.*, 2023). The principle of this method is similar to that of composting but consumes less energy, and the production process occurs relatively quickly and has an economic potential of up to 300 percent (%) of the initial investment (Rosenboom *et al.*, 2022). However, this method requires complex treatments during development and cultivation. This technology is generally used in tropical Asian countries, such as Indonesia, Malaysia, and Singapore.

4. Composting is a widely applied engineering method depending on the desired needs of each local government and stakeholder. This method adopts a third hierarchy, namely utilization. Composting is a natural process of converting food waste into high-nutrient compost (Hamid *et al.*, 2019; Palaniveloo *et al.*, 2020). This process involves a mixture of additional

ingredients in the form of dry leaves or straw, which are naturally decomposed by microorganisms. This prospective method to reduce large amounts of food waste is constrained by the time required.

5. The waste-to-energy method transforms food waste into other energy sources, such as electricity or heat, using gasification and pyrolysis processes (Hosseinzadeh *et al.*, 2022). Food waste is converted into gas or oil, which can produce energy, making it less dependent on fossil fuels (Ashokkumar *et al.*, 2022). This is similar to the fourth hierarchy of food waste management, namely, energy recovery, but requires a relatively high initial investment.

6. Anaerobic digestion, similar to the previous method, requires a higher initial investment and has a relatively high potential for environmental impact. This technology converts waste into biogas and digestates via organic digestion in the absence of oxygen (Tawfik *et al.*, 2023; Thompson *et al.*, 2020). This method produces biogas, which is an energy source, whereas the digestate produced is an organic fertilizer with rich nutrients (Baştabak and Koçar, 2020).

7. Integrated food waste management involves various technologies and methods for managing food waste, such as composting, anaerobic digestion, and BSF, until the resulting residue is disposed of in landfills and waste banks (Farahdiba *et al.*, 2023). This approach is placed at the end, even though it has a high potential for recycling because the residues are disposed of in landfills.

8. Internet of Things (IoT) and Artificial Intelligence (AI) technologies can be combined with previous approaches for monitoring, managing, and optimizing various selected food waste management approaches in integrated food waste management (Oruganti *et al.*, 2023; Ukhurebor *et al.*, 2021). Intelligent sensors, real-time data analysis, and data-smart systems help identify patterns, predict market demand, and optimize food waste management operations such that the residues generated are microscopic before disposal into landfills.

Achieving more sustainable food waste management, reducing waste, lessening environmental effects, and maximizing the value of food waste can be accomplished using a combination of technologies and methodologies relevant to local conditions and the scale of food waste management.

Multicriteria decision-making methods

This section summarizes the literature review on the use of the MCDMA method in various food-waste-related and investment-related topics. MCDMA has been implemented to aid problem modeling in selective decision-making processes related to food waste, considering various criteria (Adar Yazar *et al.*, 2023). Several MCDM/A models are applied to the subject of food waste as Elimination Et Choix Traduisant la REalite (ELECTRE), VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), Technique of Order Preference by Similarity to Ideal Solution (TOPSIS), and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) which are examples of the analytical hierarchy processes (AHP) (Sadhya *et al.*, 2021). According to Kandakoglu *et al.* (2019), common categories include the single-criterion synthesis method, which outperforms MCDMA. The synthesis method based on a single criterion must consider the incomparability of the alternatives listed below: AHP and TOPSIS (Vassoney *et al.*, 2021). This model combines many perspectives into a single function, which is then optimized. Compensatory rationality also features prominently in this approach; the outcomes of alternative food waste that performs poorly on one criterion can be improved by its performance on other criteria (Bortoluzzi *et al.*, 2021). Non-compensation and outranking approaches are the only ones where a trade-off connection between criteria and indicators occurs (Kravchenko *et al.*, 2020). Outranking approaches within the MCDMA model are tolerant of non-comparable ties between options (Akram *et al.*, 2021). The interaction between these options aids in issue-solving by establishing outranking (and under the preferences of the decision-maker, which are typically initiative and partial) (Yannis *et al.*, 2020). Therefore, the justification for non-compensation can only be provided by focusing on criteria with a clear preference between the two options, irrespective of the relative importance of those criteria (Edjossan-Sossou *et al.*, 2020). In collaboration with MCDMA, fuzzy theory has been applied to obtain the uncertainty and ambiguity often found in food waste from a scientific perspective (Javanmardi *et al.*, 2020). For instance, the outcomes of analysis (synthesis), where obtaining the frequency from fuzzy logic in conjunction with several other techniques, have led to the development of newer, more suited, and adaptable techniques that can impact future trends in sustainable food waste (Masood and Ahmad, 2021). Ukpanyang *et al.* (2022) provided an overview of the MCDMA method based on sustainable food waste generation, including AHP, PROMETHEE, and TOPSIS. The study presented the analysis results for efficiency, cost, environmental impact, reduction strategies, waste management methods, site selection, and location selection for food waste management methods (Hashmi and Alam, 2019; Llopis-Albert *et al.*, 2021). These serve as a reference for stakeholders, decision-makers, and third parties to establish the best compromise for implementation. Meanwhile, different analyses (Liu *et al.*, 2008) from various studies (including integrated and systematic approaches) and decision-making methods require assistance in planning and sustainable programming for food waste (Wu *et al.*, 2021). In this analysis, the authors discussed the importance of assisting collaboration between decision-makers, stakeholders, and third parties for the analyzed problem and suggested the most efficient approach to implementing the MCDMA model (Govindan, 2022). Furthermore, the concept of sustainable food waste applies the Circular Economy (CE) concept based on the problems that occur (Teigiserova *et al.*, 2020). This sustainability research contributes to a review of various factors, technologies, and opportunities to address food waste, resulting in a proposal for problem analysis (Lopes de Sousa Jabbour *et al.*, 2021). Various contributions and collaborations using the MCDMA have addressed global food waste problems. For example, Gardiner (2020) proposed the integration of some Life Cycle Assessment (LCA) methods, Life Cycle Cost (LCC), sustainability, and Social Life Cycle Analysis (SLCA) with approaches such as MCDA and System Dynamics (SD). This study aimed to obtain the most sustainable proposals from a life cycle perspective to analyze the complexity of systems and sustainable tools emerging for analyzing sustainable food waste in various countries (low-income, middle-income, and high-income). This study also advised low-income nations to use the ABM hybrid method while considering technological, economic, social, and environmental perspectives. Engineering is creating and implementing a systematic technique to evaluate sustainable food waste and identify numerous solutions for food waste using the AHP method in diverse developing nations. This analysis showed that increasing the efficiency and effectiveness of food waste is desirable. Simultaneously, methods such as incineration and anaerobic digestion are the least recommended because of their high energy consumption, relatively high pollution, and high initial investment from the developing countries analyzed (Khan and Kabir, 2020). Further research (Khan and Kabir, 2020) developed an assessment model in the form of an Environmental Impact Assessment (EIA) in the process of an environmental impact assessment used in project planning and development, in this case, food waste, by helping to analyze, estimate, and evaluate the environmental impact of food waste management practices, by considering these factors. The study indicated that several countries that are intense in sustainable food waste, such as Germany, the Netherlands, Denmark, South Korea, and Australia, have implemented laws for food waste, management practices, prohibiting food waste disposal in landfills, public awareness campaigns, implementation of programs and initiatives that promote responsible handling, reduction of food waste at the source, and development of management alternatives that are first implemented on a small scale (Pharino, 2021; Shen *et al.*, 2023; Terleeva, 2022). Several studies have implemented MCDMA, stressing the indicators/criteria used in addition to the numerous aspects of each food waste technology and the potential for Key Performance Indicators (KPI) (Bortoluzzi et al., 2021). Papargyropoulou *et al.* (2014) outlined a comprehensive set of policy criteria regarding alternatives to food waste in the book "Sustainable Food Waste Management: A Comprehensive Literature Review on LCA-MCDMA Methodology," examining numerous techniques and solutions employed by the scientific community to evaluate sustainability in food waste using a fusion of LCA and MCDM approaches. This study offers a collection of sustainability indicators for evaluating energy alternatives, food waste assessments, and regulations. According to the literature mentioned above, studies on rating and choosing sustainable food waste do not consider preferences when weighing the trade-offs between different criteria and performance traits (Brenes-Peralta *et al.*, 2020; Romero-Perdomo and González-Curbelo, 2023).

Numerous surveys have also provided performance information for other options based on the findings of various combinations of factor levels and performance qualities. To resolve this issue and select a sustainable food waste solution, an evaluation of the trade-offs between several performance criteria may be necessary (Muscat *et al.*, 2021). The literature review revealed that NVivo and Vos Viewer bibliometric analyses using performance criteria and MCDMA decision-making methodologies were used to prepare this study (Bortoluzzi *et al.*, 2021). The importance of this study lies in its determination of the differences between economic, social, policy, technological, and environmental indicators and the criteria used in the decision-making process for evaluating and selecting sustainable food waste management strategies from an MCDMA perspective.

Assessment Criteria for food waste sustainability alternatives

The literature contains several sample studies on the application of the MCDMA approach to assessing sustainable food waste alternatives (Allesch and Brunner, 2014). However, it is challenging to identify and select factors that allow for the selection of sustainable options. The decision maker must expend significant cognitive effort because quantitative and qualitative data, as well as more nuanced data pertinent to each criterion, will determine the optimal number of criteria to be used. This article is used in this study. Performance indicators and assessment criteria are discussed in this study because they are intended to evaluate and compare various solutions across alternative technologies. Depending on the production sector, KPI may incorporate subjective or objective indicators. It is important to know which MCDMA method is being utilized and which performance indicator is best for a decision strategy to evaluate sustainable food waste technology. The combination includes several MCDMA modes, including the grey relational analysis (GRA) approach and other techniques, including AHP, fuzzy methods, or a mixture of various techniques (Banaeian *et al.*, 2018). Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis is a matrix that uses the PROMETHEE approach (Indrajayanthan *et al.*, 2022) and suggests combining Monte Carlo simulation and PROMETHEE (Mavrotas and Makryvelios, 2021). Therefore, managers of private enterprises that create sustainable goods from food waste may have different needs when evaluating sustainable food waste technology than those in the public sector (Lohri *et al.*, 2014). Managers' reasons for systematic business planning in selecting various technologies can be supported by identifying the most commonly applied factors through the MCDMA model. In addition to food waste research, Martin-Rios *et al.* (2020) advised that the following qualities should be present in management: a) clarity that technicians, researchers, and other stakeholders can understand; b) simplicity and uniform definition to prevent overuse and misinterpretation of technical outcomes; and c) relevance for the chosen parameters to satisfy operations' and stakeholders' needs. Several studies can provide insight into the complexity of the systematization of indicators and criteria when observing issues that arise in a sustainable context. Vittuari *et al.* (2016) found that resource efficiency, food waste reduction, environmental impact, socioeconomic impact, economic sustainability, and regulatory compliance are the six general criteria for sustainable food waste. However, in this series, the authors discussed how the dimensions of sustainability categorize these six criteria. A similar approach identified five criteria but did not involve indicators representing the social dimension of sustainability. Furthermore, Yeung *et al.* (2020) used indicators and criteria consistent with the United Nations, such as the agenda for 2030, but needed to consider environmental factors. Therefore, it is not appealing to utilize these indicators and criteria. In contrast (Reisch *et al.*, 2013) described eight criteria involved with social and economic dimensions and the environment but did not involve the policy domain. Furthermore, several other studies have not considered the technical or policy dimensions of these alternatives. Utilizing additional tools to supplement the indicator portfolio and conducting a thorough sustainability assessment following the three dimensions of sustainability (economic, social, and environmental) to generate ten analysis criteria is another illustration of how the choice of indicators can vary. The authors' method, one of the most popular instruments for environmental evaluation, was LCA. The challenge in choosing indicators was to reduce sustainability concerns and concentrate on energy efficiency. The literature advises managers to select the most effective renewable energy by establishing indications and criteria to help them make decisions. Three review papers published over the past year (2015–2017) were identified from five indexed, highly regarded journals. Most of the studies the authors reviewed focused on environmentally friendly food waste. Twenty-five criteria were identified for analysis. This study aimed to show that decision-making and the issue of sustainable food waste may coexist. Finally, several settings may be involved in indication selection; therefore, these need to be studied first. This study outlines different standards that can be applied to address pressing problems and reduce food waste in various nations (low-, middle-, and high-income). The most popular or pertinent indicator for measuring sustainable food waste was mentioned in this analysis (Iyamu *et al.*, 2020). Consequently, the choice of criteria used to evaluate various options generally affects the results of the MCDMA method. Weights were applied to the performance of each criterion/indicator based on the selection, sorting, and classification of sustainable alternatives to food waste. This study's methodology aimed to enable future scholars to reproduce this research in other domains using bibliometric analysis. The aim of the current study is expected to fulfill sustainable solutions at Diponegoro University, and this study was conducted in 2023.

MATERIALS AND METHODS

This study used a bibliometric approach to effectively select and evaluate food waste technologies. Conducting a bibliometric analysis in the context of sustainable food waste management and multi-criteria decision-making is essential because it provides a data-driven overview of research trends, key contributors, and voids in the field. The first benefit of bibliometric analysis is that it offers a broad perspective on the research environment and traces knowledge development over time. This analysis highlights the expanding significance of sustainable food waste management and multi-criteria decision-making among academic and practitioner communities by quantitatively evaluating publication trends, authorship patterns, and collaboration networks. The analysis then assists in identifying gaps and regions in which the research is under-examined. This understanding is essential to focus on current research initiatives and funding in areas with the potential to make significant contributions. For instance, the analysis might highlight particular aspects of sustainable food waste management that have received less attention, such as social equality issues or technological integration, leading researchers and policymakers to concentrate on bridging these knowledge gaps. To ensure that the results of this study may be used as a reference in other areas of research addressing sustainable food waste or even to update the findings on future perceptions, a systematic review of the literature was conducted based on existing reviews identified in the literature (Redlingshöfer *et al.*, 2020). The procedure described by Kumah *et al.* (2019) in the literature review is as follows:

- Step 1: Identification of opportunities in the research conducted
- Step 2: Establishing the criteria for selection and the database for the paper selection
- Step 3: Establishing categories for the quantitative examination of scientific output from the chosen field of research
- Step 4: Identifying the pattern of ongoing research and study opportunities for future perceptions through bibliometric analysis using VOSViewer and NVivo.

The importance of sustainable food waste technologies was stressed in the introduction of this study, which served as a justification for the first phase involving identifying potential research opportunities (Cicculло *et al.*, 2021). Examining the most frequently cited passages from diverse scientific studies, the technical application of bibliometric analysis in this study crucially established standards and optimization techniques in sustainable food waste research (Roslan *et al.*, 2022; Zhou *et al.*, 2022). The second step was the selection of the literature and databases. At this stage, the selection was performed. Thus, the databases used for literature adoption were Scopus and Science Direct because they have large publishers and diverse collections of literature on sustainable food waste. The database was utilized for current systematic reviews and bibliometric publications. After selecting a database, keywords in the examined themes were identified to reduce the selection of particular literature. Therefore, the keywords used to answer the objectives of this study were food waste, multicriteria decision-making analysis, food waste technologies, food waste economy, and sustainable development. Keyword determination was the purpose of this study.

- Group 1: Accomplish the idea of food waste and its variations from numerous articles using the keyword "food waste."
- Group 2: Food waste technologies to establish the aims of papers focused on various technologies and substitutes for food waste.
- Group 3: Food waste economy to filter publications on the conversion of food waste into economic advantages.
- Group 4: Sustainable development to filter out differences and the idea of sustainability
- Group 5: Multi-criteria decision-making aid: restrict literature searches using any field of the study's MCDMA methodology.

After the initial step of keyword selection, the "AND" operator is used to split up keyword group combinations, while the "OR" operator is used to split up cooperation words within the same group. Table 1 outlines the keywords and the preferences that justified their choice.

In addition to keywords, other filters allow for selectivity in literature selection. First, only literature written in English was selected because it is a common language used in bibliometric research. In addition, this language ensures that it will have the largest readership and the highest number of citations, thereby creating opportunities for research collaboration that can be identified using bibliometric methods. Options were also limited to a literature search of conference proceedings, reviews, and early access to the Science Direct and Scopus databases, with a publication deadline for each year (time-lapse:2014–2023). The search parameters (titles, keywords, summaries, and abstracts) provided 500 literature items compiled in the Endnote reference program. A sample of 146 literary works provided statistical research methods that could support the agenda on this issue. The classification used in Step 3 to retrieve data from each cited article is described below. The following categories were created using research from 146 articles: sustainable food waste, an analysis of food waste, used performance standards for analyzing food waste, using the MCDMA technique to examine sustainable food waste, authors and collaborators on literary works, authors' and co-authors' countries, publisher's journal, publication year, and the total number of citations for each piece of literature. Apart from these categories, other data were grouped to more clearly identify advanced sustainable food waste alternatives and optimization methods. Therefore, categories were established to enhance the thematic analysis, including the most prolific author over time, the most significant journals for study, and the nations with the most noteworthy number of publications, partnerships, and citations. Step 4 involved data analysis and study opportunities in the research subjects from 146 pieces of literature chosen once the data collection categories had been determined. VOSViewer and NVivo software were used to gather and analyze the chosen sample data. The VOSViewer can produce maps and enable group viewing of the subject under study using the nodes it represents. The map developed in this study depicted the authors' keyword network and how frequently it appeared over time. Additionally, "Word Clouds" were developed utilizing NVivo software to extract quantitative data from particular literary works to define word clouds about sustainable (economic, environmental, and social), political and technological criteria, and current MCDMA. Word clouds represent the KPI and are the most popular model criteria. The 146 chosen papers were summarized using the word cloud because review papers on sustainable food waste were associated with numerous KPI and MCDMA models. The research methodologies used in Step 4 differed from those used in prior review papers, allowing for fresh analytical viewpoints. A word cloud was used to select the primary criterion or KPI models and multi-criteria to enhance the bibliometric analysis, and 146 publications were chosen randomly. Sustainable technologies to reduce

Table 1: Outline keyword preferences

Group	Keyword
Group 1	Food Waste OR Food waste OR Food Waste behavior
Group 2	Food Waste Technologies OR Food Waste Management OR Food Waste Alternative
Group 3	Food Waste Economy OR Food Waste Economy to Economy value
Group 4	Environmentally-friendly OR Environmentally-friendly OR Efficient OR Efficient OR Cleaner
Group 5	Multicriteria decision OR Food waste multicriteria OR Multicriteria evaluation OR Multi objective analysis OR Multi objective decision OR Multicriteria decision

food waste have also been considered. Consequently, cluster analysis (k-means) and dendrogram generation were performed. When evaluating sustainable food waste technologies against KPIs or MCDMA models, this analytical visualization was performed to simplify the presentation of the results and make it possible to observe patterns. The groups into which this information was collected and analyzed are depicted schematically in Fig. 1. Notably, data related to the suggested categories were gathered for each target in the literature. These data enabled a cross-analysis between the MCDMA approach and the performance criteria for sustainable food waste decision-making.

Quantitative bibliometric examination of the knowledge database

The findings of the bibliometric analysis of the 146 selected papers are presented in this section. Descriptive and inferential statistics are presented in this section.

Typical bibliometric findings

The initial analysis referred to the annual growth rate of the sample in terms of publications (literature). The annual growth rate was expected to reach 14.95% between 2014 and 2023. From 2017 onward, the number of items included in the analysis increased significantly. For five years, the 2019–2023 sample increased from 10 to 24 studies, an increase of 15.5%. These findings suggest that researchers in mathematical models based on MCDMA methodologies are beginning to capture the attention of decision-makers regarding which technology to use. The annual growth rates of publications between 2014 and 2023 are shown in Fig. 2.

Fig. 3 shows the ten journals with the most articles published on the research topic after an increase in annual publishing was noted.

The journal with the most published articles was "Sustainability (Switzerland)," and the study sample comprised 32 articles from this publication. This journal has a considerable quantity of published material compared with no more than 20 other journals. Only five and three articles, respectively, from the "Waste Management and Research" and "Waste Management" journals were used in this study. Based on these findings, journals can be viewed as viable alternatives to distributing studies on decision-making using a multi-criteria approach and sustainable food waste to enhance the number of article readers. Additionally, it is useful to ascertain the number of papers and literature most frequently cited by the journals that publish this study. Table 2 of the ten papers in the investigated database with the most citations reveals that the first three papers received 300 or more citations.

Notably, the most frequently cited papers published in "Sustainability (Switzerland)" journals did not reflect the visibility offered to publish papers due to conditions during the year of publication where the publication theme of "pandemic, COVID-19" was one of the problem factors that were appropriate to the

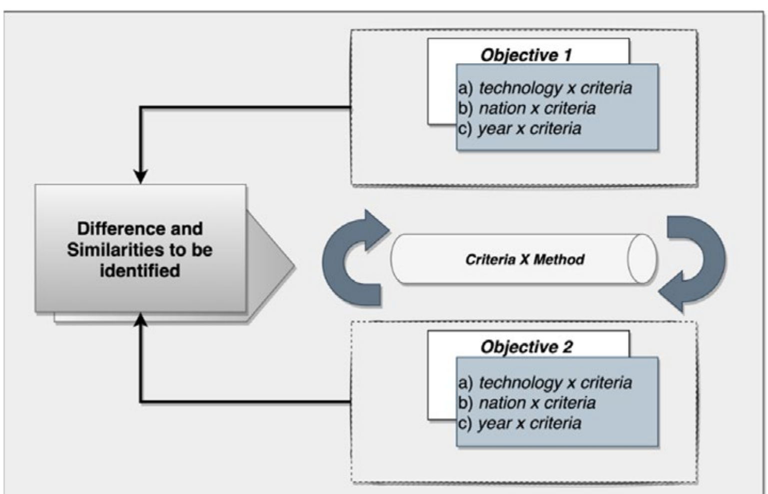

Fig. 1: Schematics representation of bibliometric analysis

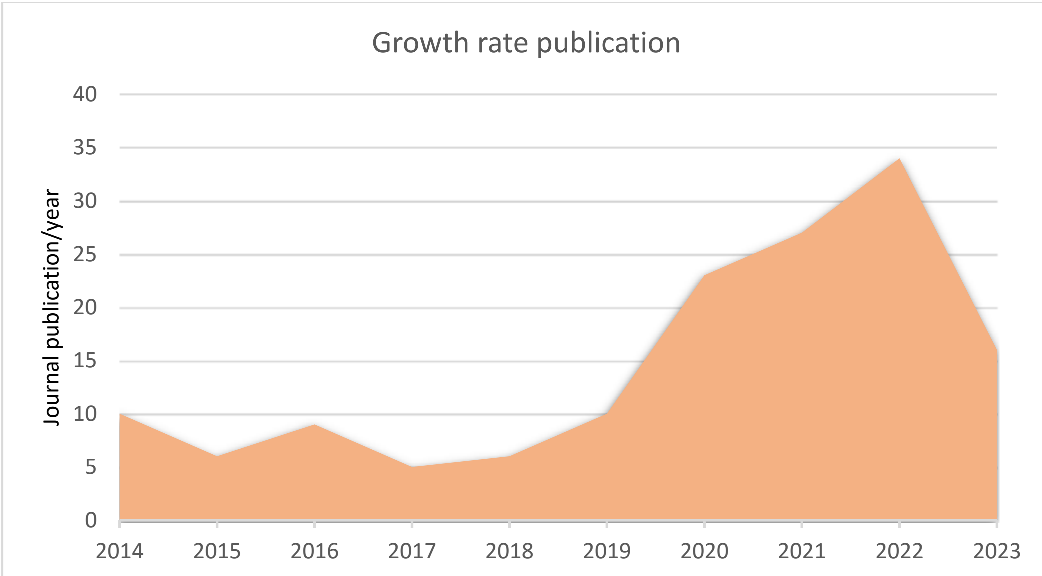

Fig. 2: The rate of publishing growth per year from 2014 to 2023

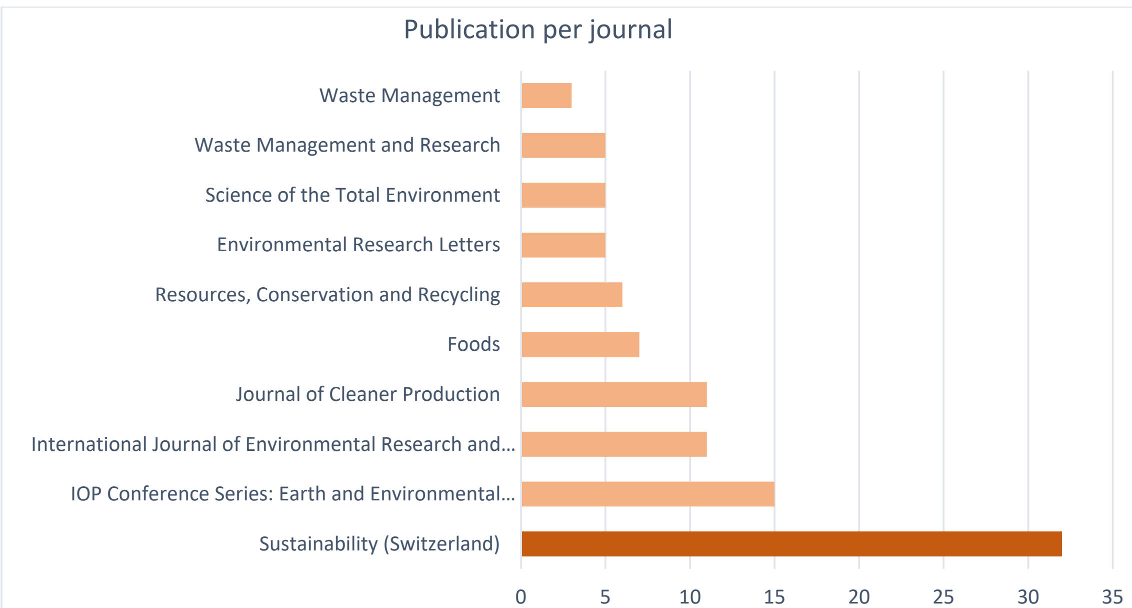

Fig. 3: Number of Publication per Journal

topic of food waste generation. This invisibility may indicate that the literature aims to identify knowledge patterns and has become a valuable reference for past and future perceptions of sustainable food waste and decision models using a multi-criteria approach. From the previous analysis, it was possible to identify the most frequently published authors on food waste. Fig. 4 shows the authors with the most published studies in the reviewed literature. One author had two publications. The author was Wong

Table 2: Most cited publication in literature for this study

Title of publication	Journal Where It Submitted	Number of citations	Sources
Challenges, opportunities, and innovations for effective solid waste management during and post-COVID-19 pandemic	Resources, Conversation and Recycling	346	Sharma *et al.,* 2020
Challenges and Practices on waste management and Disposal during the COVID-19 Pandemic	Journal of Environmental Management	135	Hantoko *et al.,* 2021
Redesigning a food supply chain for environmental sustainability – An analysis of resource use and recovery	Journal of Cleaner Production	113	Krishnan *et al.,* 2020
Data-driven optimal dynamic pricing strategy for reducing perishable food waste at retailers.	Journal of Cleaner Production	100	Kayikci *et al.,* 2020
Sustainable food systems—a health perspective	Sustainability Switzerland	84	Lindgren *et al.,* 2018
Food loss and waste in food supply chains. A systematic literature review and Framework development approach	Journal of Cleaner Production	80	Chauhan *et al.,* 2021
Performance evaluation of reverse logistics in food supply chains in a circular economy using system dynamics	Business Strategy and the Environment	56	Kazancoglu *et al.,* 2021
Repercussions of the COVID-19 Pandemic on solid waste generation and management strategies	Frontiers of Environmental Science & Engineering	54	Liang *et al.,* 2021
COVID-19 and waste production in households: A trend analysis	Science of Total Environment	53	Leal Filho *et al.,* 2021
A senior manager's perspective on food waste management in Shanghai full-service restaurants	Journal of Cleaner Production	50	Filimonau *et al.,* 2020

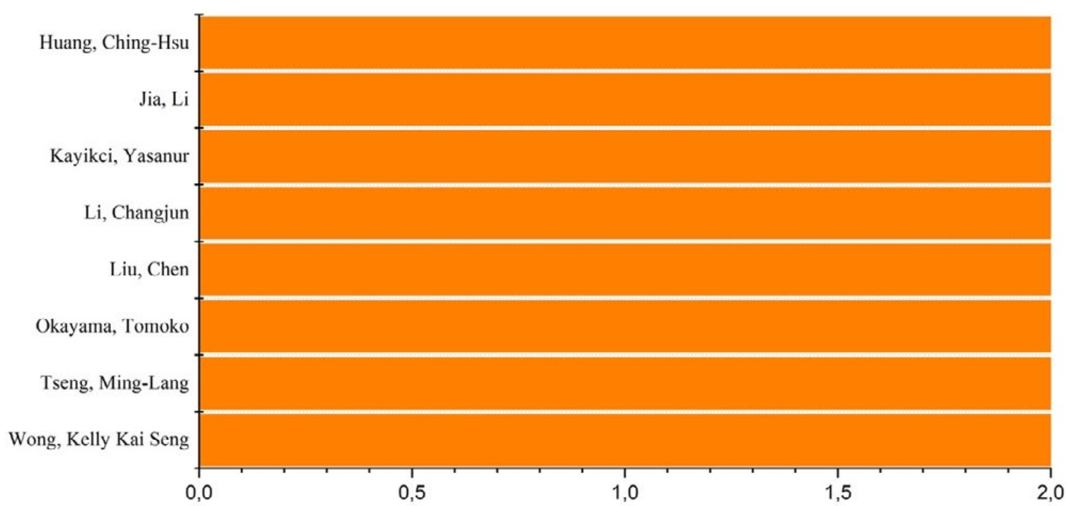

Fig. 4: Authors with the most published studies in the sample

Kelly Kai Seng from Rahman University College, Kuala Lumpur, who describes alternatives and habits to food waste that arises. Other prominent writers during the period analyzed were Li Changjhun (Department of Environmental Science & Engineering, Fudan University), Tseng Minglang (Institute of Innovation and Circular Economy, Asia University), Okayama Tomoko (Faculty of Regional Development, Taisho University, Tokyo), Jia Li (College of Economics and Management, Inner Mongolia Agricultural University), Liu Chen (Sustainable et al. Area, Institute for Global Environmental Strategies), Kayikci Yasanur (Department of Engineering and Mathematics, Sheffield Hallam University), and Huang Ching-Hsu (

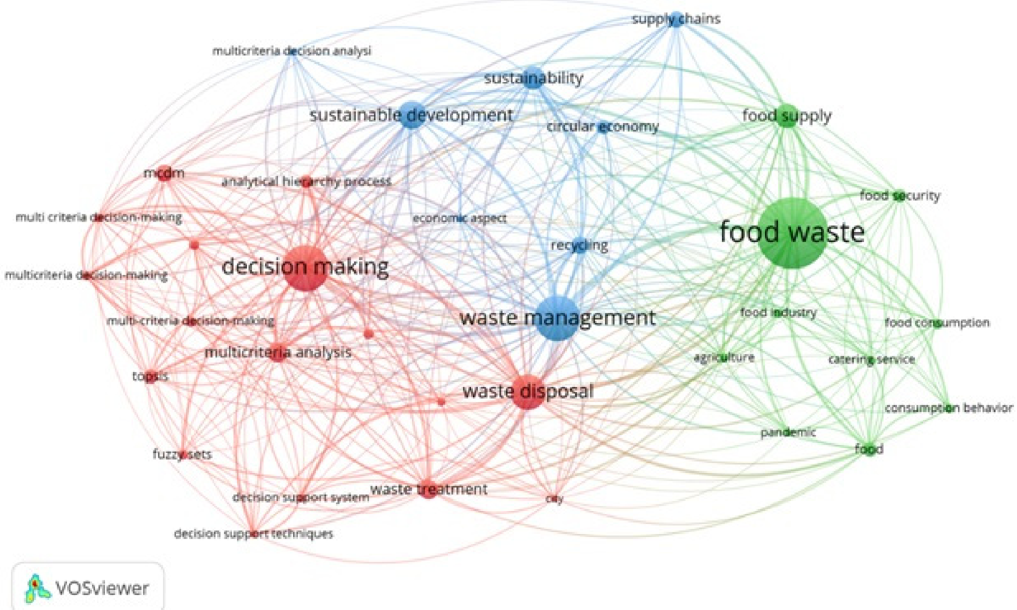

Fig. 5: Author's network keywords

Department of Hotel and Restaurant Management, National Pingtung University of Science and Technology), all of whom discuss different perspectives on sustainable food waste from different fields of study.

Ascertaining whether there is a pattern in the authors' usage of keywords is crucial when selecting reference studies to apply the multi-criteria method to food waste scenarios. Considering that each keyword in the network has at least two citations, Fig. 5 from VOSViewer shows the distribution of keywords in the network for the three groups.

The picture shows the words "Decision making'' and "Food Waste" as highlights. The word "Decision making" refers to various ways of quoting the term "multi-criteria decision making" or "MCDMA," which is simplified in this study by its acronym. Most terms in the other groupings were connected to these two words. As a result, it is feasible to confirm the author's propensity to utilize "food waste" and "decision making" to summarize their research. Confirming that the term "fuzzy" appears in various clusters is also possible. Along with other concepts and multi-criteria models, fuzzy techniques have been used to address FW, technology, and sustainability concerns. Therefore, "fuzzy sets," "fuzzy logic," "fuzzy topsis," and "intuitive fuzzy sets" are all visible. Analyzing similar word networks over time also hints at how authors might cite their studies. Fig. 6 shows that starting in 2019–2022, the keywords highlighted in the image show the frequency of use as well as possibly suggest that research will be made more visible on databases such as Scopus and ScienceDirect.

Fig. 7 shows the number of publications by country for the researchers' countries of origin. China, Turkey, and Greece published the most research papers relative to their home nations.

Word clouds

Additional bibliometric sources were chosen to fulfill the goals of this study, which include identifying the current state-of-the-art in food waste and making decisions using a multicriteria approach. As a result, a 7-word cloud was created to demonstrate the KPI in several sustainability dimensions and multicriteria decision-making models (Fig. 8a to 8g). A multicriteria approach's word cloud is shown in Fig. 8a. The managers' responses served as the primary and general data sources for this model. Other models, such as "DEA" or "PROMETHEE," are less noticeable, suggesting that fewer researchers used them in the sample.

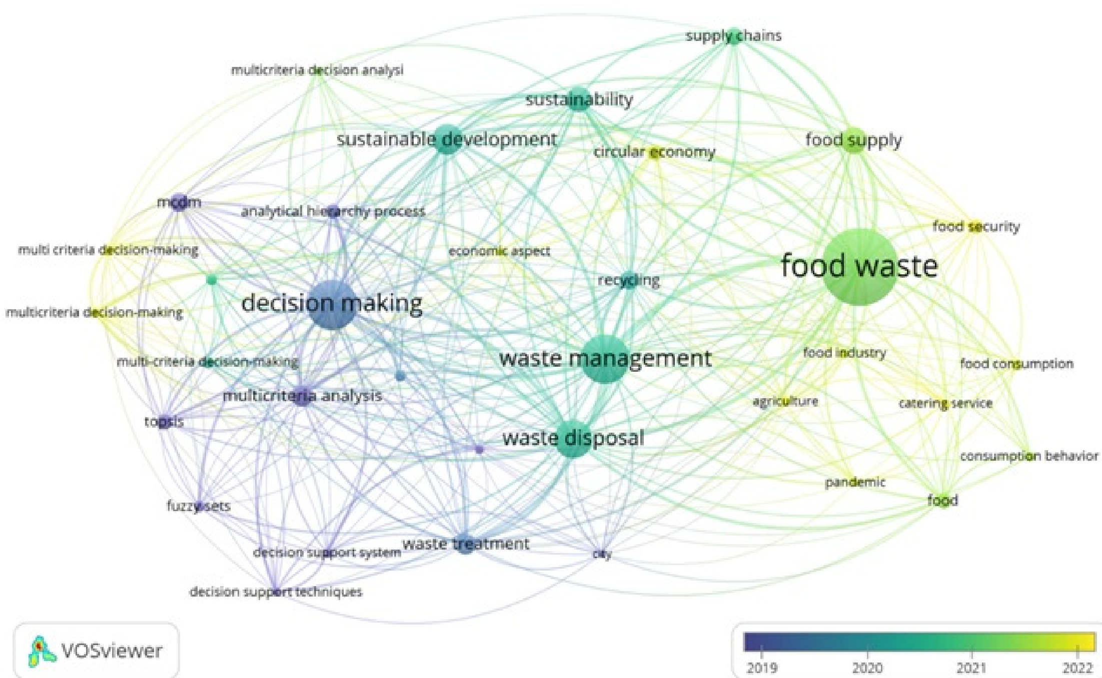

Fig. 6: Network of keywords analyzed over time

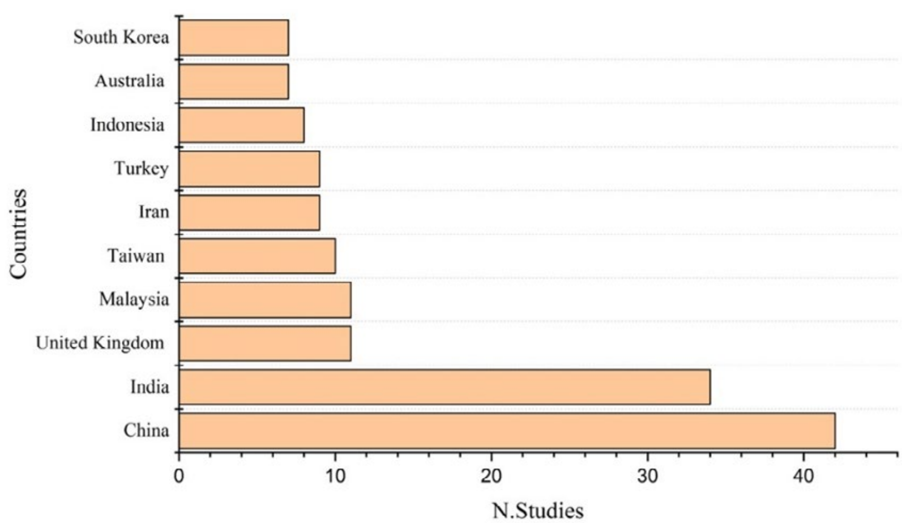

Fig. 7: Number Publication Base on Country

The KPI has a collection of word clouds to categorize the preference trends of each researcher for sustainable food waste. Fig. 8b shows a word cloud involving various sectors of food waste, sources, and factors for adopting "sustainability." The word cloud shows that the most important words are "food, waste, " and " management." However, some findings indicate that each writer must use phrases that come to mind to obtain sustainable food waste regardless of the technology or circumstances under consideration.

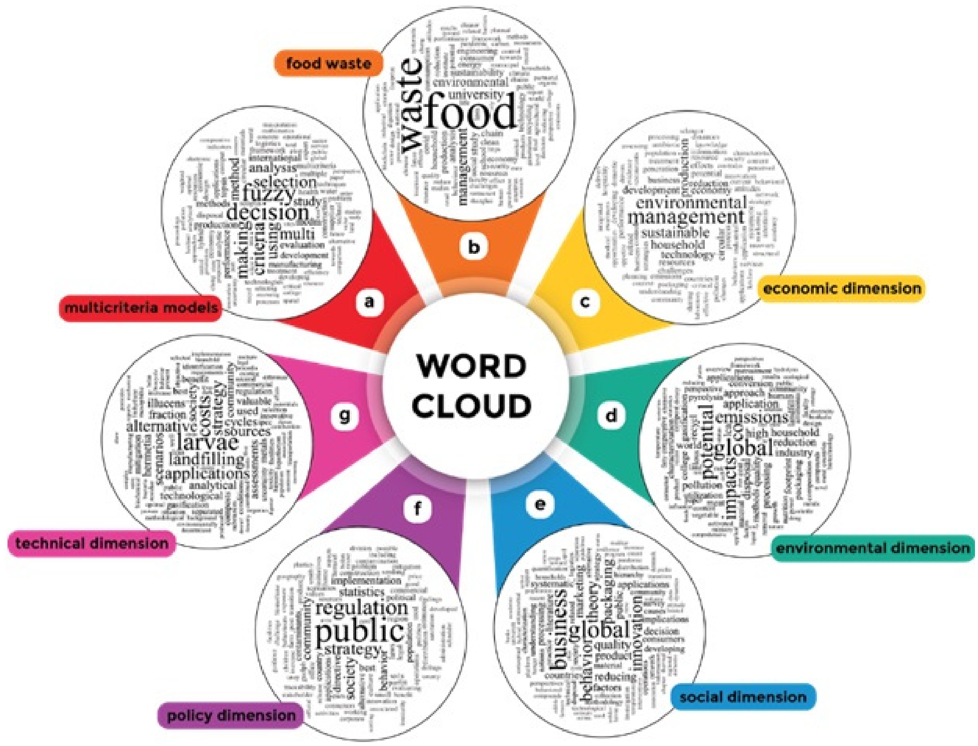

Fig. 8: Multi-criteria models and their most common indicators as a word cloud

The results of the world cloud show that the words “food, waste, and management” are fascinating to analyze the world cloud from each different sector and understand its relevance. Fig. 8c shows the word cloud exclusively in terms of economics. It is possible for an analysis of the word “economy” to be a relatively important factor in applying the concept of sustainable food waste. However, there are also words in the form of “renewable,” “business,” and “bio-economy,” which are relatively essential to observe but are still little analyzed in the economic sector. The phrases “technologies” and “optimization,” which are connected to costs for evaluating the performance of sustainable technologies and are frequently incorporated into essential elements of the economic sector, are also present in addition to these words. Therefore, sustainable food waste has a propensity to represent the economic sector. Fig. 8d displays the word cloud from the environmental sector that was employed in the research’s chosen literature, as opposed to the economic sector, which displays the phrases “impact,” “global,” “CO,” and “emission.” These findings demonstrate that each researcher attempted to study multiple options for each case and condition. The multi-criteria model simultaneously examined indicators and several alternative food waste methods. Another finding from this study is that nations have attempted to consider several indicators directly connected to the emissions produced in the context of climate change. In the social sector analysis presented in Fig. 8e, opportunities exist for stakeholders represented by the words “business,” “product,” “reducing,” “marketing,” and “innovation.” This phrase demonstrates the significant involvement of the social sector in various positive social impact issues, including higher income, the desire to lessen the sector’s influence, and numerous other repercussions. Consequently, significant problems persist in the social, environmental, and economic sectors. Global and national policy issues are crucial in assessing sustainable food waste. The word cloud of the decision-maker-related policy issues is shown in Fig. 8f. The phrases “public,” “regulation,” and “society” are conspicuous in the image as evidence.

These phrases imply that the important deciding factors for sustainable food waste are financial incentives and clear explanations of public policies. Policy concerns ultimately impact other sectors (economic, environmental, and social) because they are not entirely solved. Finally, as a sector analyzed with the subject of sustainable food waste, it can be used as a consideration for decision-making. Fig. 8g shows the words related to technical issues. This word cloud shows the words "costs," "valuable," "strategy," and "mitigation," which are relatively highly adopted. These words represent important indicators for decision-making regarding sustainable food waste. Thus, a strategy is needed to support sustainable food waste with a lower environmental impact and relatively lower investment and maintenance costs, as well as to obtain valuable products from the application of various technologies.

Bibliometric analysis result of inferential statistic

This section summarizes the findings of the analysis based on clusters connected to the principles of sustainable food waste, performance standards, and decision models using a multi-criteria approach following the objectives of the study. The next section describes the framework of multi-criteria decision-making; a methodical and deliberate procedure was used to assign matrix values for environmental, economic, social, and ethical criteria. Greenhouse gas emissions, land use, technological efficiency, technological maturity, technological capacity, energy efficiency, and land impact are only a few environmental criteria recognized alongside quantifiable units and scales. The environmental impact of the alternatives was measured using these criteria. Similar to technical criteria, economic criteria are monetary in nature and include maintenance costs, investment costs, and payback, which are scored to reflect their relative magnitudes among options. Scores that capture the social implications of each option are generated by defining and evaluating social issues using quantifiable units such as social acceptability and policy approval. Although qualitative, ethical standards are nonetheless crucial, necessitating the formulation of pertinent ethical considerations, qualitative scales, and the assignment of scores that correspond with the ethical alignment of options. These ratings are stored in matrices with rows representing options and columns representing criteria. Collectively, these matrices offer a structured basis for the following multi-criteria aggregation procedures, allowing for a thorough evaluation process that assists decision-makers in choosing sustainable food waste management options consistent with a wide range of criteria.

Sustainable food waste technologies

The results of the first analysis presented various sustainable food waste technologies that were studied in the 146 papers selected for this study sample from 2014 to 2023. Fig. 9 shows a dendrogram for sustainable food waste technology from the KPI analysis used in various studies. Categorizing these three groups is possible. These three groups were selected for in-depth analysis of how each technology group was selected for the selected studies.

Sustainable waste-reduction techniques cover a wide range of approaches to reduce waste and increase resource efficiency, which is why they are important in the development of circular economic ideas. By encouraging longer product lifespans, less packaging, and more conscientious purchasing decisions, source reduction and prevention programs can reduce waste initially. Instead of entering landfills, biodegradable materials can be recycled into nutrient-rich compost via composting, anaerobic digestion, biosolid landfill diversion, and organic waste management. By repurposing waste products through recycling and material recovery procedures using cutting-edge technologies, reliance on virgin materials can be reduced. The dual benefits of trash reduction and clean energy generation are realized through the use of waste-to-energy and biomass conversion technologies that focus on converting nonrecyclable garbage into renewable energy sources. Efforts to reduce trash can be bolstered using cutting-edge technology and methods such as smart waste management systems and sensor-based sorting. Choosing sustainable food waste management strategies requires a commitment to a set of guiding values that include respect for the natural world, economical use of resources, and active participation in the local community. One general principle is to follow a waste management hierarchy, with waste avoidance at the source (via better planning, purchasing, and consumption habits) given the highest priority. The first step in developing efficient food waste management is to

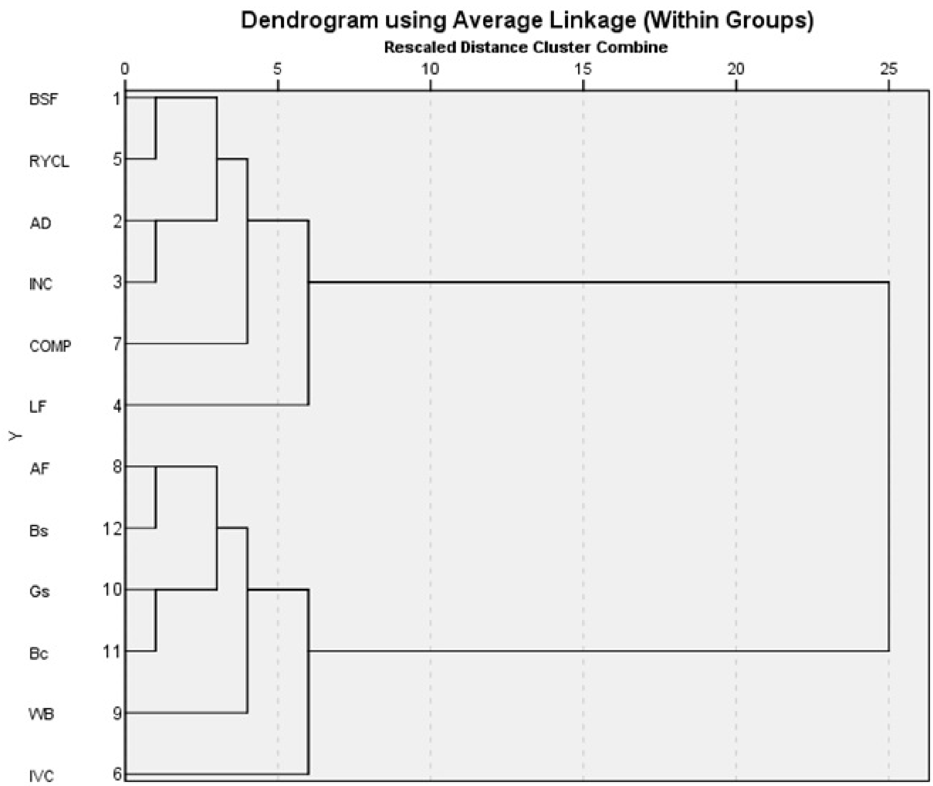

Fig. 9: Sustainable food waste technologies hierarchical cluster from KPI analysis

implement a system for source separation in which waste is separated at the point of production. In conforming to the intent of sustainability, methods that minimize the impact on the environment should be used, such as composting, BSF, waste banks, recycling, and anaerobic digestion of organic waste. The framework provided by municipal legislation and policies for waste management techniques must be carefully navigated. Fostering a culture of waste reduction and responsible consumption requires the active participation of communities and stakeholders through awareness programs. Smart bins and garbage-tracking applications are two examples of cutting-edge technologies that can be implemented to improve efficiency and collect useful data for better decision-making. The findings of this study demonstrate the value of applying economic principles to the problem of food waste by providing an enticing framework that prioritizes waste reduction, allocating resources efficiently, and encouraging effective practices at every stage of the food supply chain. Economic analysis highlights the need to minimize food waste and increase its value by evaluating the monetary costs of food production, distribution, and disposal. Businesses, households, and other stakeholders are pushed to adopt waste reduction measures in response to financial incentives that reward thrifty behavior and require them to tighten their inventory controls, reduce their portion sizes, and improve their distribution processes. Furthermore, economic principles stress the significance of resource efficiency, elaborating on how reducing food waste reduces the wasteful use of resources such as water, electricity, and agricultural inputs. This improves sustainability and solves critical problems caused by limited supplies. The KPI results show various types of food waste technologies. Table 3 presents the behavior of each cluster in several studies that employed these markers. For instance, using the indicators "GWP," "Land use," "Investment Cost," and "Payback" demonstrated that the first cluster was partially displayed. The cluster analysis results

Table 3: Citied studies’ cluster behavior

Final cluster centers			
Impact analysis	Cluster		
	1	2	3
GWP	11,4	30,21	32,02
Land use	10,60	30,12	28,01
Environmental impact	5,30	34,01	28,04
Social acceptance	21,50	28,01	9,04
Investment cost	11,72	32,12	28,04
Maintenance cost	10,05	25,12	25,42
Payback	25,01	9,02	32,04
Tech efficient	28,50	25,04	34,02
Tech maturity	18,79	30,02	27,02
Tech capacity	19,96	32,34	19,02
Energy efficient	20,78	5,34	8,04
Policy acceptance	8,45	1,23	0,02

showed that the average research assesses “Animal feed” and “Waste bank,” “Composting,” “BSF,” and “Recycle” using the same indicator. This pattern increases the possibility that these technologies may use similar signs in an evaluation study conducted prior to decision-making.

The second cluster was significantly different from the first cluster. Indicators such as “GWP,” “Land Use,” and “Investment Cost” are more widely used in the average study. This fact may indicate that the terms used are “environmental impact,” “tech capacity,” and “And maintenance cost,” indicating that the technology in the form of “landfilling, Incineration, and Anaerobic Digestion” does not include indicators of sustainable choice in the context of sustainable food waste from managers who want sustainable technology for food waste. The second cluster was significantly different from the first cluster. Indicators such as “GWP,” “Land Use,” and “Investment Cost” are more widely used in the average study. This fact may indicate that the terms used are “environmental impact,” “tech capacity,” and “maintenance cost,” indicating that the technology in the form of “landfilling, Incineration, and Anaerobic Digestion” does not include indicators of sustainable choice in the context of sustainable food waste from managers who want sustainable technology for food waste. Therefore, according to the frequency of use of indicators from 146 selected studies, managers may possibly prefer “Land Use,” “investment cost,” “payback,” “environmental impact,” and “social acceptance” as indicators that assess sustainable alternative technologies of food waste regarding which to implement. Including other technologies that exist outside of this study, implementation is not necessarily an indicator that is expected to be considered by decision-makers for wider implementation and expansion, and this depends on the existing conditions of each region and their needs.

Evaluating performance against multi-criteria decision models

Performance indicators and MCDMA models, the two primary concepts examined in this research, are combined in this part for analysis. The dendrogram for the cluster analysis is shown in Fig. 10. Three clusters of results are identified.

Performance indicators that share the same multi-criteria may be determined using non-hierarchical cluster analysis. According to the findings, cluster no. 1 includes the indicators “GWP” and “Investment cost,” as well as the indicator “Social Acceptance.” Cluster no. 2 contains the indicators “Land requirements,” “Job creation,” and “Technology returns and capacity,” whereas cluster no. 3 has all other indicators. Table 4 shows the distribution of performance metrics among clusters using the MCDMA model for selected publications.

Table 5 presents the clusters created by the MCDMA models employed in the cited papers. Using the “AHP” and “Fuzzy” models, the cluster indicators “Social Acceptance,” “CO2Eq Emissions,” and “Investment Costs” are more pronounced. This finding indicates that the MCDMA models “AHP” and “Fuzzy” are the most practical tools for examining

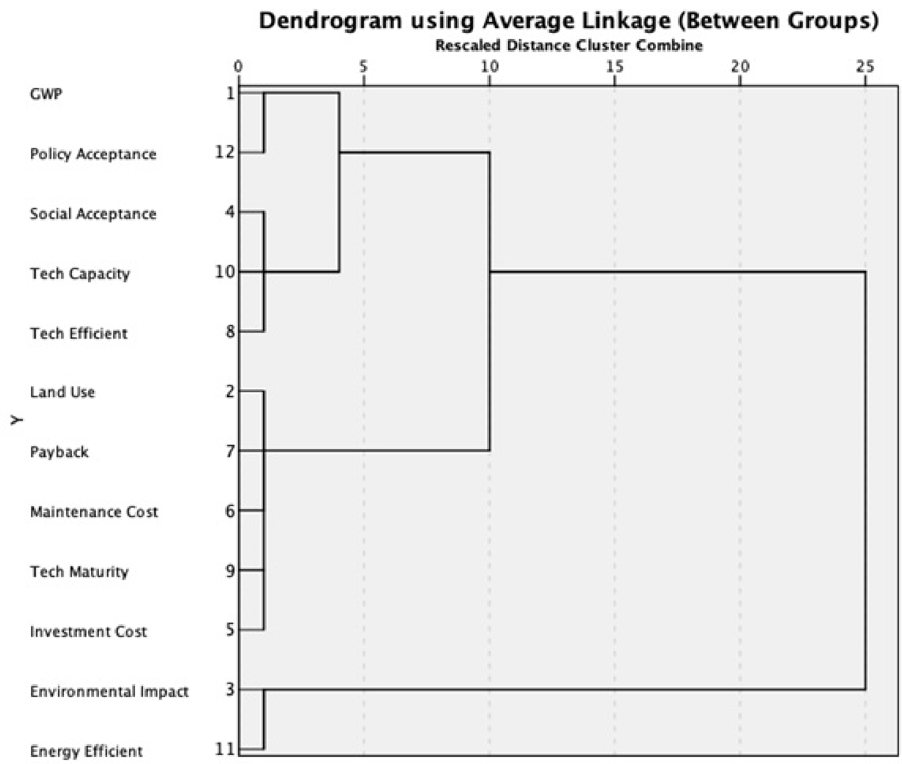

Fig. 10: Performance indicators and multi-criteria models in a hierarchical cluster

Table 4: Combining performance metrics from similar multi-criteria models

Cluster pool		
Cluster	KPI	Number of cases
1	GWP	20
1	Land use	12
1	Environmental impact	25
2	Social acceptance	15
2	Investment cost	10
2	Maintenance cost	10
2	Payback	12
3	Tech efficient	17
3	Tech maturity	10
3	Tech capacity	15
3	Energy efficient	25
3	Policy aAcceptance	20

sustainable types, which are, in this case, represented by the indicators mentioned above. Additionally, the "AHP" and "Fuzzy" methods are frequently used for cluster no. 2 ("Land Requirement," "Job Creation," "Return on Capital," and "Technological Capacity"), but this model is already more similar, indicating the potential for combining the two or the use of more objective indicators in other types of models. In the MCDMA system, Cluster no. 3 had the lowest indicator frequency. This cluster employed the "GREY" model, which was not noted in the earlier clusters, even if "AHP" and "Fuzzy" were still dominant.

Table 5: Cluster center formed from the multicriteria models

Final cluster centers			
Multi criteria method	Cluster		
	1	2	3
AHP	10,98	6,67	2,83
FUZZY	6,78	4,65	1,50
VIKOR	0,74	0,01	0,01
TOPSIS	2,01	0,75	0,15
ELECTRE	1,56	0,45	0,02
WEIGHTED	1,01	0,50	0,15
GREY	0,87	0,00	0,24

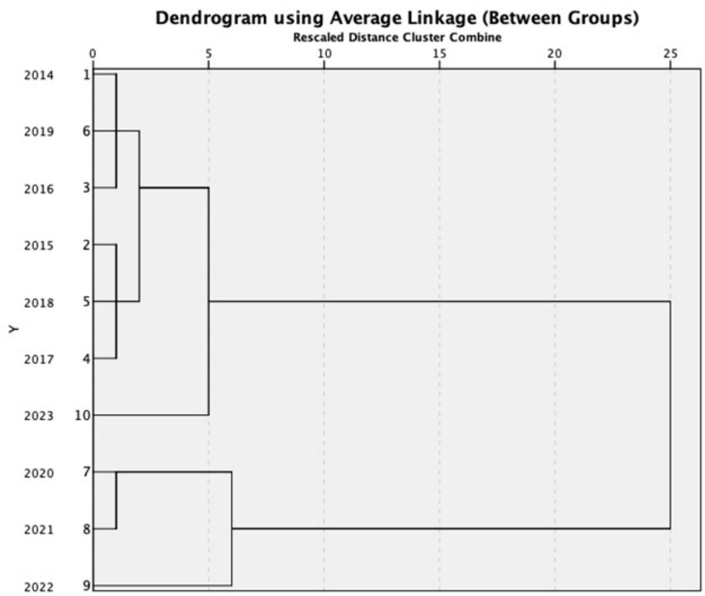

Fig. 11: Hierarchical cluster: annual publication of papers

Annual variation of publications

The annual publication rate of articles was the subject of the final analysis. Thus, based on the performance metrics and multi-criteria models, cluster analysis and graphical depiction of the year of publication were performed. As a result, the initial study focused on the development of a publishing year cluster in relation to performance measures. A hierarchical dendrogram of the annual sample article publication rate is shown in Fig. 11 as a cluster analysis.

The two clusters covered the period 2014 to 2018 and 2019 to 2023. From the cluster center, Table 6 describes the two formed clusters. The first and second clusters had the same annual frequency. The first cluster had work indicators that most often worked in the form of “Land Requirement,” “GWP,” and “Investment Cost.”

Between 2019 and 2023, the performance metrics in the second cluster that were most frequently utilized by the papers presented were “GWP,” “Investment costs,” and “Operational and Maintenance Costs.” The outcomes of this cluster demonstrated how the indicators changed in studies released between 2014 and 2023. As the first and second clusters evolved, linked performance measures, such as the economic and emission pillars, were confirmed; however, the model’s policy gradually changed. This results from a policy that has occasionally been applied to the environment and was implemented

Table 6: Using annual indicators and publications, a cluster center was created

Final cluster center		
Impact analysis	Cluster	
	1	2
GWP	2,65	7,53
Land Use	3,52	5,32
Environmental Impact	5,32	5,32
Social Acceptance	0,46	6,75
Investment Cost	1,46	8,00
Maintenance Cost	1,46	7,02
Payback	3,52	7,50
Tech Efficient	0,54	4,02
Tech Maturity	0,79	3,00
Tech Capacity	0,36	6,02
Energy Efficient	0,63	7,79
Policy Acceptance	1,64	2,64

in the 2015 Paris Agreement. As a result, decision-makers are less reluctant to embrace renewable energy sources and pursue specific environmental sustainability objectives. The outcomes of this cluster demonstrated how the indicators changed over time in studies published between 2014 and 2023. When comparing the evolution of clusters 1 and 2, what has been confirmed by economic and emission performance indicators can be observed; however, policy criteria are gradually being excluded from the model. The 2015 Paris Agreement led to the evolution of environmental regulations. This can be explained by the following: Managers should use renewable energy more frequently and set specific goals to reduce climate change. The results included 146 studies selected for bibliometric analysis, allowing for disaggregation by year of publication. These yields are presented, along with the year-in-10-year publication rate and the journal with the most published literature on sustainable food waste. Each study chose one of these as the focus. According to an analysis of publications from 2014 to 2023, there is a noticeable increase in the number of papers presenting the MCDMA approach to the issue of sustainable food waste technology. Compared with previous years, there was an increase in the number of publications between 2019 and 2022. This increase can be explained by increasing awareness of the environmental and sustainability aspects of food waste. This allows researchers to explore useful information supported by an approach that involves a decision-making process using MCDMA. The quantity of materials written between 2019 and 2021 is crucial because it demonstrates how the MCDMA strategy incorporated several sustainable technology facets. This can be attributed to the use of techniques for a more deliberate decision-making process. Recently, this strategy has attracted considerable interest from researchers. The demand for sustainable technology in food waste is the cause of a notable surge (Pardini *et al.*, 2019). Consequently, public policy requirements to support the environmental sustainability of the food waste sector have also been developed, which have prompted initiatives to improve technology efficiency as part of a plan to decrease greenhouse gas emissions and other potential effects on nations worldwide (Prosperi *et al.*, 2020). Despite the limitations of this study, it is feasible to identify established trends for indicators/criteria and the MCDMA model used to choose and evaluate sustainable food waste methods. Accordingly, the following recommendations are proposed:

Proposition 1

Policy indicators should be utilized less frequently than in studies employing MCDMA techniques, such as AHP and TOPSIS, with indicators relating to GWP, economic, and technical criteria.

First, sustainability was applied based on the Triple Bottom Line, which integrates financial, social, and ecological factors (Bachmann *et al.*, 2022; Rejeb *et al.*, 2021). This interpretation of sustainability adds to political, moral, legal, scientific, and cultural dimensions. The context of sustainable food waste was assessed in this study, and five variables were highlighted: economic, technological, political, social, and environmental (Hoang and Nguyen, 2021). To choose and assess sustainable food waste, it is crucial to consider these five factors while studying sustainability. The findings of this study are pertinent because they categorize the variables for which environmental, social, and economic indicators have been identified. The defined performance indicators and assessment criteria are handled equally based on all the indicators examined because they are intended to evaluate and compare various solutions utilizing various technologies. Depending on the KPI, subjective and objective indicators can be used. Therefore, it is important to distinguish which MCDMA method is employed and which performance indicators are most suitable for the decision strategy to evaluate sustainable food waste systems. The parameters for maintenance expenses ($/kWh), payback (year), and investment costs ($) were established to obtain revenue and reduce expenditure based on the economic issues examined. Research on food waste plays a crucial role in the adoption of sustainable food waste in terms of investments and purchasing choices (Johnston *et al.*, 2020). As a result, decision-makers should pay close attention to and consider the indicated criteria. Depending on the MCMDA approach, managers' judgments and tradeoffs between objectives and criteria are considered. Regarding technological and political components, several studies, including the findings of this study, have demonstrated that goals focused on these two areas are based on standards for operational effectiveness and efficiency: efficiency (%), technological development (on a qualitative scale), yearly energy production (in GWh), energy policy (on a qualitative scale), and political acceptance (on a qualitative scale). Because some studies concentrate more on the political aspects of assessing and choosing opportunities for sustainable food waste, this study demonstrated that policy coverage, acceptability criteria, and efficiency of food waste are still far from the global-scale criteria (Brennan *et al.*, 2021; Fesenfeld *et al.*, 2022). This topic should be considered when evaluating and choosing alternatives because it requires decisions to be made at all levels of government. The following criteria were determined for the environmental and social aspects: area of work (m^2), GWP, environmental impact (qualitative scale), employment generation (jobs/year), and social benefits (qualitative scale) (Kayaçetin and Tanyer, 2020; Soust-Verdaguer *et al.*, 2020). With sustainable food waste technology, these requirements imply limiting adverse effects on the environment and people's lives and optimizing socioeconomic impacts. To reduce global warming and other possible repercussions, nations including the United States, China, and India have concentrated on sustainable food waste research emphasizing environmental factors. Aspects connected to the Sustainable Performance Goals, as outlined by the 2030 Agenda established by the United Nations, such as Brazil and Taiwan, have highlighted the participation of people without access to sustainable distribution (Masood and Ahmad, 2021). Thus, the choice of criteria used to evaluate various sources of sustainable food waste will generally affect the outcomes of the MCDMA approach, including the importance of each criterion and indication in relation to how alternatives to sustainable food waste are chosen, sorted, and classified. Choosing indicators encompasses both issues pertaining to sustainability as a concept and those about various choices. To help decision-makers identify the most effective sustainability solutions, several criteria need to be more precisely defined and clarified. Consequently, the following hypothesis is proposed:

Proposition 2

Technological studies must address economic, political, technological, social, and environmental issues to implement sustainable food waste.

There are two primary ways to make decisions to choose the most profitable and effective option from various sustainable food waste technology solutions. The rationale for the manager's remuneration and non-compensation in expressing the choice determines which option is selected. The manager and analyst should engage in structured, interactive communication sessions as part of the decision-making process, during which the analyst records particular details regarding management preferences.

This study is pertinent to analyzing the research knowledge framework for various MCDMA methodologies and prospective KPIs. This analysis used a multi-criteria approach to evaluate, select, and rank sustainable food waste. This concept is based on sustainability. Application studies must be conducted to validate the approach and support its advancement, as well as to gather input on what else needs to be

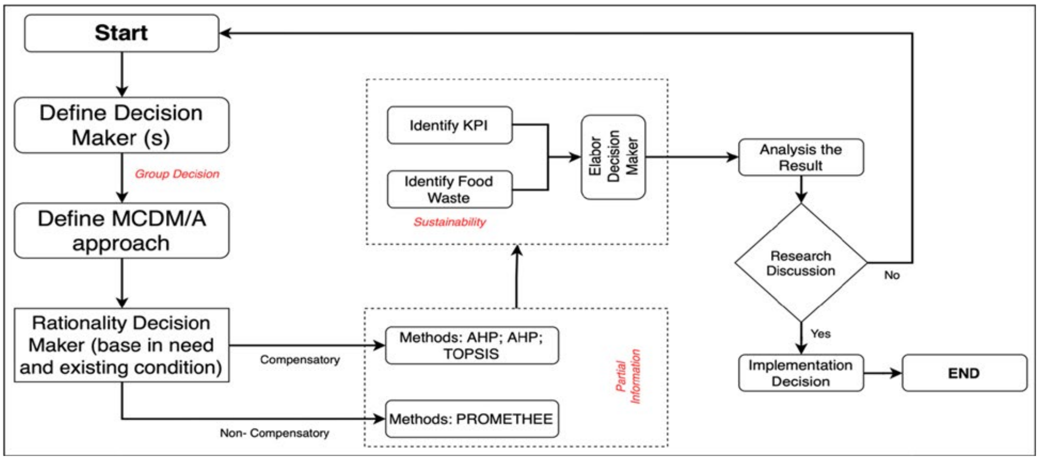

Fig. 12: Framework multi-criteria analysis method for sustainable food waste concept

produced in the study area. Using the findings of this study as a guide, sustainable food waste with a multi-criteria sustainability concept is recommended Fig. 12. Thus, the results of this study are as follows:

Proposition 3

The conclusions of this review allow the identification of options for a hybrid decision framework that combines the MCDMA approach with KPIs for recommendations.

RECOMENDATION

By collaborating together, promoting interdisciplinary cooperation among academics, professionals, and decision-makers in various sectors, including environmental science, food technology, economics, and social sciences, allows a better comprehension of the complex nature of sustainable food waste and improves the efficiency of bibliometric analysis and multicriteria decision-making. Studies of food waste have pushed for consistent data gathering and reporting procedures (Caputo *et al*., 2023; Sachs, 2012; Solangi *et al*., 2021). In addition, encouraging open-access databases and repositories containing pertinent bibliometric data allows more precise and repeatable academic analyses. Access to data is easier, resulting in more solid and trustworthy insights. A longitudinal bibliometric analysis was performed to identify emerging subjects, shifts in focus, and the effectiveness of interventions over time to follow the development of research trends. This strategy can highlight areas requiring more attention and the advancements in managing sustainable food waste. The opinions of diverse stakeholders, such as business leaders, government officials, and consumer advocacy organizations, are important in the bibliometric analysis and multicriteria selection process. Forging a holistic and lasting approach to resolving complex issues, such as food waste, requires the development of a strong decision-making policy that integrates environmental, economic, and social aspects. By integrating the capabilities of LCA, the policy may evaluate food waste management options from every perspective, including resource use, emissions, energy consumption, and potential ecological repercussions (Bolaji *et al*., 2021). Simultaneously, the framework is permeated by a cost-benefit analysis that meticulously quantifies financial dynamics by weighing the expenses of implementing waste reduction methods against the benefits of reduced waste, resource conservation, and potential revenue streams. Notably, the policy highlights the necessity for a social impact assessment that investigates the effects of efforts to reduce waste on local communities, food security, and job creation. Based on the principles of fairness and equality, this factor guarantees that social effects are considered through due diligence. This all-inclusive strategy guarantees that recommendations and research findings correspond to real-world problems and priorities that exist in the real world. The significance of managing food waste sustainably can be increased through educational programs, workshops, and community engagement. Promoting broader knowledge of the difficulties and potential solutions related to food waste by disseminating the results of the bibliometric analysis to a larger audience. Recognizing sustainable food waste is a dynamic and evolving field. Bibliometric analyses are frequently reviewed and updated to reflect new research tendencies, develop new technologies, and shift management goals for food waste. Encouraging worldwide cooperation to exchange best practices, approaches, and discoveries from sustainable food research Cross-border collaboration between researchers and practitioners can foster the sharing of insightful ideas and creative solutions, accelerating the development of sustainable food systems. However, there is a complex web of difficulties in the areas of ecology, economy, and society that must be overcome if food waste management is to be sustainable. This strategy addresses multiple problems by decreasing food waste, disposing of it properly, and using it properly. In terms of the environment, it reduces the release of greenhouse gases, saves water and power, and protects species that might otherwise have been lost owing to development. To reduce poverty and malnutrition, it also seeks new uses for food that would otherwise be wasted. Wasteful spending costs households, corporations, and governments significant amounts of money. These initiatives also aim to educate consumers to change their habits and aid in optimizing supply chains. Sustainable food waste management promotes a move from the prevalent 'throwaway' mindset to a more mindful and resource-efficient paradigm, which requires a transformation in cultural norms and social attitudes toward food consumption. This comprehensive approach requires coordinated efforts across multiple disciplines to design sustainable food systems from multiple perspectives.

CONCLUSIONS

Integrating bibliometric analysis and multi-criteria decision-making can advance research, policies, and actions toward sustainable food waste management. Incorporating these techniques offers an extensive and thorough lens through which to evaluate the shifting landscape as civilizations navigate the difficult food waste issues within the global sustainability framework. Researchers can analyze the body of information on sustainable food waste using bibliometric analysis to identify major trends, influencers, and gaps. This analytical process gives stakeholders the knowledge necessary to effectively manage resources, promote collaboration, and prioritize research initiatives. It acts as a compass directing action toward increasingly significant research projects and fact-based choices. Combining bibliometric analysis and multicriteria decision-making offers a formal framework for assessing various aspects of sustainable food waste. Decision-makers can holistically evaluate interventions and strategies by concurrently considering environmental, economic, social, and ethical criteria. The identification of the best routes that support sustainability objectives and encourage constructive change throughout the food supply chain is made possible by this methodical methodology. The combination of these techniques exceeds theoretical investigations and results in practical advice for application in actual situations. Stakeholders have the information necessary to create and implement laws, customs, and technological advancements that significantly reduce food waste and negative environmental effects and improve resource efficiency. This investigation highlights the expanding awareness of the complex interplay among environmental, economic, and social factors in the food waste crisis. Multi-criteria decision-making methods have become increasingly popular in the research community as a strong framework for addressing this complexity. Food waste, a multi-criteria model, economic, environmental, and social factors, policy considerations, and technical feasibility were some of the factors considered in this study. This makes it easier for decision-makers to understand the complex trade-offs and synergies involved in long-term food waste management. This analysis highlights the increasing commitment to comprehensive solutions that focus on waste reduction as well as resource efficiency, environmental stewardship, and societal well-being as sustainable food waste management gains traction on global agendas. However, these data indicate a need for further investigation. Metadata like keywords and abstracts affect results; therefore, data quality and coverage are crucial. The use of published literature may exclude unpublished or non-English sources and distort trends. Bibliometric statistics may not adequately reflect current trends because of the changing nature of study fields. Citations may not accurately reflect a paper's influence; therefore, their interpretation may be complicated. Owing to database disciplinary categorizations, multidisciplinary research may be underrepresented. The implementation of advanced MCDMA models requires computational resources and skills. Criteria weights are difficult to determine because stakeholder preferences vary, and consensus may be difficult. The assumptions and capabilities of multiple models make it difficult to select an MCDMA method. Finally, the interpretability of sophisticated MCDMA models may inhibit communication and decision-making, highlighting the complexity of these issues. Future research should focus on eliminating inequalities in the use of multi-criteria decision-making across regions, industries, and stages in the food supply chain. Furthermore, interesting directions for progress in this area include the incorporation of developing technologies and innovative techniques into established methodologies.

AUTHOR CONTRIBUTIONS

Syafrudin oversaw the idea, methodology design, and information gathering for the bibliometric analysis, giving a solid insight of the current state of the field. I.B. Priyambada was instrumental in developing the multicriteria decision-making framework, analysing the data, and making insightful amendments to the text. The data collection and organization, the multicriteria decision-making analysis, and the transformation of complex outcomes into illustrative visual representations were all made possible thanks to the contributions of M.A. Budihardjo. Through a comprehensive examination of the literature, data interpretation, and visualization support, S. Al Qadar provided insightful information. As the project's supervisor, A.S. Puspita assisted with project management, gave advice throughout the research process, obtained funding, and helped to polish the final manuscript.

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CONFLICT OF INTEREST

The authors declare that there are no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, were observed by the authors.

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ABBREVIATIONS

%	Per cent
$	Dollar
AD	Anaerobic digestion
AF	Animal feed
AHP	Analytical hierarchy process
AI	Artificial intelligence
Bc	Bio conversion
Bs	Biogas
BSF	Black soldier fly
CE	Circular economy
CO	Carbon monoxide
COMP	Composting
DEA	Dara envelopment analysis
ELECTRE	Elimination et choix traduisant la rEalite
EIA	Environmental impact assessment
EPA	Environmental protection agency
FAO	Food and agriculture organization
GRA	Gray relational analysis
Gs	Gasification

GWP	Global warming potential
GwH	Gigawatt Hour
INC	Incineration
IoT	Internet of Things
IVC	In vessel composting
KPI	Key performance indicators
kWh	Kilowatt-hour
LCA	Life cycle assessment
LCC	Life cycle cost
LF	Landfilling
M^2	Square meter
MCDMA	Multicriteria decision making aiding
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
PCA	Principal component analysis
RYCL	Recycle
RPIBT	Riset publikasi internasional bereputasi tinggi
SAPBN UNDIP	Selain anggaran pendapatan belanja negara universitas diponegoro
SLCA	Social life cycle analysis
SWOT	Strengths, weaknesses, opportunities, and threats
SD	System dynamics
TOPSIS	Technique of order preference by similarity to ideal solution
UN	United Nations
VIKOR	VIseKriterijumska optimizacija I kompromisno resenje
WB	Waste bank

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