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Review

Multi-Criteria Decision Analysis (MCDA) for sustainability assessment in food sector. A systematic literature review on methods, indicators and tools

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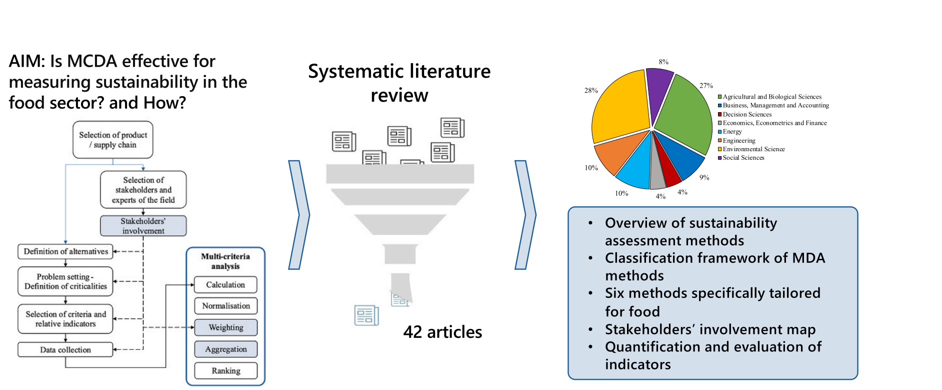
HIGHLIGHTS

- A review of the technical literature on MCDA applied to food products was accomplished.
- After a systematic selection, 42 articles dealing with case studies were analysed.
- MCDA methods were classified according to aims, tools, indicators, stakeholders.
- For food products, the relationships with sustainability were systematically considered.
- A support in selecting a MCDA method for food sustainability assessment was provided.

GRAPHICAL ABSTRACT



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ABSTRACT

In the last decades, several studies have highlighted the significant impacts of the food sector. Therefore, enhancing sustainability within this sector has become of paramount importance. A crucial step towards achieving this goal involves the definition and implementation of effective sustainability metric and measurements. In this regard, the adoption of multi-criteria decision analysis (MCDA) methods can be seen as one of the most suitable and promising approach to comprehensively capture the complex and broad-ranging effects of agricultural practices and food supply chains.

In such context, a systematic review of the scientific literature on multi-criteria approaches and tools for measuring the sustainability of food supply chains (harvest and post-harvest stages) has been carried out, resulting in the selection and analysis of 42 articles. To delve into the selected articles, three main areas of focus have been identified. The first about MCDA methods and their features, revealing the most adopted methods for sustainability assessments of food supply chains. The second, focusing on the participatory approach, led to the definition of a stakeholder's engagement map, highlighting the typology of stakeholders involved, the reasons of their involvement and engagement methods. Lastly, the third focus is related to the analysis and classification of indicators adopted in each study and the sustainability dimensions to which they refer to. The results of the present review study provide a comprehensive overview of the essential aspects to be considered when

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developing a MCDA for sustainability assessment in the food sector, serving as a valuable resource for both scholars and practitioners.

Nomenclature

AE	Authors Expertise
AHP	Analytic Hierarchy Process
AIJ	Aggregation of Individual Judgments
AIP	Aggregation of Individual Priorities
AM	Analytical Methods
ANP	Analytic Network Process
BWM	Best Worst Method
DBOD	Directional Benefit Of the Doubt
DEMATEL	DEcision MAking Trial and Evaluation Laboratory
DEX	Decision EXpert
ELECTRE	ELimination Et Choix Truisant la REalitè
ER	External Resource
EU	European Union
EW	Equal Weights
FAM	Full Aggregation Method
FAO	Food and Agricultural Organization
GAIA	Graphical Analysis for Interactive Assistance
IT2TrF-BWM	Interval Type 2 Trapezoidal Fuzzy BWM
LCA	Life Cycle Assessment
MASC	Multi attribute Assessment of the Sustainability of Cropping Systems
MAUT	Multi Attribute Utility Theory
MAVT	Multi Attribute Value Theory
MCDA	Multi Criteria Decision Analysis
MESMIS	Marco para la Evaluaciòn de Sistemas de Manejo incorporando Indicadores de Sustainabilidad
MM	Mathematical Models
MODM	Multi-Objective Decision Making
MOMP	Multi-Objective Mathematical Programming
OLPI	Organic Livestock Proximity Index
PAM	Partial Aggregation Method
PNRR	National Plan for Recovery and Resilience
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluations
SA	Statistical Analysis
SAFA	Sustainable Assessment of Food and Agriculture
SDGs	Sustainable Development Goals
SMART (method)	Simple Multi Attribute Rating Technique
SMART (tool)	Sustainability Monitoring and Assessment RouTine
SWOT	Strengths, Weakness, Opportunities and Threats
TAPE	Tool for Agro-Environmental Performance Evaluation
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
VIKOR	VIekriterijumsko KOmpromisno Rangiranje

1. Introduction

Nowadays, the food sector stands as a significant contributor in global greenhouse emissions, accounting for around one third of the total (Ritchie et al., 2022). However, the associated environmental implications extend beyond climate change, encompassing energy consumption (De Luca et al., 2017) soil degradation, deforestation, freshwater contamination, biodiversity loss, and other interconnected challenges (Blanco-Gutiérrez et al., 2020). Moreover, also the COVID-19 pandemic, other crisis and conflicts have added other layers of complexity to the agricultural sector, directly and indirectly threatening global food security objectives (Balezentis et al., 2023).

In this framework, it emerges the need to foresee a balance between economic, environmental, and social aspects, replacing the previous sole focus on increasing land productivity, crop yields, and input efficiency (De Luca et al., 2017). Increasing sustainability in food sector has become of upmost importance, necessitated not only by the growing awareness among consumers, producers, and policymakers (D'Ammaro et al., 2021), but also to meet Sustainable Development Goals (SDGs) and the European objectives (European Commission, 2019), in particular those related to the common agricultural policy (European Commission, 2022).

Therefore, the development of assessment tools and methods for measuring sustainability, able to capture the multi-dimensional characteristics and the wide-ranging impacts of food sector and agricultural practices, assume critical importance (Leknoi et al., 2023). Given the complex, multiscale, and multidimensional nature of the topic, it is imperative to analyse and systematize heterogeneous variables from various fields. This necessitates the use and development of practical approaches capable of delivering transparent and comprehensible results for the diverse stakeholders involved.

In response to this need, the scientific community started to implement sustainability assessments based on multi-criteria methods, originally used within the operational research and decision analysis fields (Cinelli et al., 2020). Nowadays several methods, standards and tools have been developed and made available to users, such as the Sustainability Assessment of Food and Agriculture (SAFA) (FAO, 2014) and the Tool for Agroecology Performance Evaluation (TAPE) (FAO, 2019), both developed by FAO and the Sustainability Monitoring and Assessment RouTine (SMART) Farm tool.[1]

In this framework, the present study aims to enhance the understanding of the Multi-Criteria Decision Analysis (MCDA) methods and tools available for assessing sustainability in the complex framework of food production and distribution. By systematically synthesizing existing knowledge, it aspires to lay a foundational contribution, providing a valuable resource for researchers in the field of food sustainability and for relevant stakeholders.

The research grounds in the framework of ONFOODS,[2] an interdisciplinary national research project under the national plan for recovery and resilience (PNRR[3]) and it is aimed to review the scientific literature about MCDA methods for assessing the sustainability in the food sector.

To understand how these methods are adopted and implemented in practice, the review focuses on studies implementing MCDA methods in case studies applications, addressing the following research questions:

- Which MCDA methods are most adopted for assessing the sustainability of food supply chain?
- How are stakeholders involved in such assessment?
- Which tools are most frequently employed to support sustainability assessments through MCDA of food sector?
- How to select the most appropriate and effective method?

1 https://www.fibl.org/en/themes/smart-en.
2 https://onfoods.it/.
3 https://www.governo.it/sites/governo.it/files/PNRR.pdf.

In response to the above-mentioned gaps in literature and the raised research questions, Section 1.1 discusses the application of MCDA to the food sector, highlighting it main features and characteristics. Section 2 delves into the method defined and adopted, focusing on the search and selection process (Section 2.1) and on how the analysis of the selected articles was conducted (Section 2.2). Section 3 contains the results of the analysis divided in bibliometric analysis (Section 3.1), results on the MCDA methods (Section 3.2), results on stakeholders' engagement (Section 3.3) and lastly results on indicators and metrics (Section 3.4). Section 3.5 contains a summary of characteristics related to the most used MCDA methods and then conclusions are made in Section 4.

1.1. *Assessing sustainability in the food sector by MCDA*

MCDA is not confined to a singular, specific method; rather, it embodies a comprehensive umbrella concept that encompasses various methods and tools (Dean, 2022). While historically rooted in computer science and decision-making contexts, MCDA has found application in diverse fields and problem typologies. In general, it serves as a versatile framework within which multiple objectives and decision criteria (or attributes) can be systematically integrated into the analysis of a given problem (Dodgson et al., 2009).

Different MCDA methods can be found in literature, specifically within the food and agriculture domains (De Luca et al., 2017; Poulsen, 2022). These methods include, e.g., the Analytic Hierarchy Process (AHP) (Saaty, 1987), the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Hwang and Yoon, 1981; Kobryn and Prystrom, 2016), the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) (Brans, 1982), the Best Worst Method (BWM) (Rezaei, 2015) and others.

Three main reasons why a multi-criteria approach is well-suited for the multidimensional nature of sustainability assessments are:

- It allows formally incorporating multiple objectives and decision criteria, very often conflicting, thus aligning them with the complexity of multi-dimensional sustainability assessments (Dean, 2022);
- It enables participatory and non-participatory weighting procedures, allowing the prioritization of specific criteria and the evaluation of qualitative and quantitative performances based on the specific research objectives (Poulsen, 2022);
- It guarantees a transparent and structured process (Talukder et al., 2016), enhancing stakeholders' engagement and communication.

In literature, there are several reviews of MCDA methods, such as (Huang et al., 2011) and (Cegan et al., 2017) which, for instance, provide an overview of MCDA methods applied in environmental sciences. Other reviews, e.g. (Kandakoglu et al., 2019), address the broader field of sustainability, considering all its pillars rather than solely environmental aspects. However, to our knowledge, just few recent systematic reviews concerning the application of such methods for sustainability assessment, specifically in the food sector, are available. In particular, some of them, e.g., (Madoumier et al., 2019; Vergara-Solana et al., 2019), treat the sustainability of the food sector but focusing on very specific topics, such as processes and aquaculture. Another review conducted by (Gésan-Guiziou et al., 2020), which stands out due to its comprehensive analysis of 954 article. It explores the diversity and potentiality of MCDA methods for food sector and encompasses a wide range of purposes of the MCDA study, however not explicitly addressing the purpose of sustainability assessment in the food sector. Moreover, in (Gésan-Guiziou et al., 2020) the analysed papers are classified according to the type of MCDA study adopted but without referring to a specific method such those mentioned above. Similarly, (Poulsen, 2022) focuses on food sustainability assessment in the European context and confirms the versatility and flexibility of MCDA methods for the multi-dimensional evaluation of the food sector. Lastly, the critical review of (De Luca et al., 2017) demonstrate the effectiveness of MCDA in sustainability evaluation, particularly in cases involving contrasting alternatives and complex context and it provides insights into the specific methods analyse. However, its specific purpose is to explore the various ways in which Life Cycle Assessment (LCA) and MCDA can be integrated.

These experiences underline the need to explore more in detail the MCDA methods applied for the evaluation of sustainability in the food sector, collecting and discussing results and providing indications for stakeholders involved in the food-related decision-making processes.

Analysing the relevant literature, a generic methodological framework of MCDA approaches for evaluating sustainability of food-related products was traced (Fig. 1). The scheme has been defined to highlight the main generic steps and activities involved in the application of a MCDA method, regardless of the aim of the study (assessments, decision making problems, comparisons, etc.). The preliminary activities, crucial for the development of the whole process, are deeply influenced by the context, the availability of data and the decision about if, when and how to involve stakeholders in the process. For this reason, the review has been focusing on the most determinant steps and aspects of the selected articles, which are:

- The multi-criteria approach and tools adopted;
- Stakeholders involvement;
- The selection of criteria and indicators.

2. Method

The review study is based on a mixed approach, combining a systematic search protocol followed and a conceptual review. The search protocol begins with the choice of the fields of analysis, i.e., MCDA, food sector and sustainability. Once the search string has been defined and prompted, results have been screened, according to the research questions presented in Section 1, to reach the final selection of papers.

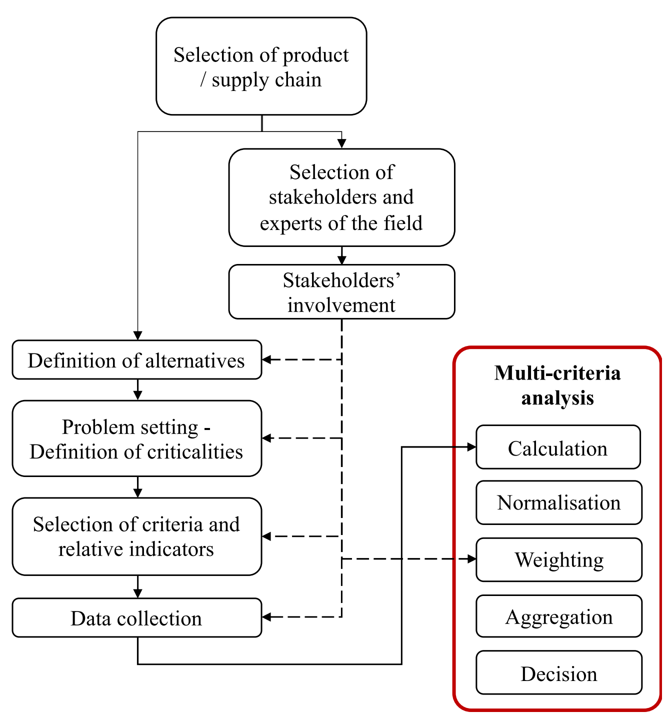


Fig. 1. General methodological framework of MCDA method applied to food supply chains.
(Source: (Aidonis et al., 2015), edited by authors).

2.1. Literature search and selection

To find, filter and select the scientific articles to be reviewed, a systematic approach has been followed (Fig. 2), consisting in four main steps, as it follows.

- Step 1. Construction of the query and the selection of the scientific database.

The aim of this literature review is to analyse articles that use an MCDA method for sustainability assessments inside the food sector. For this reason, these three words (i.e., multi-criteria, food, and sustainability) were combined in the query.

For the word multi-criteria, synonyms or acronyms were also used (i.e., "multicriteria", "multi criteria", "MCA"). The word SAFA was added, since to the authors' knowledge it is one of the most used MCDA methods for food sector sustainability assessment. The string "*food" was also added to the query to include terms such as agri-food or food, while for sustainability "*sustainab**" was used to include both the words, sustainable and sustainability.

Therefore, the following query was formulated:

*TITLE-ABS-KEY ((("multi criteria" OR "multicriteria" OR "multi-criteria" OR "MCDA" OR "MCA" or "SAFA") AND ("*food") AND ("sustainab*"))).*

Scopus was chosen as database since, compared to others, such as Web of Science, it has a broader Journal coverage in the context of scientific papers (Mongeon and Paul-Hus, 2016). The query was then used on October 9th, 2023, inside the Scopus database, obtaining a set of 593 articles.

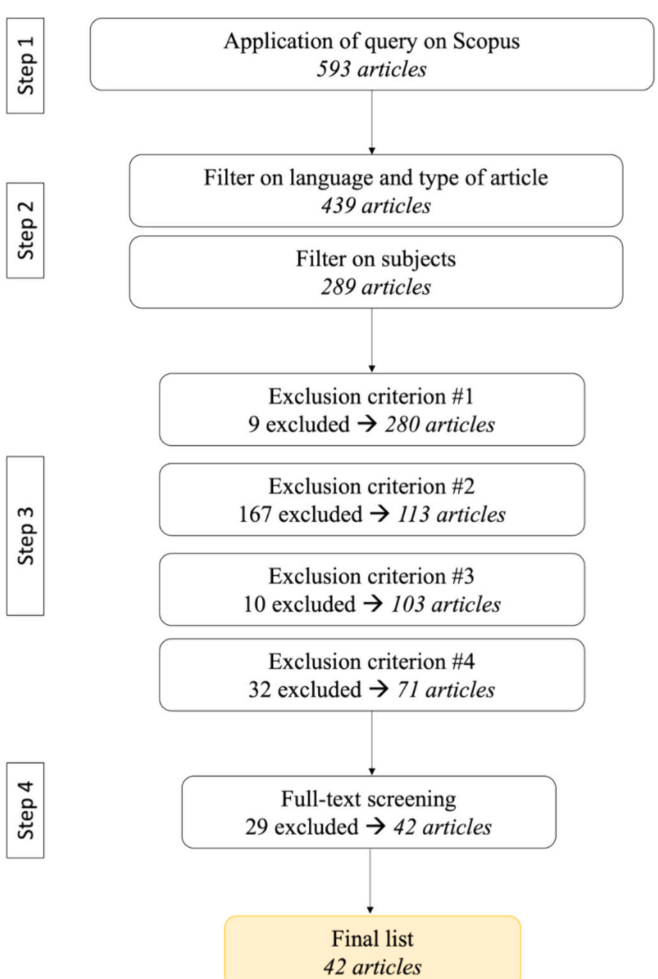


Fig. 2. Articles' selection process.

- Step 2. Selection of articles

Restrictions were applied to the type of articles and journal subjects. Firstly, only articles from scientific Journal were considered (excluding therefore conference papers and reviews as well as book chapters). This led to 452 articles. Then only articles written in English were included. This restricted the number of articles to 439. As further filter, only scientific fields strictly related to food and sustainability disciplines has been considered, excluding the articles published in journals belonging to other disciplines such as "*Computer Science*", "*Medicine*", "*Chemical Engineering*", "*Mathematics*", "*Biochemistry, Genetics and Molecular Biology*", "*Chemistry*", "*Material Science*", "*Veterinary*", "*Immunology and Microbiology*", "*Nursing*", "*Physics and Astronomy*", "*Health Professions*", "*Psychology*" and "*Earth and Planetary Sciences*". This resulted in a list of 289 articles.

- Step 3. Abstract screening

According to a preliminary screening of the results, due to the large diffusion of the words food and sustainability in recent literature, further restrictions have been introduced. To narrow the selection, according to the study objectives introduced in Section 1, an additional screening was accomplished by reviewing each abstract, using the following exclusion criteria:

1) The article does not use the multi-criteria method.
2) The article does not deal with food production or food distribution.
3) The article is not directly referred to a case study.
4) The article is not directly referred to a sustainability assessment or comparison or development or testing of a method, or optimization or design of a new alternative or decision-making problem.

For this reason, 9, 167, 10 and 32 paper were excluded respectively, resulting in a final list of 71 articles.

- Step 4. Full-text screening

Afterward, a further analysis of the full text of the 71 manuscripts led to the exclusion of 29 more articles, 28 according to the 4 exclusion criteria mentioned before (respectively 6, 15, 1, 6) and 1 since the authors did not have access to it, resulting in a final list of 42 articles.

At the end of the selection procedures, reported in Fig. 2, only the 7 % of the articles initially founded were kept and included in the further review process according to the specific focus and research questions defined.

2.2. Analysis of the selected papers

After the selection process, data of the 42 articles were collected in an Excel file where bibliometric, authors, journals and year of publishing, were mapped.

According to the MCDA characteristics discussed in Section 1.1 and to Fig. 1, four main characteristics of MCDA were mapped and analysed. Firstly, their characteristics, the weighting procedure adopted (Section 2.2.1) and on how MCDA was applied in case studies and whether a software was used or not (Section 2.2.2). Subsequently, the analysis focused on the stakeholder's engagement (Section 2.2.3) and on the definition of criteria and indicators (2.2.4).

The detailed list of the 42 included articles is provided in Table 1, mapping:

- the authors and year of publication (first column);
- the subject of the case study (second column);
- the geographic area of the case study (third column).

Table 1
Final list of selected articles.

#	Authors	Subject of the case study – Food products or patterns					Geographical area	MCDA method
		P	PS	L	S			
1	(Aidonis et al., 2015)	x				Food product supply chains	Europe (*Macedonia*)	ELECTRE III PROMETHEE
2	(Alletto et al., 2022)		x			Cropping systems	Europe (*France*)	MASC
3	(Al Shamsi et al., 2019)		x			Organic farms	*UAE* and *Italy*	SAFA
4	(Avadí and Fréon, 2015)	x	x			Anchoveta PS and other aquaculture products	South America (*Perù*)	Not Specified
5	(Cammarata et al., 2021)		x			Organic farms	Europe (*Italy*)	SAFA
6	(Cánovas-Molina et al., 2021)		x			Peri-urban agriculture	Europe (*Spain*)	MESMIS
7	(Cap et al., 2023)	x				Nuts and seeds	Not specified	Not Specified
8	(Castellini et al., 2012)		x			Poultry systems	Europe (*Italy*)	ELECTRE
9	(Chandran et al., 2023)		x			Cropping systems	Asia (*India*)	TOPSIS AHP
10	(Curran et al., 2020)		x			Organic farms	Europe (*Switzerland*)	SMART TOOL
11	(D`Ammaro et al., 2021)	x				Italian red wines	Europe (*Italy*)	Not Specified
12	(Emran et al., 2022)		x			Rice cropping systems	Asia (*Bangladesh*)	Factor Analysis
13	(Ghamkhar and Hicks, 2021)	x				Aqua-feeds production	North America (*USA*)	PROMETHEE II
14	(Haque et al., 2021)		x			Pangasius farms	Asia (*Bangladesh*)	SAFA
15	(Heredia et al., 2022)		x			Traditional agricultural systems	South America (*Brazil*)	SAFA
16	(Karlsson Potter and Röös, 2021)	x				Plant-based foods	Europe (*Sweden*)	Not specified
17	(Król-Badziak et al., 2021)		x			Maize tillage systems	Europe (*Poland*)	FAHP
18	(Leitgeb et al., 2023)		x			Organic and conventional farms	Europe (*Austria*)	SMART TOOL
19	(Leknoi et al., 2023)	x	x			Maize supply chain (monoculture)	Asia (*Thailand*)	SAFA
20	(Lucantoni et al., 2023)		x			Conventional farms	Africa (*Mali*)	TAPE
21	(Melkonyan et al., 2020)			x		Distribution networks	Europe (*Austria*)	PROMETHEE
22	(Mena et al., 2012)		x			Organic dairy goat systems	Europe (*Spain*)	Not specified
23	(Montemurro et al., 2018)		x			Agricultural practices	Europe (*Italy*)	DEXi-MET
24	(Moraine et al., 2014)		x			Integrated cropping-livestock systems	Europe (*Different countries*)	Not specified
25	(Mosnier et al., 2023)		x			Farms (with or without pigs)	Europe (*France*)	D-BoD
26	(Painii-Montero et al., 2020)		x			Agricultural Productive Units of soybean	South America (*Ecuador*)	Not specified
27	(Reina-Usuga et al., 2023)			x		Distribution patterns (local and global)	*Colombia* and *Spain*	ANP
28	(Rocchi et al., 2019)		x			Poultry systems	Europe (*Italy*)	PROMETHEE I & II
29	(Rodriguez et al., 2021)		x			Cropping systems	Europe (*Sweden*)	DEXI-PM
30	(Rojas-Downing et al., 2018)	x	x			Milk level and pasture composition	North America (*USA*)	VIKOR
31	(Schmitt et al., 2017)			x		Distribution patterns (local and global), for cheese, ham, bread, and wine	Europe *(Switzerland, United Kingdom, Italy, France)*	PROMETHEE I & II
32	(Segura et al., 2019)				x	Suppliers of food distribution companies	Europe *(Spain)*	PROMETHEE MAUT
33	(Sharifi et al., 2023)				x	Suppliers of a soybean company	North America (*Canada*)	IT2TrF-BMW
34	(Soldi et al., 2019)		x			Agricultural systems (agroecological, conventional, neo-rural, indigenous)	South America (*Paraguay*)	SAFA
35	(Ssebunya et al., 2019)		x			Production system (organic, fair trade, conventional)	Africa (*Uganda*)	SMART TOOL
36	(Talukder et al., 2016)		x			Agricultural areas with different PS	Asia (*Bangladesh*)	MAVT
37	(Tapia et al., 2021)		x			Urban agriculture models	Europe (*Denmark*)	Not specified
38	(Tuni and Rentizelas, 2022)	x				Bread supply chain	Europe *(Italy)*	Not specified
39	(Tziolas et al., 2022)	x				Different crops	Europe (*Greece*)	Not specified
40	(Verdecho et al., 2021)				x	Suppliers for sustainable supply chain	Not specified	AHP
41	(Viguier et al., 2021)		x			Innovative cropping systems in five crops	Europe (*France*)	DEXi-PM
42	(Winter et al., 2020)		x			Production system (organic, fair trade, conventional) in coffee	*Ethiopia* and *Brazil*	SMART TOOL

P = Product; PS = Production System; L = Logistic; S = Suppliers.

2.2.1. Classification of MCDA methods based on their features

MCDA methods can be classified according to various criteria. One of the most common classifications in the literature is the binary distinction between methods with an infinite number of alternatives, which are defined by means of a set of mathematic constrains (Dean, 2022), and methods with a discrete number of alternatives explicitly defined. The former are usually known as Mathematical Programming (Zimmer et al., 2016) or Continuous Methods (Dean, 2022), or multi-objective decision-making methods (Ibáñez-Forés et al., 2014). Under these labels usually methods like multi-objective and non-linear programming, goal programming, and constraint programming, appears. The latter are usually addressed as mathematical analytical methods (Zimmer et al., 2016), discrete methods (Dean, 2022), or Multi-Attribute Decision Making (Ibáñez-Forés et al., 2014). According to the authors, the Multi-Attribute Decision Making may include methods such as AHP, VIekriterijumsko Kompromisno Rangiranje – multicriteria compromise ranking (VIKOR), TOPSIS, Elimination Et Choix Traduisant la Realitè – elimination and choice trussing reality (ELECTRE) (Roy, 1968), PROMETHEE, Decision Making Trial and Evaluation Laboratory (DEMATEL), Analytic Network Process (ANP), Multi Attribute Utility Theory (MAUT) (Fishburn, 1970), Multi Attribute Value Theory (MAVT) and others.

Conversely, the authors of (Diaz-Balteiro et al., 2017) do not endorse this type of binary distinction. They consider methods such as goal programming and compromise programming, as part of the category of methods based on a minimization of a distance function problem. Among the classifications identified by (Greco et al., 2016), the category of methods with an infinite number of alternatives, called multi-objective mathematical programming methods, does not present a binary opposition to discrete methods. It is indeed considered part of a framework of four categories along with the outranking methods such as ELECTRE and PROMETHEE, the MAUT methods such as MAVT, AHP and ANP and the Non-Classical methods which encompass fuzzy methods. Another possible distinction found in literature lies between MCDA methods that yield a single score representing overall performance and those based on the notion of outranking. The former are the Full Aggregation Methods (FAMs) (Dean, 2022),single synthetizing criterion (Guitouni and Martel, 1998) or full aggregation approach (Ishizaka and Nemery, 2013), while the latter are the Partial Aggregation Methods (PAMs), outranking methods (Diaz-Balteiro et al., 2017; Guitouni and Martel, 1998; Herva and Roca, 2013; Ibáñez-Forés et al., 2014) or outranking approach (Ishizaka and Nemery, 2013). The PAMs (e.g., ELECTRE, PROMETHEE) operate on the principle of establishing direct preferential relationship between alternatives, while the FAMs, e.g., MAUT, MAVT, AHP, ANP, BWM, Simple Multi Attribute Rating Technique (SMART) and TOPSIS, provide a singular performance score (Dean, 2022; Guitouni and Martel, 1998) (Ishizaka and Nemery, 2013).

FAMs are often associated with additional subcategories. MAUT and MAVT can be both considered part of the multi-attribute and utility value category (Herva and Roca, 2013; Ibáñez-Forés et al., 2014), with (Diaz-Balteiro et al., 2017) placing them in the class of optimizing averages. (Dean, 2022) suggested that they may fall under the umbrella of multi-attribute approach or weighted additive model. AHP and ANP are based on a hierarchy among the main goal of multi-criteria analysis, criteria, sub-criteria, and the considered alternatives. For this reason, they can be classified under the category of hierarchical methods, as done by (Diaz-Balteiro et al., 2017). However, authors like (Dean, 2022; Greco et al., 2016; Herva and Roca, 2013; Ibáñez-Forés et al., 2014) consider AHP and ANP as belonging to the family of multi-attribute and utility value theory.

It is also common to categorize methods such as the simple additive weighting model under the label of simplified methods (Dean, 2022), elementary methods (Guitouni and Martel, 1998) or elementary aggregation methods (Ibáñez-Forés et al., 2014).

Methods can also be classified based on the types of decisional problems they aim to solve, which were identified as choice, ranking and sorting (Roy, 1996), or they can be classified by whether the method is determinist, stochastic or fuzzy (Pohekar and Ramachandran, 2004). Nevertheless, according to (Dean, 2022), the same method can be applied in different ways or variations depending on the type of data and information that the method can handle (qualitative, quantitative, complete, or fuzzy). While some consider fuzzy applications of methods as belonging to a specific category that can be called non-classical methods (Greco et al., 2016; Ibáñez-Forés et al., 2014) or simply Fuzzy MCDA (Herva and Roca, 2013).

The illustrated framework highlights the diversity of existing methods, classifications, and terminologies. The classification framework for MCDA methods adopted in the present study, shown in Fig. 3, has been defined to be instrumental for the analysis of the reviewed articles about sustainability assessment in the food sector. The classification proposed in (Dean, 2022) has been adopted as a starting point and furtherly elaborated. A broader and more comprehensive analysis of MCDA methods features can be found in (Cinelli et al., 2022; Gomes et al., 2020).

The present study focuses on formal methods and not on simplified methods. Continuous methods have not been investigated since finite alternatives scenarios are predominant within the food sector. The first level of classification of discrete methods is based on the aggregation algorithm used, namely on the method preference model (Cinelli et al., 2020) which depends on the preference information used (Cinelli et al., 2022, Gomes et al., 2020). Based on the preference model it is possible to distinguish two groups of methods: PAMs and FAMs. The subcategories of FAMs and PAMs are based on a more qualitative classification criterion, which is the dominant problem-solving approach, i.e., the logic through which the problem is addressed, leading to the final recommendation.

Having selected such classification criteria for the second level of classification, the defined MCDA method categories are exclusive to each other. However, the proposed classification is especially useful for schematising the selected articles, facilitating the analysis of the connection between methods and indicators and between methods and objectives of the analysis. To deepen interactions between categories and/or methods falling into multiple classes, we suggest the reader refer again to (Cinelli et al., 2020).

As previously mentioned, FAMs are based on performance aggregation, indeed they are designed to synthesize the performance of an option across various criteria into a singular, comprehensive score (Dean, 2022). Therefore, such methods, by introducing some suitable trade-off weights, allow for full compensation between criteria since strong performances in one criterion can offset a lower score in others. Consequently, an alternative that exhibits good performance across all criteria may exhibit an overall performance that is comparable or identical to an option that excels in a few criteria but performs inadequately in others (Dean, 2022), that must be appropriately exploited to provide the final recommendation. Such methods, which necessitate decision makers to indicate their preference for an alternative over another assigning a cardinal value to each evaluation criteria, may be referred to as “cardinal methods” (Gomes et al., 2020).

On the other hand, PAMs are characterized by direct comparisons of each pair of alternatives, therefore these methods are based on the concept that one alternative outranks (or dominates) another if there are sufficient arguments (significant number of criteria) to conclude that the

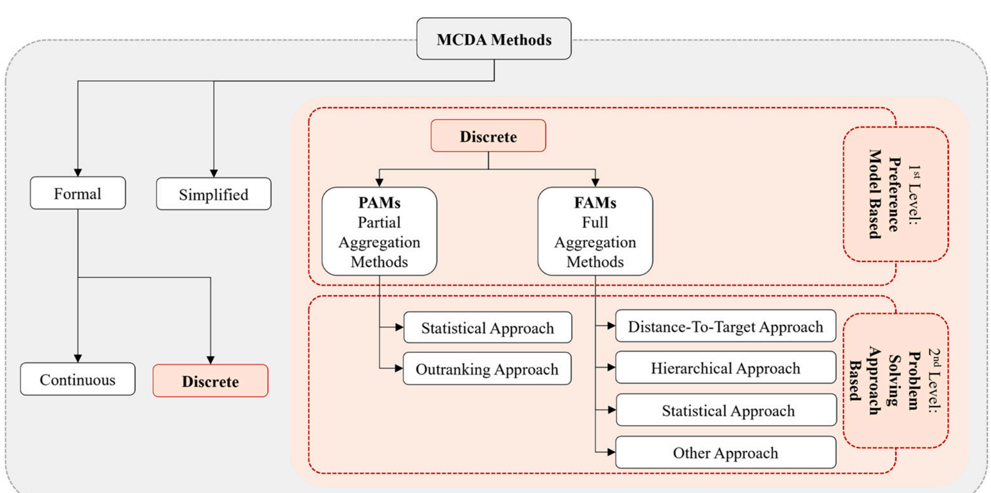


Fig. 3. Classification of MCDA methods.
(Source: (Dean, 2022) edited by authors).

former outperforms the latter (Greco et al., 2016). Therefore, the output of this assessment does not yield an overall score for each option, instead it establishes an outranking relation among the available alternatives (Dean, 2022). In contrast to FAMs, PAMs are often referred to as "ordinal methods" since, instead of employing cardinal values for each criterion, they merely necessitate ranking alternatives for each criterion (Gomes et al., 2020). PAMs are partially or totally non-compensatory (Dean, 2022), meaning that the optimal alternative is determined by its strong performance across multiple criteria, and it cannot be an alternative that excels only in few criteria. PAMs require an alternative to have comprehensive and balanced performance across a broader spectrum of criteria to be considered the best one.

However, it's worth emphasizing that PAMs may not always result in a definitive ranking of options. This is because the concept of incomparability is permitted, when there is a strong conflict among performances of alternatives and therefore insufficient evidence to establish the superiority or inferiority of an option over another (Dean, 2022).

The subcategory "statistical approach" belongs to both FAMs and PAMs and includes methods relying on the use of statistical techniques, such as factor analysis (Emran et al., 2022) or correlation studies (D'Ammaro et al., 2021), to analyse and evaluate relationships and patterns among the criteria. To further elaborate the classification within the family of PAMs, the category of outranking approaches, based on pairwise comparison among alternatives for each criterion (Cinelli et al., 2022), has been introduced. Examples of methods falling into this class include PROMETHEE and ELECTRE.

In FAMs three other subcategories were introduced, based on their logic and distinctive approaches: distance to target approach, hierarchical approach and other approach. The category "distance to target approach" comprehends all those methods calculating the distance between each alternative and a predetermined goal or target. Alternatives closer to the target are considered superior. An example of a method falling into this category is TOPSIS.

The "hierarchical approach" category includes those methods employing a tree structure in problem definition and evaluation. An example of methods falling in this category is AHP.

Finally, the "other approach" methods attempt to assign a cardinal value (Diaz-Balteiro et al., 2017) to each alternative by simultaneously considering several criteria. An example of this approach is provided by the MAUT method which assign a utility U that could be a value or a function, called Utility Function, that represent the aggregated preference of the decision makers with respect all the considered criteria (Guitouni and Martel, 1998). It is important to note that alongside the Utility Function also other aggregation function exist, such as the Choquet Integral (Silva et al., 2018) or the linear aggregation function on which is based the SMART method (Dean, 2022).

As mentioned earlier, several authors, such as the ones of (Herva and Roca, 2013), emphasize that hierarchical methods can be related to MAUT/MAVT theories, although their approach is not strictly in line with those of (Sadok et al., 2008). The reason why AHP and MAUT/MAVT are often related to each other relies on their preference structure: in both methods a value is assigned to each criterion, however in MAUT/MAVT such value is obtained through an evaluation function while in AHP is obtained comparing each pair of criteria using a nine-point semantic scale (Saaty and Ozdemir, 2003). However, (Dean, 2022) highlights that MAUT and AHP are presented by their developers as two to entirely distinct approaches. Therefore, the category of "hierarchical approach" was treated separately. Indeed, in methods falling under the label of hierarchical approach, the graded structure among the goal of the analysis, criteria, and indicators significantly characterizes the problem-solving scheme of the multi-criteria issue, which results inherently tied to the development and utilization of the hierarchy itself. However, it is crucial to note that the category of hierarchical methods does not simply embrace MCDA methods capable of handling a hierarchy; in fact, such methods, while having this characteristic, might fall, considering their dominant problem-solving approach, into another category.

As anticipated, a further analysis has been carried out on the weighting approaches adopted in the papers selected, key step of a MCDA method. Two types of weights can be fundamentally distinguished: trade-off weights, which characterize compensatory approaches, and importance weights, typical of partially or non-compensatory approaches. Assigning weights to different criteria enable tailored and context-specific assessments and allow decision makers to provide a varying significance to criteria and indicators, thereby making the results of the overall evaluation more legitimate and relevant. This adaptability is a key asset, ensuring that the method remains versatile and applicable across diverse decision-making contexts. However, it is essential to acknowledge that weighting is also one of the most critical and controversial phases (Pamučar et al., 2018), introducing a degree of subjectivity into most approaches arising from the necessity of human judgment in determining the relative importance of different criteria. Striking a balance between subjectivity and objectivity is therefore crucial to ensure the robustness of a MCDA method.

To comprehensively understand how criteria and indicators can be weighted, according to the selection of the article analysed, a classification framework has been defined and adopted.

Such classification scheme is composed of two levels, the first one mapping who assigned the weights, and the second one related to how weights of single indicators are combined to achieve the final weight.

According to articles selected, four categories has been individuated for the first classification level:

- Stakeholders' involvement (SI): weights have been assigned by involved stakeholders;
- Authors Expertise (AE): weights have been assigned based on authors experience;
- Analytical Methods (AM): weights have been calculated through an analytical approach;
- External Resources (ER): weights have been assigned by referring to external databases or software's dataset.

Concerning the second classification level, nine categories have been individuated, listed, and described in the following list:

- Aggregation of Individual Judgments (AIJ): aggregation of qualitative judgments or opinions of different stakeholders, experts, etc., on the performance of alternatives with respect to each criterion (typically using rating scales);
- Aggregation of Individual Priorities (AIP): aggregation of priorities assigned by different stakeholders, experts, etc. to different criteria (usually using ranking scales);
- Mathematical Models (MM): weighting procedures involving the definition and/or adoption of mathematical models (e.g. CRITIC (Cap et al., 2023), Directional Benefit of Doubt Model (Mosnier et al., 2023), etc.);
- Equal Weights (EW): weights not assigned or indicators and criteria with equal weights;
- Statistical Analysis (SA): weights assessed by analysing available statistical data;
- Based on tools adoption: weights assigned following the procedures based on an MCDA tool adopted, which, accordingly to the 42 articles selected, are the SAFA Tool (FAO, 2014), SMART Farm Tool, TAPE (FAO, 2019) and DEXi, a computer program based on the hierarchical method DEX (Decision Experts) (Bohanec, 2021).

It should be noted that the information concerning the subjective preferences of the decision makers can be expressed either analytically, by directly producing weights or other parameters needed by the method used such as in AIJ or holistically, just by providing examples of preferences on a sample of alternatives, such as in AIP.

Besides investigating how weights have been assigned, what was weighted (indicators, criteria, or both) and whether the weights were objective or subjective were mapped.

2.2.2. Classification of MCDA methods based on their use

Following the MCDA classification presented in Section 2.2.1, an analysis of how these methods were employed by the authors of the investigated articles is proposed. The diagram reported in Fig. 4 has been employed for the examination of reviewed articles. The category “Application” refers to the articles where methods were directly implemented, while the category “Elaboration” was used when the methods served as a basis for the development of further methods. Additionally, in some articles more than one MCDA method was used, allowing for an examination of the nature of integration among multiple methods.

The analysis on how the method was used is enriched also by the evaluation of the software used, if any, and of the main aim of each selected article, to determine whether the use of software is a common practice in supporting the application and development of MCDA methods in the food sustainability assessment.

Concerning the main aims of each selected article, five categories have been individuated, even if in some cases more than one aim may coexist in the same study. The five selected categories are:

a) Assessment (A): when the aim is to measure the sustainability performance of a single problem option;
b) Comparison (C): when the aim is to compare different problem options to understand which one is more sustainable;
c) Method development (M): when the aim is the developing or testing of a method;
d) Recommendation (R): when the aim of the study is to give a final recommendation as a result of the analysis;
e) Design/Optimization (D/O): when the aim is to compare an optimised or new solution with the current status and to understand if this solution is more sustainable or not.

It is important to note that, consistently with the information provided in (Fig. 1), all the identified categories of aims can ultimately be traced back to decision making. Nevertheless, the aim of such analysis was to delve into a spectrum of specific objectives of the selected articles to understand to what extent the purpose of a MCDA might influence the analysis itself, particularly regarding the selection of the MCDA method.

2.2.3. Stakeholders’ involvement

Since the role of external stakeholders in the various MCDA applications is fundamental, a further classification framework was introduced in the literature review. Firstly, articles that used a participatory approach were distinguished from those who adopted a non-participatory approach. Then, for those involving stakeholders’ engagement, different aspects have been mapped.

In the selection of paper analysed, nine different typologies of interaction with stakeholders have been individuated:

- Data Sourcing (DS): if stakeholders were engaged to collect the necessary data to conduct the analysis.
- Indicators Selection (SI): if stakeholders were asked to select the most appropriate indicators or criteria to evaluate the subject of the analysis.
- Weighting (WI): if stakeholders were involved in the weighting procedure (see Section 2.2.1).
- Individuation of the alternatives (A): if stakeholders were engaged to individuate the subject of the analysis, or the alternatives to be compared.
- Benchmark/Thresholds (B/T): if stakeholders were involved in defining the benchmarks or the thresholds, as required for example in the ELECTRE method.
- Validation (V): if stakeholders were engaged for validating the collected data or assumptions (e.g., validation of the selected indicators or validation of primary data collected).
- Problem Setting (PS): if the stakeholders were involved in problem setting for the individuation of criticalities and priorities to be assessed.
- Case study (CS): if stakeholders were involved in the individuation of the case study to analyse.
- Conduction of interviews (CI): if stakeholders were trained by the authors to conduct the interviews themselves.

A further classification introduced deals with the type and qualification of the stakeholders involved. In this case five categories have been individuated (i.e., farmers or production, policy makers, consumers, academics, and experts). Farmers and producers also include the employees or the managers of the production company under study.

Lastly, information about the number of stakeholders involved, and the data collection method were mapped. A summary is reported in Fig. 5.

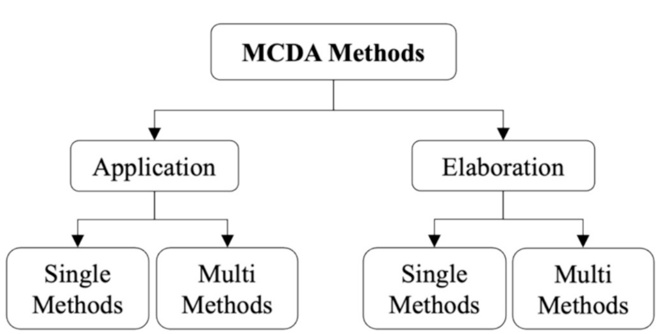


Fig. 4. Classification of reviewed Articles based on their use.

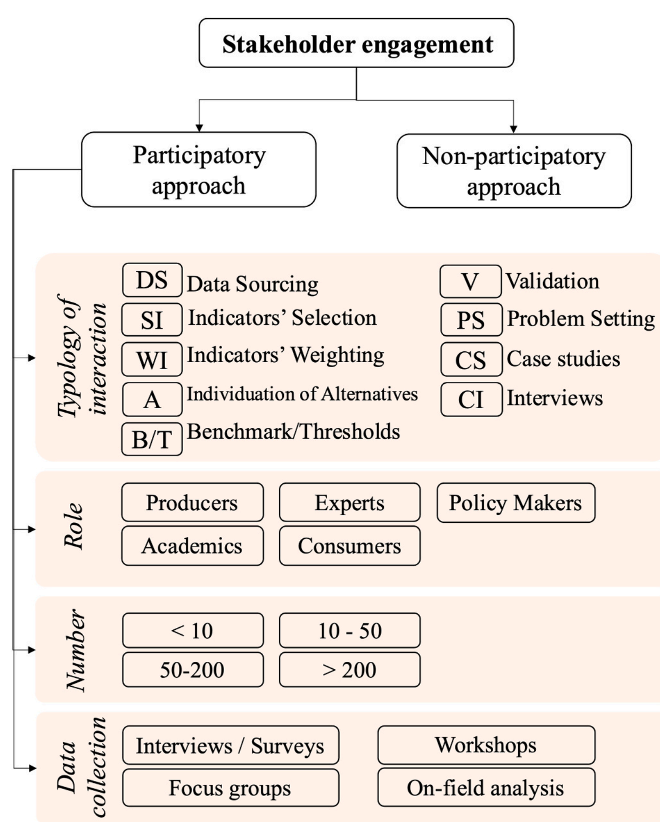


Fig. 5. Approaches in stakeholders’ engagement.

2.2.4. Indicators and metrics

The selection of the indicators adopted in MCDA deeply affects the effectiveness and potentiality of the method and of the outcomes. Several indicators belonging to different domains were found in the articles reviewed.

To provide a framework about indicators and metrics is a challenging activity that can be tracked in different ways. Firstly, the SAFA approach (FAO, 2014), i.e., one of the most recognized systems to evaluate sustainability, was used to classify the different indicators found inside the articles according to its four-dimensions sustainability: environmental, economic, social and governance.

Some articles already classified their indicators in one or more of these categories, while others made no classification or used different names for their categories. In the latter case, they were classified according to the approach described. For example, indicators belonging to the category animal welfare were classified as environmental indicators while indicators of food safety were classified as economic indicators. Some logistic indicators were not present in the SAFA fields and were classified as economic.

Following the classification in fields, the indicators have been divided in qualitative, quantitative, or mixed, using the rule that, if the indicator has a unit of measurement or it is expressed as a percentage it is considered a quantitative indicator, while if the indicator is related to a score, an evaluation or a rating scale, it is a qualitative indicator.

3. Results and discussion

Results are provided in the present section according and following the review method presented in Section 2. The chapter is articulated as follows: the first part provides a general overview of the final articles' selection through a systematic bibliometric analysis (Section 3.1). It follows a detailed examination of the following aspects: MCDA methods (Section 3.2), stakeholders' involvement (Section 3.3) and performance indicators (Section 3.4).

3.1. Bibliometric analysis

An overview of the chronological distribution of the 42 articles selected is provided in Fig. 6. The graph illustrates an overall increasing trend in the annual number of published articles adopting MCDA methods for sustainability assessment in the food sector, indicating a growing interest in the topic. The first studies are dated back 2012, while from 2019 to 2023, a minimum of five articles per year have been recorded.

After, the categories, individuated in the step 2 of the selection process (Section 2.1), were mapped as shown in Fig. 7. The articles belong more frequently to the environmental (28 %), agricultural and biological categories (27 %). The other dimensions of sustainability are visible inside the categories of economy (economics, econometrics, and finance), society (Social Sciences) and governance (Business, management, and accounting).

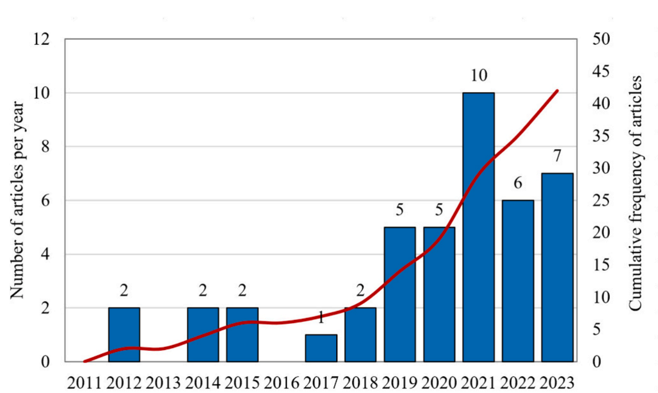


Fig. 6. Distribution of the 42 selected articles per year (bars) and cumulative curve (line).

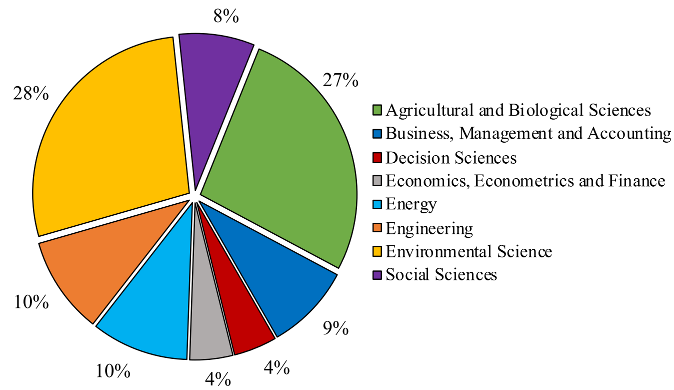


Fig. 7. Distribution of the 42 selected articles per subject area.

3.2. MCDA methods

In this section results of the analysis on the MCDA methods used are presented. In the first sub-section, results of the classification based on their main features and characteristics (Section 3.2.1) is provided, focusing also on the weighting procedure (Section 3.2.2). After results of the classification based on how they are used inside the selected articles, focusing also on the use of software (Section 3.2.3) and the aims (Section 3.2.4), are presented.

3.2.1. Features of MCDA methods

The classification scheme of MCDA methods proposed in Section 2.2.1 has been employed for the analysis of the selected articles. The results of this analysis are presented in Fig. 8.

As shown in Fig. 8, the total number of methods found in the selected articles is 17: AHP, ANP, BWM, D-BOD (Directional Benefit Of the Doubt), DEXI-MET, DEXI-PM, ELECTRE, Multi-attribute Assessment of the Sustainability of Cropping system (MASC), MAUT, MAVT, Marco para la Evaluación de Sistemas de Manejo incorporando Indicadores de Sostenibilidad (Framework for the Evaluation of Management Systems incorporating Sustainability Indicators, MESMIS), PROMETHEE, SAFA, TOPSIS, SMART Farm Tool, TAPE, VIKOR. The additional category named "Generic" contains all the specific approaches used by authors who, however, did not specified a distinctive name. Instead, they defined their method more broadly, for instance, as "multi-criteria comparison of alternatives" (Avadí and Fréon, 2015) or "multi-criteria decision analysis" (Cap et al., 2023).

Inside the category "Generic", it is still possible to classify these unnamed methods within one of the subcategories of FAMs and PAMs defined in Section 2.2.1. Specifically in the category "Generic", the 45 % (Karlsson Potter and Röös, 2021; Mena et al., 2012; Painii-Montero et al., 2020; Tuni and Rentizelas, 2022; Tziolas et al., 2022) of the methods could be traced back as FAMs "other approach". For example, (Mena et al., 2012) uses an aggregate index, known as the Organic Livestock Proximity Index (OLPI), reflecting the level of adherence of each livestock farm to the organic model based on diverse considerations. The trade-off weights assigned to each indicator during the index calculation capture the relative importance attributed to each evaluated aspect. In this context, these weights serve as cardinal values. Notably, this method mirrors the MAUT method in its final resolution of the multicriteria problem by means of an aggregation mathematical function which relates indicators and associated values among them. Among the articles inside the "Generic" category, the 27 % (Avadí and Fréon, 2015; Moraine et al., 2014; Tapia et al., 2021) can be classified as PAMs outranking approaches. These articles are distinguished by a direct

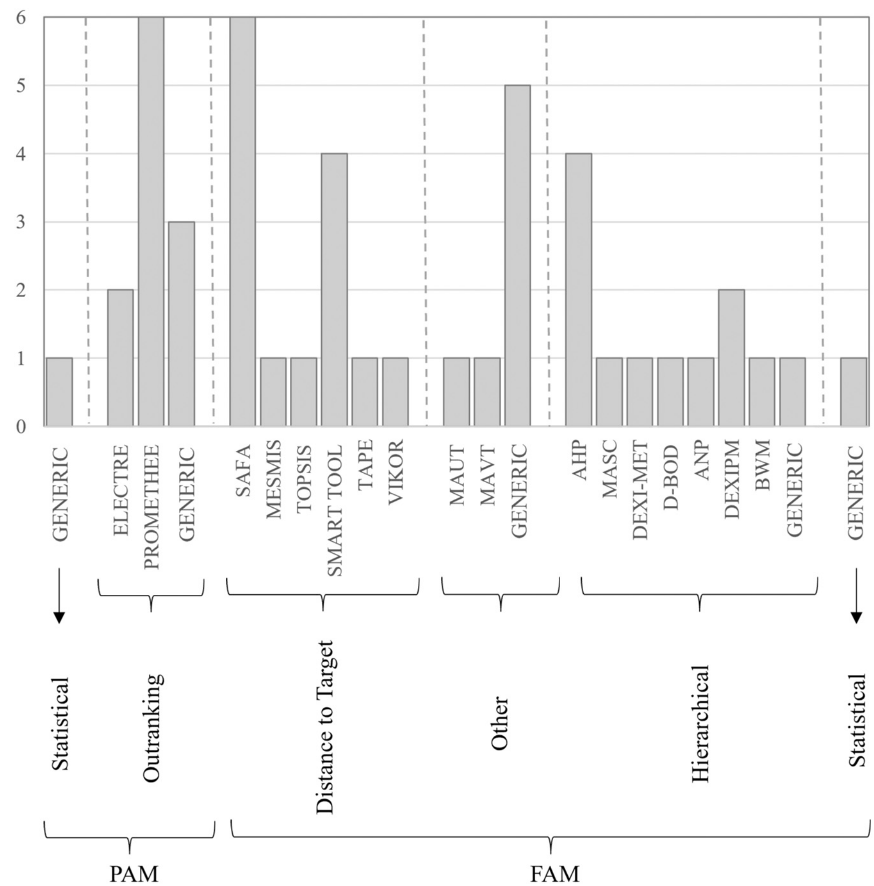


Fig. 8. Absolute frequency of MCDA methods adopted in the 42 reviewed articles. The total frequency is equal to 46 because in two articles two methods are adopted and in one article three methods are adopted.

evaluation of alternatives based on the number of criteria in which options outperform. Unlike methods using a global single final aggregated score, PAMs outranking approaches may maintain, as in the analysed articles, a disaggregated representation of decision criteria.

The remaining articles inside the "Generic" category have been examined as follows:

- one (Cap et al., 2023) employed a FAM hierarchical approach;
- one (D'Ammaro et al., 2021) utilized a PAM statistical approach:
- one (Emran et al., 2022) employed a FAM statistical approach.

The statistical approaches adopted by (D'Ammaro et al., 2021; Emran et al., 2022) can be viewed as having a more objective and mathematical nature compared to approaches that directly involve stakeholders or decision makers in expressing preferences and assigning weights to criteria.

Starting from the FAMs, the most frequently adopted approach is the distance to target, with 14 out of 42 articles. Inside the distance to target approach, SAFA and SMART Farm Tool have been found to be the methods with the highest absolute frequency, 6 and 4 articles respectively. The utilization of these methods occurs through dedicated software. In these cases, therefore, the separation line between the application tool and the multi-criteria analysis method is quite thin (further details in Section 3.2.3). In this category, also MEMSIS, TOPSIS and VIKOR can be found.

The hierarchical approach represents the second most widely used category, adopted in the 29 % of the reviewed articles. Among the hierarchical methods the AHP stands out as the most widely employed. The AHP involves three main hierarchical levels: the goal, decision criteria and alternatives (Dean, 2022), and additional middle layers can be added if useful for the analysis. Criteria are compared using a nine-point semantic scale in a pairwise matrix (Saaty and Ozdemir, 2003). Criterion weights can be determined either rigorously through the normalised principal eigenvector or more simply using a geometric mean. Eventually, criteria and weights are aggregated using a mathematical function, resulting in a global performance score for the evaluated option. (Dean, 2022) reports that many authors question the reliability of AHP results, especially regarding its weighting method, pairwise comparisons, and the interpretation of the semantic nine-point scale. In addition, AHP can be time-consuming, requiring N(N-1)/2 pairwise comparison for N criteria. Indeed, authors of (Saaty and Ozdemir, 2003) recommend comparing only seven ± two elements at a time. In fact, for example, among the articles selected for this review, (Chandran et al., 2023) employs AHP using only three criteria. However, among the 42 reviewed articles, (Verdecho et al., 2021) highlights the versatility of the AHP in incorporating simultaneously both qualitative and quantitative criteria and propose the use of the *Superdecisions Software* to manage the high number of criteria. The review reveals that AHP can be also used to integrate other methods, as demonstrated by Chandran et al. (2023), Segura et al. (2019). In particular, (Chandran et al., 2023) adopts TOPSIS as MCDA and AHP to determine criteria weights to enhance the performance of TOPSIS. Also, (Segura et al., 2019), referring to (Saaty and Peniwati, 2007) and (Xu, 1998), highlights that AHP can provide a robust mechanism to collaboratively obtain criteria's weights. Among the reviewed articles, only one (Król-Badziak et al., 2021) employed a Fuzzy version of the AHP. In (Król-Badziak et al., 2021) it is emphasized that AHP stands out as one of the most powerful and commonly used MCDA methods, mainly due to its intuitive understanding. However, a weakness is acknowledged, namely its tendency to reflect human thinking uncertainties. To address this limitation (Król-Badziak et al., 2021) decided to complement AHP with fuzzy theory to represent natural preferences and judgments. Specifically, they employed fuzzy membership functions capable of capturing uncertainties arising from different expert's opinions.

With the goal of developing a more streamlined and less heavy method while retaining the use of pairwise comparison, (Rezaei, 2015) introduced the BWM which entails a pairwise comparison only between the worst and the best criteria arbitrarily selected. A more opaque and complex version of the BWM, namely the Interval Type 2 Trapezoidal Fuzzy BWM (IT2TrF-BWM) has been implemented for supplier selection by (Sharifi et al., 2023). (Guitouni and Martel, 1998) have underlined the usefulness of hierarchical models emphasizing that assessing them is not always an easy task also due to their axiomatic foundation of mutual preferential independence between different hierarchical levels and elements (Dean, 2022).

In summary, among the 12 articles employing a hierarchical model for addressing multicriteria problems, four specifically adopt an AHP method. Among these, two (Chandran et al., 2023; Segura et al., 2019) employ AHP as a preliminary step to the main method, while the remaining two (Król-Badziak et al., 2021; Verdecho et al., 2021) directly apply it as a resolution method for the multicriteria problem. In the last two cases, a sensitivity analysis was conducted by varying the values of the pairwise comparison matrix to assess the robustness of the results.

The last category of FAMs is the "other approach" category (adopted in 8 out of 42 articles), which include the MAUT and MAVT. The MAUT method aims to establish the overall utility of an alternative. The utility expresses the decision maker's satisfaction level for a specific outcome of an option with reference to a given number of criteria, here termed attributes. (Dean, 2022) emphasizes that the MAUT method allows incorporating non-additive preferences and takes into account that decision makers may have complex preferences which is reflected in the interaction between criteria. MAUT involves posing complex questions to stakeholders, including random lotteries to reveal preferences introducing risk and uncertainty. Instead MAVT is a simplified, deterministic version of MAUT. In MAVT, questions are framed in a context of certainty (Diaz-Balteiro et al., 2017), using the weighted arithmetic mean or the weighted geometric mean. The MAUT method has been employed only in one (Talukder et al., 2016) of the selected articles. (Segura et al., 2019) highlighted its suitability for measuring the sustainability of products and supplier in the food industry and praised certain advantages of the method such as its understandability and the absence of the rank reverse problems. MAVT method has also been applied only once in the reviewed articles by (Talukder et al., 2016).

Inside the selected articles PAMs are less used than FAMs, but they are still frequently present. PROMETHEE assesses the deviation between evaluations of two alternatives on each criterion, where a larger deviation indicated a stronger preference for one alternative over the other (Rocchi et al., 2019). Like the ELECTRE method, which has multiple versions, the PROMETHEE method also has distinct iterations, specifically PROMETHEE I and PROMETHEE II. According to (Rocchi et al., 2019), PROMETHEE I offers a partial ranking of alternatives while PROMETHEE II is described as a full ranking method. Moreover (Rocchi et al., 2019) referring to (Brans and De Smet, 2016) also recommends, for real world application, the utilization of both PROMETHEE I and II.

However, among the 42 articles selected for this review, six utilized PROMETHEE, and within these six:

- two (Rocchi et al., 2019; Schmitt et al., 2017) applied both approaches;
- one (Ghamkhar and Hicks, 2021) used PROMETHEE II;
- three (Aidonis et al., 2015; Melkonyan et al., 2020; Segura et al., 2019) adopted PROMETHEE I;
- only(Rocchi et al., 2019) conducted a sensitivity analysis to ascertain stability of obtained results.

Only two articles (Aidonis et al., 2015; Castellini et al., 2012) out of 42 have adopted an alternative outranking approach to PROMETHEE: ELECTRE.

3.2.2. *Weighting procedure*

As anticipated in Section 1.1, the weighting phase revealed to be a delicate step, tackled by the 42 studies analysed in various ways, according to specific objectives, data availability and MCDA method adopted. As shown in Fig. 9, the most adopted approach for weighting is to assign equal weights (EW) to all the indicators and criteria, as a percentage of the total. This approach is common in studies adopting few indicators and, in general, to preserve objectivity. Although in such cases it may be considered a subjective objectivity, since it still represents a subjective choice by mean of authors. For the weighting methods adopting an external resource (ER), such as tools or datasets, in the most of cases weights assignment is carried out according to the default settings of the tool adopted. In one exception (Montemurro et al., 2018), the predefined weights of the tool used (DEXi) have been modified by involving stakeholders through focus groups and negotiation.

3.2.3. *Uses of MCDA methods and tools*

In this section, the results of analyses conducted on selected articles are presented in Fig. 10, based on the framework outlined in Fig. 3. It is possible to observe that articles employing a singular method to address the multi-criteria problem are the majority (39). Among these 39, 29 apply an existing and codified method, while 10 develop a new one, adapting an existing approach to the boundaries conditions of the specific problem addressed. Among the 3 articles employing more than one method, those by (Segura et al., 2019) and (Chandran et al., 2023) rigorously adopt existing methods according to a principle of integration between different methods, with the goal of strengthening the obtained results. In addition, (Segura et al., 2019) have conducted a comparison between methods highlighting the pros and cons of the FAM MAUT and the PAM PROMETHEE to measure the sustainability of products and supplier in food distribution companies. (Aidonis et al., 2015) instead, developed a novel method for the evaluation of sustainable supply chains in the food sector, building upon the two outranking methods, ELECTRE and PROMETHEE.

For what concerns the software used, in 45 % of the selected articles, no software is employed to support the application of the chosen method. An overview of the software used in the analysed articles is presented in Table 2. Each software is inherently linked to a specific method. Our analysis does not reveal the existence of software for MCDA that can be detached from a specific method and capable of allowing

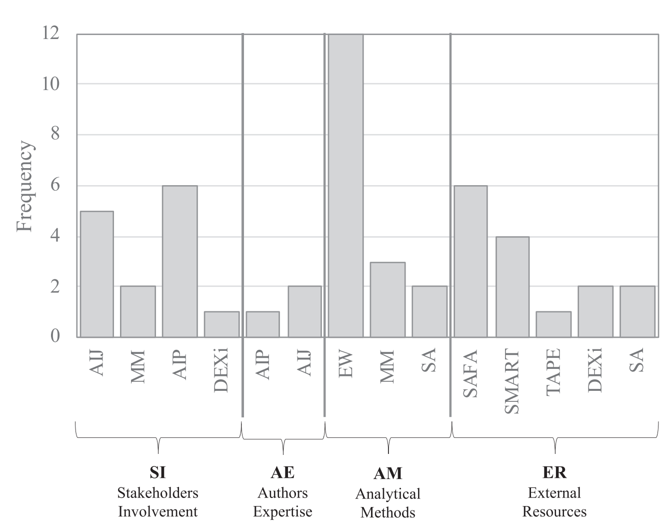


Fig. 9. Results of the classification of the 49 weighting approaches (the approaches mapped are more than the papers analysed because some papers tested different methods) in the articles' selection.

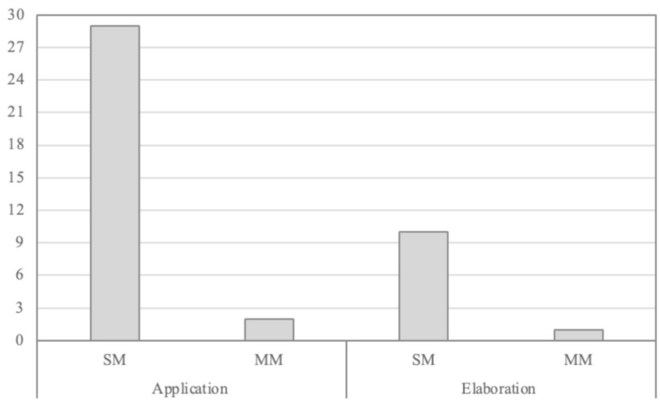


Fig. 10. Article classification according to the scheme presented in Section 2.2.2.

Table 2
Overview of most used software and their characteristics.

Software	Free to use	MCDA method	Reference/website
SAFA Tool	Yes	SAFA	(FAO, 2014)
SMART Farm Tool	Yes (on request)	SMART Farm	https://www.fibl.org/en/themes/smart-en
TAPE	Yes	MEMSIS	(FAO, 2019)
Visual Promethee	Yes (for academics)	PROMETHEE, GAIA	(Mareschal, 2015)
DeXi	Yes	DEX	(Bohanec, 2021)
D-Sight	No	PROMETHEE, GAIA	http://aca.d-sight.com/
Superdecision	Yes	AHP - ANP	https://www.superdecisions.com/

flexible adoption across various approaches.

Certain methods such as SAFA, Smart Farm Tool and DEXi can be identified with the software in which they are implemented.

The use of these tools may simplify user operations, providing support not only in terms of calculations but also guiding the method's progression. Software defines a closed field for the method development as if they established rails from which deviation is not possible. This is particularly valuable because it means that studies that adopt software are easier to compare but at the same time may pose limitation to the method development. Software, indeed, may result static and uncapable of adapting to unique situations, for example SAFA, Smart Farm Tool and DEXi incorporate a significant number of indicators but the addition of new ones to extend the analysis domain with further decision criteria is not feasible.

As highlighted by (Segura et al., 2019), PROMETHEE lends itself to graphical data visualization. In our literature review, in most of cases with PROMETHEE, also the Graphical Analysis for Interactive Assistance (GAIA) has been used, typically adopting the Visual Promethee software which incorporates it. GAIA is an auxiliary descriptive method to PROMETHEE aimed to provide a graphical representation of the major features of the decision problems (Mareschal, 2015). Specifically, in 3 out of 6 articles using PROMETHEE, the results were presented through GAIA planes. The objective of employing GAIA planes is to convey maximum information through a two-dimensional representation about alternatives, criteria, and weights (Ghamkhar and Hicks, 2021). Out of the six PROMETHEE users, four have opted for the Visual PROMETHEE software. (Segura et al., 2019) deviated from this trend by employing another software, called D-sight, for the application of PROMETHEE.

3.2.4. Aims

The different aims of the articles (i.e., assessment, comparison, decision making, method and optimization/design) have been mapped, as described in Section 2.2.1. To understand if a correlation was present, the aims of each article have been combined with the MCDA method category used. The results are reported in Table 3. The total number of applications differs from the number of selected articles since three articles adopted more than one MCDA method and three articles have used MCDA for multiple aims (e.g., (Aidonis et al., 2015)). The methods belonging to the category Generic have been classified as reported in Section 3.2.

The selected articles have used MCDA with the aim of performing a comparison between two or more alternative (42 %), an assessment (16 %), the development or testing of a new method (14 %) or an optimization or design of a new alternative (20 %). Only the 8 % of the selected article have explicitly conducted the MCDA analysis for decision making.

Concerning the comparison of the main aim, FAMs Distance to Target category is the most used MCDA method (8 out of 21). Distance to target methods can be more used for this aim since having a target can allow comparability between alternatives, since the selected targets, also called ideal points, can function as benchmark. Also, FAMs Hierarchical (5 out of 21) are used.

When an assessment is the main aim, FAMs Distance to Target methods are the most used methods (4 out of 9). In 3 of these cases, SAFA method was used.

For the optimization/design aim, the most used MCDA methods are the FAMs Hierarchical (5 out of 10). For the other aims, different methods have been used, without one prevailing over another.

The FAM "other approach" were used for all the aims. Also, the PAMs without threshold were used for all the aims, excepts for the optimization/design category. These two classes can be considered more versatile inside the selected articles.

3.3. Map of the stakeholder's engagement

A non-participatory approach is proposed only in 3 of the 42 selected articles, i.e. (Avadí and Fréon, 2015; Cap et al., 2023; Chandran et al., 2023). For data sourcing they use data taken from literature or from databases. In particular, (Chandran et al., 2023), uses data taken from in-situ observation, but that does not require the involvement of any stakeholders. Instead, for the weighting procedure, these three articles, use three different approaches. (Avadí and Fréon, 2015) uses an equal weight for all the indicators and criteria, (Cap et al., 2023) uses a statistical approach to assign weights, while (Chandran et al., 2023) rely on authors' experience to assign weights.

In the other 39 articles a participatory approach is proposed, and results of the stakeholders' engagement mapping are reported in Fig. 11, according to Section 2.2.3.

Inside one paper, the same group of stakeholders can be engaged in more than one interaction (e.g., a group of farmers can be engaged for data sourcing and for weighting) and the same interaction can be done by more than one stakeholder (e.g., for weighting both farmers and experts have been engaged). Moreover, also two different groups of stakeholders with the same roles can be engaged for the same or different interactions (e.g., two different groups of experts have been engaged for weighting or two different groups of experts have been engaged, one for weighting and one for validation). Primarily engaged stakeholders are:

- farmer and producers, mainly employed for DS but also in all interactions except CS and CI due to their role as subjects of analysis;
- experts and academics, engaged across all interaction categories;
- policy makers, involved in all interaction types except CS, CI and A
- consumers, engaged only in V and WI.

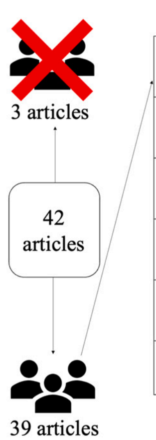
Consumers are generally less involved due to the focus of selected articles on production phase and potential complexity, knowledge construction might be necessary prior to their engagement.

The number of involved stakeholders is on average 78 (ranging from

Table 3
Classification of the 42 selected articles by method's categories and aims. Colors, from red to green, indicate the increasing correspondence between methods and aims.

	Category	A	C	M	R	D/O
PAM	Outranking Approach	2 articles *(13, 21)*	4 articles *(4,28,31,32)*	4 articles *(1, 8, 24, 37)*	2 articles *(1, 21)*	
PAM	Statistical	1 article *(11)*				
FAM	Distance to Target	4 articles *(3, 5, 6, 19)*	8 articles *(9, 10, 14, 15, 18, 34, 35, 42)*			2 articles *(20,30)*
FAM	Hierarchical		5 articles *(7, 9, 17, 27, 32)*	1 article *(40)*		5 articles *(2, 23, 25, 29, 41)*
FAM	Other	1 article *(26)*	4 articles *(16, 32, 36, 39)*	1 article *(38)*	1 article *(38)*	2 articles *(22, 33)*
FAM	Statistical					1 article *(12)*
		8	21	7	4	10

A = Assessment
C = Comparison
R = Recommendation
M = Method
D/O = Design or Optimization



	DS *(34 p.)*	SI *(7 p.)*	WI *(14 p.)*	A *(3 p.)*	B/T *(5 p.)*	V *(5 p.)*	PS *(3 p.)*	CS *(1 p.)*	CI *(2 p.)*
Farmers/Producers *(36 papers)*	32	6	12	3	3	4	3	0	0
Policy Makers *(6 papers)*	2	2	4	0	1	2	1	0	0
Experts *(15 papers)*	8	3	3	3	2	3	1	1	1
Academics *(11 papers)*	3	1	4	2	1	2	1	1	1
Consumers *(3 papers)*	0	0	2	0	0	1	0	0	0

Fig. 11. Stakeholders' engagement maps.

1 to 501). Each group of stakeholders can be constituted by stakeholders with different roles (e.g., a group of 40 stakeholders can be composed only by farmers or by a mix of farmers, experts, and academics). 33 groups of stakeholders are fewer than 150, four groups are composed of 150–300 and two groups from 300 to 450. Only in one case the stakeholders were more than 450.

Data sourcing is present in 34 of the 39 articles and it is the main reason why stakeholders are involved. Data gathering can happen through different number of stakeholders, primarily farmers and producers, but also through policy makers, academics, or experts. When farmers or producers are involved for data collection, a variable number of stakeholders have been engaged by each article ranging from 1 (Rocchi et al., 2019) to 501 (Emran et al., 2022). The selection of indicators can be done in a participatory way (7 out of 39), engaging mainly farmers but also policy makers, experts, and academics. Participatory weighting is present in 14 out of 39 articles. The procedure of weighting can be done by all the different stakeholders, without a clear preference.

For example, in 12 articles farmers have been engaged during the weighting phase, in 8 cases alone while in 4 cases with other stakeholders. The other types of interaction are less present in the selected articles. B/T, PS can be done by all the involved stakeholders, excluding the consumers while CS and CI are done by experts and academics only, excluding therefore consumers, farmers, and policy makers. The process of validation through stakeholders is the only type of interaction, along with weighting, that can be done thought the engagement of all the categories. However, is not largely present in the selected articles (only 5 out of 39 articles).

Focusing on the way data were collected, the detected methods are interviews or survey (18 articles), workshops (3 articles), focus groups (2 article). In the other cases more than one method was used:

- interviews/survey and focus groups (1 article);
- interviews/survey and workshops (6 articles);
- interviews and on-field analysis (3 articles).

In the other 6 cases the method for data collection was not specified.

In many articles the method and criteria for the selection of the involved stakeholders are not explicitly indicated, reducing the transparency of the method. Transparency in this phase of MCDA is fundamental, since the engagement of stakeholders introduces subjectivity to the analysis, which can significantly influence the results.

3.4. Most used indicators field

Fig. 12 summarizes the sustainability domain investigated in each article.

In general, in the 62 % of the selected articles, the 3 "classic" dimension of sustainability (economic, environmental, and social) or the 4-dimensions proposed by SAFA (with governance) were analysed.

This was expected since MCDA in sustainability is used to combine different field of analysis.

Based on the accomplished review, governance is handled only if combined with the other 3 dimensions. While the social and economic dimensions are never analysed without also including the environmental dimension, with the exception of (Leknoi et al., 2023). The environmental dimension can also be analysed alone, but more frequently in relation to the economic dimension.

Concerning the number of used indicators, an average value of 52 indicators (median equal to 19) is detected, ranging from 3 (Leknoi et al., 2023; Tziolas et al., 2022) to 327 (Winter et al., 2020). Usually if the article uses the SAFA method or the Smart Farm Tool, the number of indicators is averagely higher (average of 85 and 169 respectively).

In 40 % of articles a mix of qualitative and quantitative indicators were used. In some of these cases there was balance between the two types of indicators (Cánovas-Molina et al., 2021; Curran et al., 2020), in other cases there were more quantitative indicators (Cap et al., 2023; Król-Badziak et al., 2021), while in other cases there were more qualitative indicators (Talukder et al., 2016). In the 24 % of articles used only quantitative indicators, while in 26 % only qualitative indicators. In (Alletto et al., 2022; Montemurro et al., 2018) also mixed indicators were used. Additional information about indicators can be found in Supplementary material.

3.5. Summary of main results

In this section the main results of the review in relation to the 4 most used MCDA methods, among the articles reviewed, are presented and can constitute a preliminary guide to practitioners in the choice of an MCDA method for sustainability assessment in the food sector. Table 4 describes the main characteristic for the AHP, PROMETHEE, SAFA and SMART Farm Tool, divided per methods characteristics, stakeholders' engagement, and indicators.

Referring to Table 4, it is interesting to notice that all the main adopted MCDA methods for sustainability assessments in the food sector, foresee the involvement of stakeholders in the different phases of the methods (more details in Section 3.3). Such necessity is explained in the fact that the sustainability of food production and distribution has a

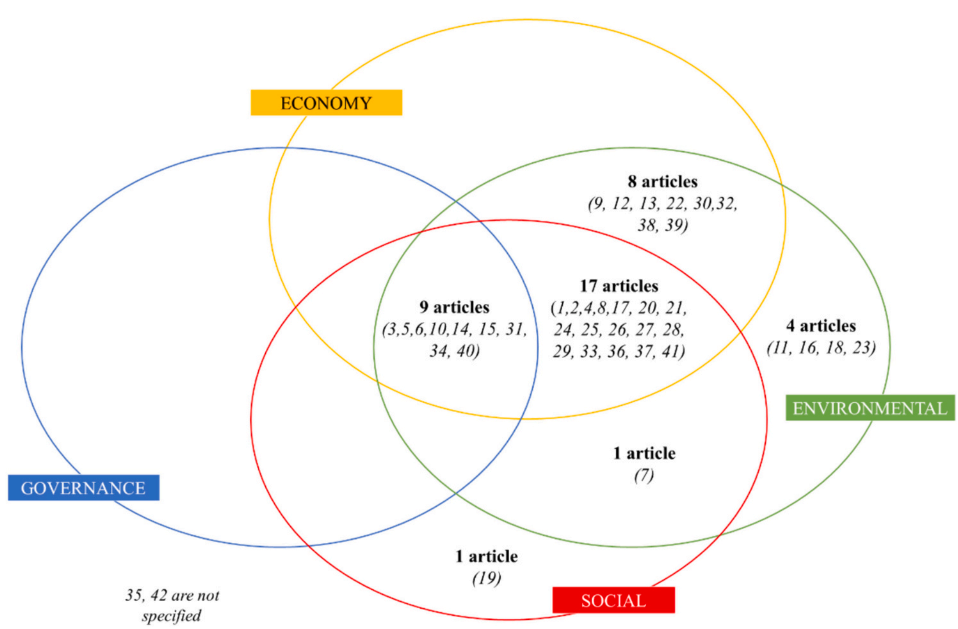


Fig. 12. Indicators fields.

Table 4
Summary of results for the first four most used MCDA methods.

			AHP (4 times)	PROMETHEE (6 times)	SAFA (6 times)	SMART FARM TOOL (4 times)
Method' characteristics	Classification		FAM – Hierarchical	PAM – Outranking Approach	FAM – Distance to Target	FAM – Distance to Target
	Compensatory		Yes	No/Partially	Yes	Yes
	Weighting		Yes	Yes	Yes	Yes
	Aim		C, M	A, C, M,R,	A, C	A, C
	Software		Yes / No	Yes / No	Yes	Yes
Stakeholders	Stakeholders' engagement		Yes / No	Yes	Yes	Yes
	# stakeholders involved *average (min-max)*		4*	14 (1–32)	57 (10–150)	152 (26–245)
	Type of interaction	DS	x	x	x	x
		SI	x	x	x	
		WI	x	x		
		B/T	x	x		
		PS	x	x		
		CS			x	
		CI				x
	Data sourcing		I W	I W	I W	I W
Indicators	% of papers across sustainability dimensions		- 50 % Ec + En - 25 % 3d - 25 % SAFA 4d	- 50 % 3d - 33 % Ec + En - 17 % SAFA 4d	- 83 % SAFA 4d - 17 % S	- 75 % SAFA 4d - 15 % En
	Qualitative		x	x	x	x
	Quantitative		x	x		x
	N° Indicators		12 (3–19)	30 (11–100)	84 (19–116)	208 (45–327)

I = Interviews, surveys or questionnaire / W = Workshops.
Ec = Economic Sustainability / En = Environmental sustainability / S = Social sustainability / 3d = social, economic, and environmental sustainability / 4d = social, economic, environmental and governance.
* Only 1 of the 4 articles adopting AHP has declared the n° of stakeholders.

strong cross-sectoral nature, involving transversally many different aspects. For this reason, for sustainability assessment of food-related products, the involvement of experts and stakeholders of the field, it is strongly encouraged to foster solid and comprehensive results.

As summarised in Table 4, two main different approaches can be individuated in the most common used methods. One involves the use of well codified and standardised tools (SAFA and SMART FARM TOOL), which on one hand allows to simplify the process by following the requests of the software, but, on the other hand limits the customisation and tailoring of the method on the specific characteristics of the problem analysed. The other approach, represented by AHP and PROMETHEE, even if some software is available for such methods, allows users to modify and tailor the method according to the problem analysed, but a full understanding of the process is necessary to handle the complexity of its implementation. For this reason, as highlighted in Table 4, the latter usually involves the use of less indicators, compared to SMART FARM TOOL and SAFA.

The final choice of the method to be adopted is, in summary, a function of

- the application field,
- the MCDA process characteristics,
- the problem analysed,
- objectives of the study,
- the available data and the number of indicators to be used,
- the skills of the users implementing the method.

Indeed, as also many authors highlighted (Diaz-Balteiro et al., 2017; Guitouni and Martel, 1998), it is difficult to identify an ideal, universal MCDA method suitable for all decision-making problems. Findings of this study also align with the observation by (Ebert and Welsch, 2004) that underlines the significance of choosing the relevant method for a specific application to avoid neglecting critical aspects, prevent undesired compromises, and provide recommendations aligned with stakeholders' characteristics and preferences.

Among the numerous studies addressing the theme of supporting method selection, for instance, the pioneering work of (Cinelli et al., 2022), based on a comprehensive taxonomy, has resulted in the development of a software recommending the most suitable MCDA method for a given decision-making problem. However, among the 205 possible MCDA methods that can be suggested by (Cinelli et al., 2022) decision support system, none of the earlier mentioned methods appears to be specifically tailored for the food sector. It is common for authors to lean towards methods with which they are more familiar with, therefore by utilizing such decision support software, methodological inconsistencies that may arise from the preference for a familiar method, which may not necessarily be the most appropriate, can be avoided. Nevertheless, it is important to note that although the software recommends the most suitable method, even an expert may not apply it if unfamiliar with the suggested approach. This recognition underscores the importance of knowing which method is optimal while maintaining a critical and informed approach towards the method employed.

4. Conclusions and further development

This review has examined the MCDA methods employed for evaluating sustainability in the food supply chain, providing an overview of existing sustainability assessment MCDA methods in the food sector, focusing on delineating their primary differences and commonalities, highlighting limitations, and exploring potentialities.

Referring to the first research question, distance-to-target emerged as the most frequently adopted approach, since it is used in 14 out of 42 articles. Within this approach, SAFA and SMART Farm Tool demonstrated the highest absolute frequency.

Among the selected articles, 17 methods were identified with six (SAFA, SMART TOOL, TAPE, MASC, DEXi-MET, and DEXI-PM) specifically tailored for sustainability performance assessment in the food sector.

Referring to the second research question, the stakeholders' involvement has been mapped revealing that the most necessary engagement is in data sourcing and, secondarily, in the weighting and in the selection of indicators, while defining benchmarks or thresholds, when required, remain critical. Academics and experts represent the stakeholder groups involved in each engagement type, while consumers have been found to be engaged only for choices' validation or weighting. The transparency of the involvement is fundamental since the subjectivity can significantly influence the results. The process of obtaining the necessary subjective preferences must be very clear, highlighting any possible conflict and the path taken to resolve them.

Referring to the third research question, a software is employed as methodological support in the 55 % of the selected articles. The most frequently adopted are SAFA, Smart Farm Tool and DEXi, which are intrinsically connected to the homonymous methods. Even if tools may simplify user operations, they could also result static and not customizable in some contexts of assessment, or even affect the selection of the method itself.

In conclusion, this review contributes to the technical literature by a comprehensive summary of crucial information for a preliminary understanding of MCDA in the food sector, especially for scholars and practitioners new to the field.

However, as further developments, the results of this review could be strengthened by extending the developed analysis and classification; by addressing how the availability or lack of some data and their technical characteristics could prevent the application of specific methods; and by evaluating the effectiveness of such methods in the food sector.

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CRediT authorship contribution statement

Giulio Ferla: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Benedetta Mura:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Silvia Falasco:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Paola Caputo:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Agata Matarazzo:** Writing – review & editing.

Declaration of competing interest

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

Data availability

No data was used for the research described in the article.

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