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Literature review: Multi Criteria Assessment of food-based systems

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Summary

This literature review analyses the use of multi-criteria assessment (MCA) in food-based systems in order to assess sustainability. MCA is an umbrella term for methods and tools that can be used when different indicators/criteria need to be incorporated in an analysis. Scoring and weighting can be used in MCAs to compare indicators with different units of measurement (Dean, 2022).

12 articles are reviewed, and they show different approaches to the MCA methodology. The studies use MCA to meet political goals/regulations, increasing resilience of farming systems, and/or for methodological development. The indicators assessed and the use of weighting differ between the studies. Furthermore, the methodological choices of an MCA and the use of software tools is assessed.

To conclude, there are several different ways of applying MCA in a study, and the methodology shows great flexibility in order to be fitted to the subject of study and the involved stakeholders. The weakness of MCA is that the methodology can be viewed as arbitrary, especially when applying weighting. Therefore, it is important to be transparent with regards to the methodology.

Contents

1 What is Multi-Criteria Assessment?

Multi-Criteria Assessment (MCA; also known as multi-criteria analysis, multi-criteria decision-making, multi-criteria decision analysis, multi-object decision analysis, multiple-attribute decision making, multi-dimensional decision making (Dean, 2022)) is not a single, specific method, but an umbrella term for different techniques and tools to incorporate multiple criteria and objectives in the analysis of a problem, and to analyse trade-offs between different indicators. MCA methods can be both qualitative and quantitative. Because MCA is used to analyse different criteria with different units of measurement, scoring and weighting can be used to evaluate how each criterion performs with regards to meeting the objectives.

Subjectivity in the scoring and weighting of different indicators is unavoidable, and because of this, weighting is referred to as the 'achilles heel' of MCAs. The chosen weights for criteria can seem highly subjective and arbitrary, and it is not mandatory to include weighting when doing an MCA. However, Dean, 2022 argues that the exclusion of weighting in an MCA can be seen as just as subjective and arbitrary. The lack of weighting can lead to a lack of guidance for decision-makers and thus inconsistent decisions being made based on the MCA.

Before weighting can be applied, the different indicators must be scored (Dean, 2022). Scoring – also sometimes known as normalization - is the practice of converting indicators/criteria with different units to a common scale in order to be able to compare them (e.g., CO_2-equivalents to m^3 water). The score can be applied based on the indicator's performance towards reaching an objective on a scale of 0-100 or whichever scale is deemed most suitable. Some studies might set a bar for a degree of performances that are deemed unacceptable (e.g., net loss of jobs in the local community) and this should then be reflected in the scoring scale. Different ways of scoring can be seen in Dean, 2022, pp. 45-52.

A general overview of the characteristics of MCAs can be seen in Table 1 below.

Table 1: Overview of the characteristics of MCA. Adapted from Hermann et al., 2007.

Purpose of analysis	Evaluating the overall consequences of an alternative by taking multiple criteria into account (and weighting them if wanted)
Procedure	Establishing a decision context, identifying relevant criteria, scoring, weighting (optional), and examining the results
Final output	A single, comparable score for each alternative based on the aggregation of criteria
Strengths	A single score for overall evaluation. The possibility to use weighting.
Weaknesses	Subjectivity both with and without weighting. Reliant on expert and stakeholder input

2 Method for literature review of MCAs in food-based systems

In order to understand how MCAs are and have been applied to analyse sustainability of food-based systems, a literature review was conducted.

2.1 Purpose of the literature review

The goal of the review was to gain an understanding how MCA has been applied to assess sustainability of food systems in previous studies and assess the purpose of the selected MCA studies, how the three pillars of sustainability are covered, and which indicators are included, as well as whether weighting is applied to reach a conclusion.

2.2 Methodology

The literature review was conducted in the ScienceDirect database, using the search string *"multi-criteria assessment" AND food AND sustainability*. Only articles from 2013 and onwards were included in the review to ensure that the data was somewhat up to date with regards to the methodology of MCA.

The search gave 291 hits on ScienceDirect. These were then sorted first by title, then by abstract and finally by full text based on criteria for inclusion: The articles must be related to food systems to be relevant. Furthermore, only articles concerning European food systems were included in order to include the most relevant articles for a Norwegian context.

After sorting, 10 articles remained for further analysis. An additional two articles, which were sent by colleagues, were included in the analysis (Rocchi et al., 2019; Hagman & Feiz, 2021).

3 Results

In order to gain an overview of the purpose of the selected studies, the articles are summarised in Table 2 with a list of their goal and scope as well as indicators (Figure 1, Figure 2, Figure 3) analysed in each article. This will be illustrated in the following sections.

3.1 Purpose of the selected studies

The following table gives an overview of the analysed articles, the particular food system of analysis, the purpose of the study, and whether they included analysis of trade-offs and/or weighting of indicators.

Table 2 ***Overview of reviewed articles***

Title	Author(s)	System	Goal and scope	Trade-offs	Weighting
From stakeholders narratives to modelling plausible future agricultural systems. Integrated assessment of scenarios for Camargue, Southern France	Delmotte et al. (2017)	Future farming scenarios (Southern France)	Assessing the potential of future farming systems	Yes	No
Assessment of feedstocks for biogas production, part II—Results for strategic decision making	Ammenberg & Feiz (2017)	Feedstock for biogas production (Sweden)	Develop a method for assessing feedstocks for biogas production	Yes	No
Advancing the Circular Economy Through Organic by-Product Valorisation: A Multi-criteria Assessment of a Wheat-Based Biorefinery	Hagman, L. & Feiz, R. (2021)	Stillage by-product from wheat-based biorefinery. Fodder, fertilizer, incineration or biogas (Sweden)	Assess environmental performance, feasibility and risk. Industry-gate to final usage	No	No
Environmental and socio-economic performance of different tillage systems in maize grain production: Application of Life Cycle Assessment and Multi-Criteria Decision Making	Król-Badziak et al. (2020)	Tillage systems in maize grain production (Poland)	Comparing different tillage systems. Cradle to farm-gate	No	Yes
Comparison of exemplary crop protection strategies in Swiss apple production: Multi-criteria assessment of pesticide use, ecotoxicological risks, environmental and economic impacts	Mathis et al. (2022)	Apple production systems (Switzerland)	Comparing different plant protection strategies	Yes	No
Farming system design for innovative crop-livestock integration in Europe	Moraine et al. (2014)	Crop-livestock integration (Europe)	Comparing different system designs based on stakeholder perceptions	No	No
Integrated design and sustainable assessment of innovative biomass supply chains: A case-study on miscanthus in France	Perrin et al. (2017)	Biomass supply chains (France)	Comparing scenarios	Yes	No

Title	Author(s)	System	Goal and scope	Trade-offs	Weighting
Multi-criteria evaluation of plant-based foods - use of environmental footprint and LCA data for consumer guidance	Potter & Röös (2021)	Plant-based foods (Sweden)	Designing a guide to compare plant-based food products. Cradle to retailer	No	Yes
Assessing the sustainability of different poultry production systems: A multicriteria approach	Rocchi et al. (2018)	Poultry production systems (Italy)	Comparing conventional and free-range systems. Cradle to farm-gate	No	Yes
Assessment of the sustainability of wild rocket (Diplotaxis tenuifolia) production: Application of a multi-criteria method to different farming systems in the province of Udine	Troiano et al. (2019)	Wild rocket production (Italy)	Comparing conventional, organic and bio-dynamic farming systems	Yes	Yes
Sustainability of European maize-based cropping systems: Economic, environmental and social assessment of current and proposed innovative IPM-based systems	Vasileiadis et al. (2013)	Maize-based cropping systems (Europe)	Sustainability assessment of cropping systems	No	Yes
Combining diversification practices to enhance the sustainability of conventional cropping systems	Viguier et al. (2021)	Diversification practices in conventional agriculture (France)	Comparing diversified cropping systems to local less-diversified systems	Yes	No

As can be seen in the above table, the overall purpose of the articles is comparison of different systems within agriculture. This can be in order to achieve different objectives such as adhering to regulations, meeting a political goal, or becoming more resilient against challenges such as climate change. Other purposes are methodological development or development of consumer guides. The inclusion of trade-off analysis and weighting is mixed. Only one article includes both, whilst two articles include neither. Overall, trade-off analysis is included in 6/12 articles, and weighting is included in 5/12 articles.

3.2 MCA indicators within the three pillars of sustainability

To gain an overview of the use of economic, social, and environmental indicators in the articles, three bar charts were analysed, where the y-axis is the number of articles that included each indicator. It is also important to note that the articles analysed different types of food-systems, so the inclusion/exclusion of certain indicators cannot be directly compared. However, the charts are used to gain an overview of the type and number of indicators used:

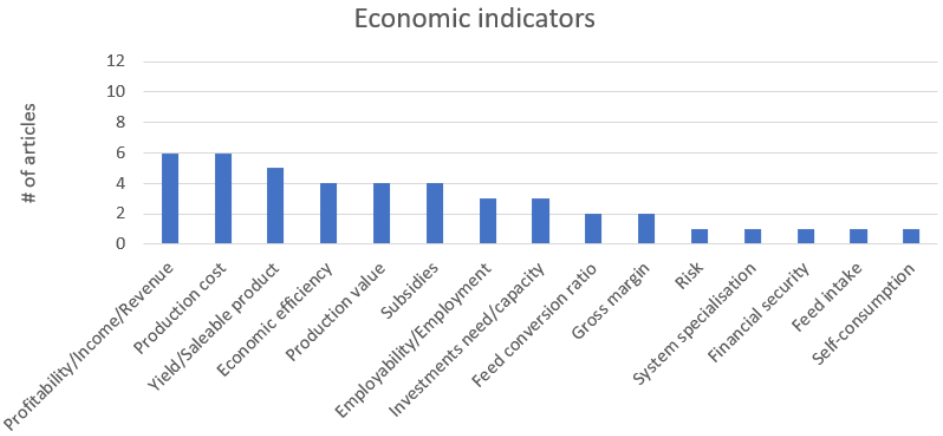


Figure 1 ***Overview of economic indicators***

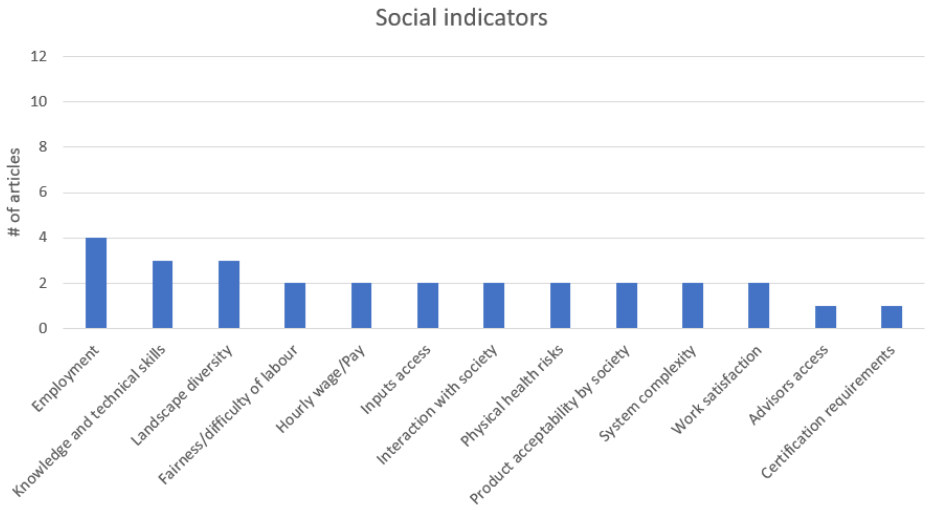


Figure 2 ***Overview of social indicators***

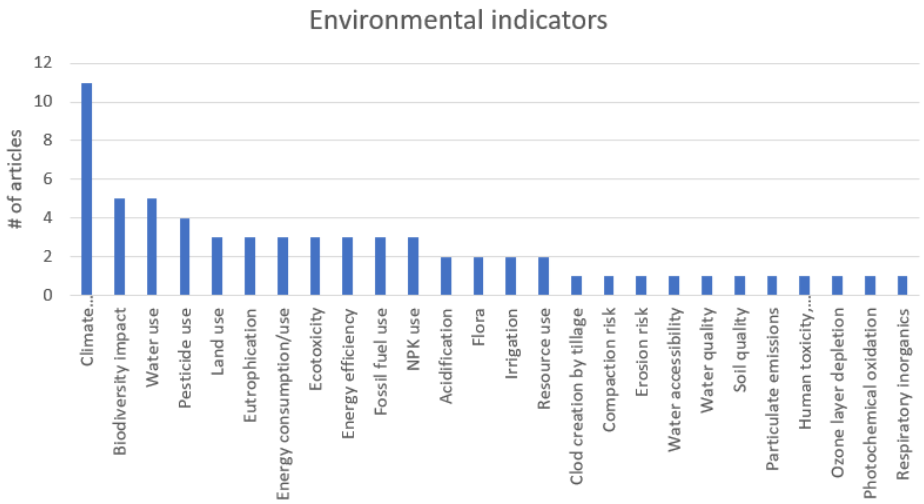


Figure 3 ***Overview of environmental indicators***

By looking at these figures, social indicators appear to be the least standardised where indicators are less consistently repeated between different studies. There are more unique indicators for environmental sustainability than in the other two sustainability pillars. However, some indicators are repeated more consistently between articles than for the social indicators, and the indicator for climate change/impact/GHG emissions was included in all but one of the reviewed articles (Troiano et al., 2019).

The number of indicators that are only represented in one or two articles can represent the number of specialised studies requiring unique indicators and thus the susceptibility of each sustainability pillar to require indicators developed to fit the subject of study. For example, Viguier et al., 2022, included several environmental indicators which were unique to this study, such as 'clod creation by tillage' and 'compaction risk'.

Some overlap can be identified between social and economic indicators, such as indicators related to employability and wage. This is assumed to be due to employment and wages being directly linked with both better economic and social welfare. One article even grouped social and economic indicators together as socio-economic indicators (Delmotte et al., 2017). All but one article (Potter & Röös, 2021) included all three sustainability pillars in their assessment. Potter & Röös, 2021, evaluated four environmental impact indicators for plant-based food in order to develop a consumer guide. However, these four indicators were also weighted differently for different food product groups to account for the difference in dietary functions (e.g., protein or vegetables).

With regards to the conclusions of the studies, one common theme is that the more indicators that are included, the more complex the analysis becomes. Troiano et al., 2019, call multi-criteria decision-making (MCDM/MCA) a flexible method, with which individual decision-makers can make the decision that fit them best based on their context. Delmotte et al., 2017, conclude that the linkage of global impacts, such as greenhouse gas emissions, and regional/local impacts, such as employment, is difficult.

3.3 Use of weighting

There was no consistency whether the articles used weighting and/or analysed trade-offs, and only one article used both weighting and analysis of trade-offs (Troiano et al., 2019), further substantiating the lack of

a standard for whether to include it or not in an MCA. Ammenberg & Feiz (2017), did not include weighting, but acknowledged that it would have given a more clear and simple answer, which some stakeholders might have liked. They justify their omission of weighting by stating that the objective of their study was to give an overview of the different indicators, and that weighting can lead to a lack of transparency. Hagman & Feiz (2021), justify the omission of weighting with some of the same arguments. They cite their priorities as assimilation and summarisation of knowledge and wanting to avoid aggregation of results which can decrease transparency. This leaves it up to the stakeholders themselves to use the knowledge that these studies have collected and weight them if they please.

When weighting is used, it can be done either in a compensatory or non-compensatory manner.

Compensatory weighting assumes that negative impacts on one or more indicators can be compensated by sufficient positive impacts on other indicators. Thus, each indicator's weight represents the proportion of the indicator that decision-makers are willing to 'give up' in order to achieve positive impacts in other indicators. This makes compensatory weighting useful when you want to identify trade-offs (Dean, 2022).

In *non-compensatory weighting* the weight of each indicator represents an 'importance-coefficient'. The more weight that is put on an indicator, the more important it is deemed to be. However, there is no compensation between indicators (Dean, 2022).

Collier et al., 2014, argue that the best weights are based on the views and priorities of involved stakeholders in order to make the weights compatible with their wishes and/or needs.

As mentioned earlier, weighting can lead to a lack of transparency, subjectivity, and disagreement with stakeholders over the assigned weights. On the other hand, weighting gives a clear basis for decision-making, thus resulting in more consistent decisions being made based on the study. The stakeholders might not have the resources themselves to be able to do a proper weighting of the indicators, which could lead to non-optimal decisions being made.

The weighting methods from two of the analysed articles will be presented to show examples of how it can be done. The two articles have been chosen because their weighting methodology is transparent and focuses on involving stakeholders in the calculation of weights.

The first method is from Troiano et al., 2019. The article compares production of wild rocket in conventional, organic, and biodynamic farming systems. They define two scenarios: an ecological scenario, where more weight is put on environmental indicators, and an economic scenario, where more weight is put on economic indicators. The weights were then assigned based on stakeholder interviews and each farming system was ranked based on the sum of weights in each of the two scenarios (See Figure 4 and Figure 5 below) (Troiano et al., 2019).

Weighted decision matrix –Ecological scenario.

Farming methods*/Indicators										
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
C	0.017	0.017	0.017	0.017	0.005	0.000	0.005	0.015	0.000	0.017
B	0.000	0.003	0.017	0.000	0.000	0.000	0.000	0.017	0.017	0.000
O	0.000	0.000	0.000	0.006	0.017	0.017	0.017	0.000	0.016	0.013
	E11	E12	ENV1	ENV2	ENV3	ENV4	ENV5	ENV6	ENV7	ENV8
C	0.017	0.017	0.000	0.088	0.000	0.088	0.000	0.000	0.000	0.000
B	0.000	0.002	0.019	0.053	0.088	0.000	0.088	0.088	0.088	0.088
O	0.017	0.000	0.088	0.000	0.088	0.000	0.028	0.087	0.088	0.083
	S1	S2	S3	S4	S5	S6	S7	S8	S9	
C	0.011	0.000	0.011	0.000	0.000	0.006	0.000	0.006	0.011	
B	0.000	0.004	0.011	0.011	0.011	0.011	0.011	0.000	0.005	
O	0.005	0.011	0.000	0.011	0.003	0.000	0.011	0.011	0.000	

* C = conventional, B = biodynamic, O = organic.

Figure 4 ***Assignment of weights to indicators in the ecological scenario (Troiano et al., 2019)***

Ranking of alternatives.

	Farming methods*/Scenarios			
	Ecological scenario		Economic scenario	
C	0.362	3rd	0.593	1st
B	0.628	1st	0.402	3rd
O	0.613	2nd	0.537	2nd

* C = conventional, B = biodynamic, O = organic.

Figure 5 ***Ranking of alternatives in the two scenarios (Troiano et al., 2019)***

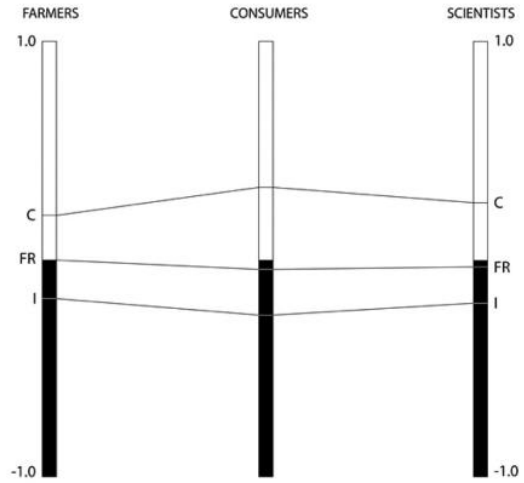
By using this method, the researchers give clear guidance to decision-makers on which farming system is preferable depending on which scenario is preferred. This is an example of an article that both uses weights and analyses trade-offs by showing the score for each indicator.

The second weighting method is from Rocchi et al. (2019), who assess different poultry production systems: free-range, intensive and combined production. Here, each stakeholder group was asked to assign a value from 1 to 3 to each indicator, where 1 is most important and 3 is least important. The stakeholders were not asked to rank the indicators against each other, but just to assign a value of 1-3 to each indicator (See Figure 6). These values were then used to calculate weights for the indicators. Afterwards, the PROMETHEE method (Abdullah et al., 2019) was used to rank the three production systems based on each stakeholder group's ranking of indicators. Figure 7 shows the results of an overall ranking of the three systems based on the indicators.

Preference assigned by different group of stakeholders (farmers, consumers, scientists).

	FARMERS	CONSUMERS	SCIENTISTS
Environmental			
Respiratory Inorganics	3	3	3
Climate change	3	1	1
Acidification/Eutrophication	3	2	2
Land use	2	2	2
Fossil fuel	3	1	1
Biodiversity index	3	3	1
Social			
Labour safety index	1	2	2
Moving index	2	2	2
Stocking density	3	2	2
Time spending outdoor	2	1	1
Breast blister	1	2	1
Severe foot pad lesions	2	2	2
Landscape	3	1	3
Economics			
Net income per kilo	1	3	3
Feed conversion	1	3	2
Mortality rate	1	3	3
Tenderness	2	1	3
Fat content	2	1	1
n-3 fatty acids	2	1	1

Figure 6 ***Overview of stakeholder preferences regarding indicators (Rocchi et al., 2019)***



Legend
C: Combined; FR: Free Range; I: Intensive.

Figure 7 Comparison of stakeholder group perceptions of the three analysed production scenarios based on their ranking of indicators. ***The combined production system (C) scores highest across all three stakeholder groups. The white part of each bar represents a net positive system, and the black part represents a net negative system (Rocchi et al., 2019).***

As can be seen, the different poultry production systems were ranked based on the perspectives of the different stakeholders. However, there is no trade-off analysis in this report.

4 MCA methods and tools

When doing an MCA, a methodology must be chosen. Dean (2022), describes the variety of methods in MCA as a 'methodological chaos', and states that it has been demonstrated that the choice of method can lead to different results for the same analysis.

"*Therefore, selecting an appropriate MCA method can turn out to be, almost paradoxically, a multi-criteria problem itself*" (Dean, 2022, p. 12).

Dean (2022) goes on to state that the choice of MCA method largely is based on the practitioner's knowledge of a given method, availability of tools, and the existence of comparable studies to emulate. Wątróbski et al., (2018), provide a framework to enable informed choices of which MCA method to use. For further description of methods such as PROMETHEE I & II and TOPSIS, see Abdullah et al., (2019) and Chakraborty (2022), respectively.

To ease the application of MCAs and make the process more practical, different software tools can be used. Three software tools are presented below to give an overview of the possible tools that can be used. The software tools are also presented in Table 3 below.

DEXi is a free software tool. It is a qualitative tool, which means that each indicator must be assigned a qualitative score (e.g., bad, medium, good or yes/no) in order to be able to compare them (Bohanec, 2021). This means that it is up to the practitioners to determine what constitutes e.g., a 'bad' score when converting quantitative data for use in this model. In DEXi, it is possible to assign weights to the different indicators, which is done by assigning a numerical score to each indicator. It is also possible to determine a limit for what makes an alternative unacceptable, e.g., a 'bad' score in this/these indicator(s) makes the alternative unacceptable. DEXi can generate graphical presentations of the analysis through different charts depending on the number of attributes (indicators) in the analysis. DEXi was used in Vasileiadis et al., 2013 and Viguier et al., 2021.

SANNA is a free extension to Microsoft Excel, which can implement several different methods for use in MCA. It can compute up to 50 indicators and 200 alternatives. Weighting of indicators is possible. The use of SANNA will vary depending on the chosen method (Jablonsky, 2014).

The Visual PROMETHEE software is a free software, which, as the name suggests, uses the PROMETHEE method. The tool allows for weighting of indicators (Mareschal, 2022). Visual PROMETHEE software was used in Rocchi et al., 2019.

Table 3 Free *software tools for use in MCA*

Name	Web-based or download	Tutorials/Guidelines	Weighting	Tool output
DEXi	Download	User manual (Bohanec, 2021)	Yes	Charts (Bar, Scatter, Radar)
SANNA	Download	Short written description (Jablonsky, 2014)	Yes	Depends on chosen method
Visual PROMETHEE	Download	2 minute video (Mareschal, 2022)	Yes	Several different chart options

The three tools presented above have been chosen based on being used in the reviewed articles, or in the case of SANNA, being an extension to Microsoft Excel, which the writer has pre-existing knowledge of.

Several different tools for MCA exist – some as standalone software, others as extensions to other programs such as Excel, R, and Matlab. This gives practitioners a wide variety of choice, depending on their preferences and pre-existing knowledge of these programs. The International Society of Multiple Criteria Decision Making has compiled a list of free and commercial software tools related to MCDM/MCA (International Society on MCDM, n.d.). Compared to free software, commercial software often has the benefit of more frequent updates and more extensive tutorials and help services. This list can therefore be consulted before choosing which software tool to use. It should be noted that the list does not represent recommendations from the International Society on MCDM.

5 Conclusion

The literature review shows that MCA has been applied in several studies to assess sustainability of food-based systems. It can be used in order to meet a political objective or regulation, becoming more resilient, or for development of methods and guides.

The review showed that the inclusion of trade-off analysis and weighting is very much up to the researchers, and different arguments can be made for inclusion and exclusion. Weighting has been said to lack transparency and be too arbitrary and subjective. Omission of weighting has been said to be just as arbitrary and subjective, as well as putting too much responsibility on decision-makers themselves to be able to weight different indicators. The example from Troiano et al., 2019, gives an example of using weighting whilst still being transparent. The use of indicators within the three pillars of sustainability shows that there is room to use unique indicators in order to fit the subject of study. Overlap between economic and social indicators is seen, such as with indicators for wages and employment.

To conclude, the use of MCA in the reviewed articles differs in several ways, but this also credits the methodology as being flexible and able to fit different subjects of study. Furthermore, this gives different stakeholders an opportunity to make decisions that best fit their context.

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