Food and Agriculture Organization of the United Nations

Development of an indicator-based framework for farm sustainability assessment

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Abbreviations

AHP	analytical hierarchy process
DEA	data envelopment analysis
DEXiPM	DEXi Pest Management
FARMTOOLS	indicator-based framework for farm sustainability assessment
IDEA	*Indicateurs de durabilité des exploitations agricoles* (Farm sustainability indicators)
LCA	life cycle assessment
MASC	multi-attribute assessment of cropping systems
MESMIS	*Marco para la evaluación de sistemas de manejo de recursos naturales incorporando indicadores de sustentabilidad* (Framework for the evaluation of natural resource management systems using sustainability indicators)
MOTIFS	monitoring tool for integrated farm sustainability
PCA	principal component analysis
SAFA	sustainability assessment of food and agriculture systems
SAFE	sustainability assessment of farming and the environment
TAPE	tool for agroecology performance evaluation

1 Introduction

This report was developed under the framework of the project FARMTOOLS ""Design of Farm Business Optimization Tools in the Context of Economic and Environmental Crises" (project number 351488), funded by the Food and Agriculture Organization of the United Nations (FAO) and implemented by the Universidad Politécnica de Madrid.

The objective of this report is to provide a technical proposal for the development of a framework for assessing sustainability performance at farm level. The framework proposed has been conceived as an indicator-based assessment tool that includes the different dimensions of sustainability. It is intended to be sufficiently flexible to be adapted to various agricultural contexts and to different levels of availability of data and resources, and simple enough for general use. This framework will contribute to 1) supporting decision-making at the farm-level, guiding producers towards more sustainable production, and 2) providing guidance to policymakers, investors and donors in targeting policies, actions and investments that foster sustainable farm development from economic, social, and environmental perspectives.

According to the report of the Brundtland Commission, *Our common future*, published in 1987, sustainability can be defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987, p. 16). Most frequently, the system's sustainability is considered across three dimensions: economic (profitable operation), social justice (fair and equitable distribution of the wealth it generates) and environmental friendliness (compatible with the maintenance of natural ecosystems) (Gómez-Limón and Sanchez-Fernandez, 2010). In addition, a fourth dimension, governance, has gained importance and political relevance over time, becoming part of the concept of sustainable development itself (UNDP, 2014) and a key pillar of the 2030 Agenda (under the theme of Peace and partnerships).

The United Nations Sustainable Development Goals (SDGs) address a vast array of challenges which must be overcome in order to achieve global sustainable development. These goals are shared by the world's countries and constitute a plan to eradicate extreme poverty, reduce inequality and protect the planet by 2030.

Agriculture is a key sector for the achievement of many of the goals, particularly SDG 1: No poverty, SDG 2: Zero hunger, SDG 8: Decent work and economic growth, SDG 12: Responsible consumption and production, and SDG 13: Climate action. Efforts and funds earmarked for this sector and these goals should contribute to the optimization of agricultural production without compromising the socioeconomic and environmental future of farmers and nations (Goswami *et al.*, 2017). To ensure that, policy action and investments must be guided by sustainability assessments. Moreover, sustainability assessments should also contribute to on-farm decision-making. This will enable policymakers to better design and assess policies and will provide farmers with a self-assessment tool through which to analyse and address the sustainability of their operations (Goswami *et al*., 2017).

Sustainability assessment is a tool for decision-making that determines sustainability by examining multiple criteria. Its application requires understanding the local context and adapting the tool to it. In recent decades, different institutions have developed numerous approaches to sustainability assessment, which have gained broad acceptance. However, the definition of sustainability in agricultural systems and the framework for evaluating it remain unclear. Each method has its advantages and disadvantages, and there is no one-size-fits-all approach.

This report aims to provide a new framework for farm-sustainability assessment, building on existing frameworks and tools, that can be implemented in developing countries to support policy action and investment.

The report contains five chapters. This first chapter details the objectives, motivations and structure of the report. Chapter 2 begins with a brief presentation of the current landscape of sustainability assessment, discusses the different aspects of sustainability assessment and classifies the main assessment methods proposed in the literature. Chapter 3, based on an extensive literature review, presents a brief analysis of a selection of methods, categorized according to the classification provided in Chapter 2. Each method is described and discussed, with emphasis on the practical implications, the advantages and the disadvantages of each. Chapter 4 describes the new framework developed for the assessment of sustainability at farm level, explaining each step of the proposed framework in detail. Chapter 5 provides conclusions and final remarks.

2 Current landscape of sustainability assessment

2.1 Characterizing sustainability assessment

Sustainability assessment is a process that supports decision-making towards sustainable development in a given context (Cruz *et al.,* 2018). It can be performed using participatory approaches, across different scales, and considering various types of data and spatial, temporal and analytical dimensions (Van Passel and Meul, 2012).

2.1.1 TYPE OF DATA

Quantitative data can either be directly quantified or obtained from existing studies, subsequently expanded upon and applied in the calculation of indicator values. Typically, quantitative data are employed for indicators within the economic sustainability dimension, including metrics like farm profitability or energy productivity (Gharsallah *et al*., 2021). Many indicators under the environmental sustainability dimension are also based on quantitative data, such as greenhouse gas emissions or pesticide use efficiency.

Qualitative data are frequently used to address different aspects within the social and governance sustainability dimension, such as indicators related to working conditions or social security, as well as cultural or governance issues. Typically, qualitative data are gathered via stakeholder engagement, employing surveys or interviews, frequently utilizing closed-ended queries to guarantee the comparability and statistical processability of the collected data. The outcomes are subsequently amalgamated to derive a value that can be categorized (for instance, “safe”, “relatively safe”, and so on), or transformed into a score that can be referenced on a scale (for instance on a range 0 to 100, with higher values indicating a higher safety levels) (Gharsallah *et al*., 2021).

2.1.2 SPATIAL SCALE

Most assessments are conducted on a group of farms within a territory or on a single farm. Other assessment dimensions are: field, country, continent and global (Soulé *et al*., 2021).

2.1.3 TEMPORAL SCALE

Sustainability assessments can be either retrospective, based on a real past situation (*ex post*) or prospective, based on a possible situation (*ex ante*) (Soulé *et al*., 2021).

2.1.4 TYPES OF PARTICIPATION

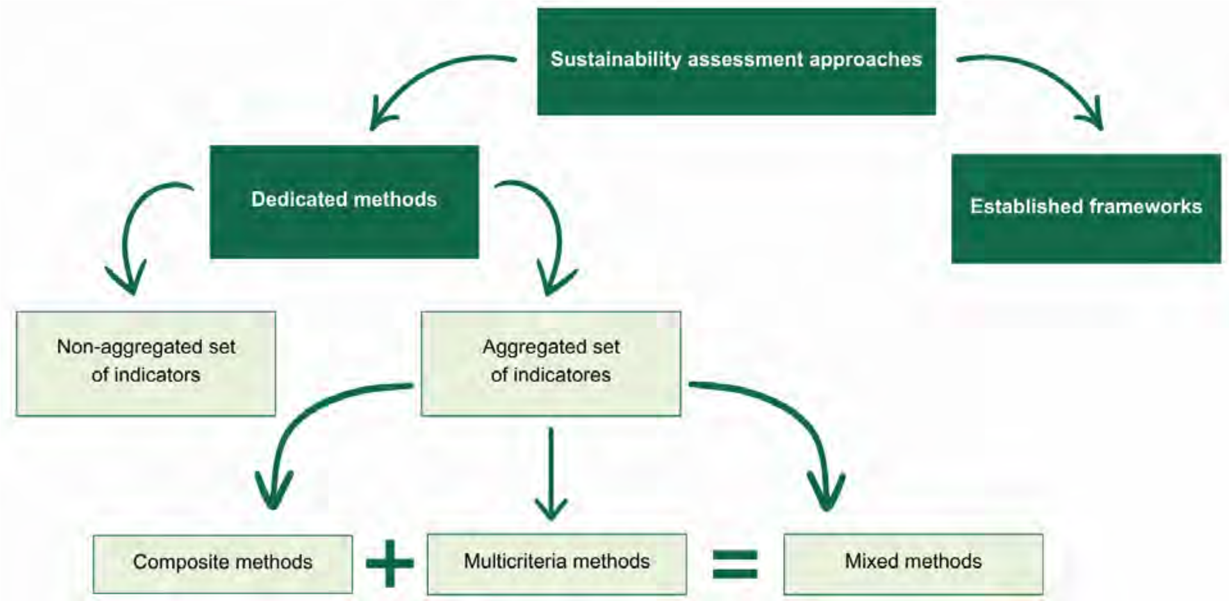
Depending on the degree of stakeholder involvement, there are two main approaches to participation in sustainability assessment:

- the **bottom-up approach**, which requires the systematic participation of stakeholders in applying the framework and in developing the indicators;
- the **top-down approach,** in which specialists or scientists establish a framework for attaining sustainability, and then decompose it into a series of indicators (Singh *et al*., 2012).

2.2 Sustainability assessment approaches

Figure 1 summarizes the main types of approaches for sustainability assessment.

Figure 1. Classification of sustainability assessment approaches



Source: Authors' own elaboration based on Soulé, E., Michonneau, P., Michel, N. and Bockstaller, C. 2021. Environmental sustainability assessment in agricultural systems: A conceptual and methodological review. *Journal of Cleaner Production*, 325. https://doi.org/10.1016/j.jclepro.2021.129291

As seen in Figure 1, sustainability assessment, approaches can be divided in two main groups:

1. Established frameworks. These methods utilize pre-defined general traits, including criteria for choosing indicators that are used to define sustainability assessment tools (a typical example of such a framework is the Life cycle assessment, or LCA) (Soulé *et al*., 2021).

2. Dedicated methods. This group of methods utilize standard sustainability evaluation techniques grounded on a collection of sustainability indicators that are more or less organized within a theoretical framework. The indicators could be aggregated at different levels and can be applied by end users (Soulé *et al*., 2021). Dedicated methods may apply a reductionist approach or a pluralist approach. Reductionist strategies assess the sustainability of an entire system using a limited number of indicators, simplifying processes, and making it easier to communicate information that is complex and intricate (Singh *et al*., 2012). The risk of this approach is that they may lose sight of the complexity of reality, as well as what is important at the local level. Pluralistic approaches, on the other hand, consider many more indicators in order to achieve a more complete understanding of the given context (Schindler *et al*., 2015).

In indicator-based sustainability assessment, indicators can be used individually, as a part of a group, or combined with a composite index. While it is preferable to use a set of indicators to represent all aspects of the system to be assessed, indicators can be analysed separately or integrated into a single or various indices of sustainability (numerical integration). For a more comprehensive presentation and to facilitate comparison, the individual indicators can be represented graphically (for example, using radar plots or bar graphs). When integrating several indicators into a composite indicator, challenges may arise as they usually do not share the same units of measurement and weighting. Several methods exist to overcome these difficulties, such as the Sustainable value approach (SVA), modelling approaches and multicriteria analysis (Van Passel and Meul, 2012).

Dedicated methods based on indicator aggregation can be grouped as follows:

Composite indicators are based on the multi-attribute utility theory, wherein a single indicator synthesizes different dimensions of sustainability. There is an issue of subjectivity in these methods (mainly related to the process of weighting the indicators), and as such they depend on normalization and on an aggregation method.

Outranking methods or multicriteria assessment methods, which can support decision-making when there are multiple competing criteria and priorities. The limitations of these methods is the difficulty in mixing qualitative and quantitative data (Lindfors, 2021).

Mixed methods structure indicators in decision trees, as a compromise solution between composite and multicriteria methods. They use linguistic rules (if–then) to integrate qualitative and quantitative information. The rules can be predefined (making the method more objective and transparent) or based on expert knowledge (Bockstaller *et al.*, 2017).

3 Review of sustainability assessment methods

This chapter presents an overview of the main methods of a farm sustainability assessment. It is based on an extensive literature review and presents the main characteristics, strengths and weaknesses of the different methods found in the literature.

3.1 Bibliometric data analysis

An initial list of methods and frameworks for sustainability assessment was developed through a literature study, based on a review of 38 agricultural sustainability assessment studies at farm-level conducted by Lampridi *et al*. (2019). From the studies included in their review, 35 were considered for this study, while 3 were excluded as they focused only on a single dimension of sustainability. Subsequently, seven additional studies were selected using the snowball approach and included in the analysis. In total, the sample included 42 studies published in peer-reviewed scientific journals addressing the sustainability assessment of agricultural systems (see Table A1 in Annex 1). The following inclusion criteria were applied in the study selection:

1. Scale: farm level.
2. Type of publication: published in a peer-reviewed scientific journal or by relevant international organizations and expert bodies.
3. Scope: including at least economic, environmental and social sustainability dimensions.
4. Date of publication: studies conducted in the last 15 years.

The reviewed studies assess sustainability across economic, social, and environmental dimensions, with a strong emphasis on farm-level and agrifood systems across diverse regions. This literature has consistently explored agricultural sustainability in both developed and developing countries, employing various methods as outlined in the following sections.

3.2 Critical perspective of sustainability assessment methods

Based on the previous bibliometric review, selected sustainability assessment methods were compared, following a structured approach. First, the model components were analysed. Methods were classified as established frameworks or dedicated methods, differentiating between non-aggregate and aggregate sets of indicators (further distinguishing between composite index, multicriteria and mixed methods of aggregation). Then each method was analysed summarizing its use and presenting its advantages and limitations. Finally, the implementation of each method was reviewed, including its application in case studies and its main features and innovations. (See Annex 2 for summary tables covering the main advantages and limitations of the methods analysed).

3.2.1 ESTABLISHED FRAMEWORKS

In assessment approaches using established frameworks, the frameworks are the basic structures underlying the sustainability conceptualization that provide the general characteristics. These general characteristics can be defined, for example, by guidelines for the selection of indicators (Soulé *et al*., 2021). The following sections describe a selection of established frameworks for sustainability assessment that have gained traction in recent years.

LIFE CYCLE ASSESSMENT

Life cycle assessment (LCA) is a widely used framework for assessing the environmental impacts of a product over its life cycle with the aim of improving processes or comparing products (Muralikrishna and Manickam, 2017).

Several authors, including Theurl *et al*. (2017), Van Cauwenbergh *et al*. (2007) and Walter and Stützel, (2009b), have used LCA to assess the ecological sustainability of different cropping systems. Theurl *et al*. (2017) examined the socioeconomic sustainability of different cropping system by comparing innovative and existing production technologies. This study applied environmental and socioeconomic indicators from FAO's Sustainability Assessment of Food and Agriculture systems (SAFA) guidelines. However, the field trials conducted in Austria and Italy concentrated primarily on environmental sustainability, addressing only a limited range of socioeconomic factors.

Walter and Stützel (2009b) used LCA to compare different land use systems against a threshold by standardizing indicators for comparison. Van Cauwenbergh *et al*. (2007) combined LCA with the Sustainability Assessment of Farming and the Environment (SAFE) framework. SAFE is an assessment tool for the identification, development and evaluation of agricultural production systems, techniques and policies. Its key advantage is its holistic approach, as it considers all important agroecological functions. However, a limitation is that it excludes certain activities, such as transport and fertilizer use.

In summary, LCA allows for comparison between systems or against a threshold, facilitating decision-making for policymakers, farmers and other stakeholders. However, it primarily targets environmental impacts, offering only a partial view of sustainability. Furthermore, LCA requires a considerable amount of data (a limitation for implementation on smallholder farms).

GUIDELINES FOR INDICATOR SELECTION

Guidelines are designed to guide policymakers in selecting or formulating the most relevant indicators in order to facilitate decision-making (Van Asselt *et al*., 2014).

The driver–pressure–state–impact–response (DPSIR) and the sustainable livelihoods (SL) frameworks are among the more well-known guiding conceptual frameworks. These two frameworks inspired Goswami *et al*. (2017) to create their own guidelines for choosing the most relevant indicators for measuring sustainability on small farms in order to support decision-making. These indicators were subsequently aggregated, creating the small farm sustainability index (SFSI). Van Asselt *et al*. (2014) also proposed a guideline for selecting indicators relevant to the decision-making process of policymakers. These two guidelines make the process of selecting indicators more transparent. Nevertheless, both Goswami *et al.* and Van Asselt *et al.* recognize that the incorrect use of their frameworks could backfire, leading to the loss of objectivity and transparency. Another constraint is the fact that the criteria used for selecting indicators may influence the outcome of the sustainability assessment. This limitation can be solved by involving stakeholders in all stages of the process. However, neither of the studies included a participatory approach. What is more, although Van Asselt *et al*. (2014) applied the framework to a case study in the Kingdom of the Netherlands, Goswami *et al*. (2017) only developed the guidelines, but did not apply them to a case study (although the guidelines were later applied by Dasgupta *et al*. [2021] to assess the sustainability of smallholder farms in India).

FRAMEWORK FOR THE EVALUATION OF NATURAL RESOURCE MANAGEMENT SYSTEMS, INCORPORATING SUSTAINABILITY INDICATORS

The framework for the evaluation of natural resource management systems using sustainability indicators (or MESMIS, the Spanish acronym for *Marco para la evaluación de sistemas de manejo de recursos naturales incorporando indicadores de sustentabilidad*) was developed in 1995 by researchers in Mexico. Its goal is to translate core sustainability concepts into practical definitions, indicators, and practices for assessing natural resource management in rural areas (Astier *et al*., 2012).

The MESMIS framework is designed to identify anthropogenic changes in a system based on sustainability standards. The method can be used in agricultural, forestry and livestock production systems (López-Ridaura *et al*., 2002). Over the last 15 years, the framework has been applied in 60 case studies and 20 undergraduate and graduate programmes, mostly in Mexico and other Latin American countries (Astier *et al*., 2012). The objective of the framework is to define the limits and possibilities of sustainability of a system, considering the economic, social, and environmental dimensions. The structure of the methodology is based on an initial characterization of the system and its critical points. Once the system has been characterized, the indicators are selected and measured for the three dimensions of sustainability. Finally, the values of the indicators are integrated using mixed techniques and multicriteria analysis. The results are summarized in conclusions and recommendations for improving the sustainability of the system (López-Ridaura *et al*., 2002).

The system has a flexible structure that can be adapted to diverse economic, technical and information-access conditions, thanks to its holistic and multidimensional approach. Nevertheless, its flexible nature can lead to neglecting relevant aspects of the system to be assessed. An advantage of MESMIS is that, due to its participatory, interdisciplinary and multi-institutional approach, it can be applied in very diverse agricultural systems in a wide range of socioecological contexts. However, if the system to be assessed is highly complex, the process of applying the framework will be long and costly (López-Ridaura *et al*., 2002).

MONITORING TOOL FOR INTEGRATED FARM SUSTAINABILITY

The monitoring tool for integrated farm sustainability (MOTIFS) is a visual monitoring tool used to aggregate indicators of various themes, creating benchmarks for the rescaling of indicator values (Lampridi *et al*., 2019). The difficulties in putting the theoretical concept of sustainability into practical terms motivated Meul *et al*. (2008) to develop MOTIFS in order to establish a visual interpretation of farm sustainability (covering social, economic and ecological dimensions) using a group of relevant indicators. The tool was tested and validated on a dairy farm in Belgium. The participation of stakeholders and the simplicity of the tool make it easy to apply. However, the tool has some weaknesses since the indicators are selected according to the availability of data rather than their scientific relevance.

After the work by Meul *et al*. (2008), Van Passel and Meul (2012) combined MOTIFS with the SVA method to perform multilevel and multi-user assessments. The combination of methodologies offered more advantages than using just one of them for all end-users at all levels. Taken together, the SVA method and the MOTIFS indicator tool both considered the same sustainability aspects, the same system boundaries, and similar data. SVA provided the sustainability assessment at the sector level to support policymakers, while MOTIFS provided sustainability guidelines for farmers. The study included a case study in Belgium, where the authors assessed and compared crop and dairy farms in order to guide farmers in implementing actions towards sustainability.

As demonstrated by Van Passel and Meul, combined approaches do not require significantly more time and data and can generate transformational knowledge. On the one hand, the visual integration and representation of MOTIFS met farmers' requirements, while policymakers preferred numerical assessment tools such as SVA.

RESPONSE-INDUCING SUSTAINABILITY EVALUATION

The response-inducing sustainability evaluation (RISE) is an interview-based method for holistic assessment of the sustainability of farming operations. The evaluation is based on ten indicators that reflect environmental, economic and social aspects (de Olde *et al*., 2016).

RISE was adopted by de Olde *et al*. (2016) to identify sustainability challenges for the development of food production systems (conventional and organic). The assessment of each subtheme (specific sustainability challenges) is based on the aggregation of various indicators. Specifically, de Olde *et al*. (2016) assessed the sustainability performance of vegetable, dairy, pig and poultry farms in Denmark. The model allowed for the comparison of farms with different species and ages of animals.

The main strength of the RISE tool is its flexibility with regard to data – data from other tools can be used, qualitative data and quantitative farm data can be integrated, and regional and master data covering a wide variety of themes can be used. As such, RISE can be applied to a wide range of themes and subthemes. The tool's limitations are the subjectivity of the practitioners who collect qualitative data and the need to find appropriate reference values.

FARM SUSTAINABILITY INDICATORS

The farm sustainability indicators method (known as IDEA, the French acronym) was created by Zahm *et al*. (2008). IDEA seeks to apply the concept of sustainability in practical terms. It was designed as a self-assessment framework for farmers and provides operational content for assessing agricultural sustainability. The stages of the model implementation include identifying clear objectives, developing indicators to measure achievements, determining the method of calculation (threshold and standards), and testing the method. The model was validated by applying it to 65 case studies representing three different crop regions.

The model was adopted by Biret *et al*. (2019) to assess and compare the sustainability of various types of rubber tree family farms in Thailand, targeting different farm organizations. To make the comparison more visible, the authors used radar plot diagrams to present the strengths and weaknesses of the different types of family farms. For the study, 25 rubber farmers were grouped according to two criteria: labour and geographical location (district).

The IDEA method focuses on the farm level and considers the three general dimensions of sustainability (economic, social, and environmental). It is useful for analysing sustainability differences across agricultural systems. Critics point the fact that IDEA was developed for the European context and may not be effective for use in tropical countries. Accordingly, the method must be adapted to the local context and to the specific agricultural system (Zahm *et al.,* 2008)

SUSTAINABILITY ASSESSMENT OF FOOD AND AGRICULTURE SYSTEMS

The sustainability assessment of food and agriculture systems (SAFA) framework provides a protocol for assessing sustainability. The framework covers four dimensions of sustainability (economic, social, environmental, and good governance), which are further developed into 21 themes that define universal sustainability goals, and 58 that define objectives that are specific to food and agricultural supply chains (FAO, 2014). For each subtheme, a list of default indicators is provided with five-point rating scale, generally the best and the worst scale is defined, and the three middle ones are determined by the user depending on the context. SAFA was built by FAO to provide a methodology for assessing sustainability following defined reference points (themes, subthemes and default indicators). The objectives of SAFA are to encourage continuous improvement, to characterize the components of sustainability in a system and to assess the system's weaknesses and strengths.

To date, several studies have employed the SAFA framework. Heredia-R. *et al*. (2020) applied the framework in Ecuador, where they assessed and compared the sustainability of food systems in different rural populations (Kichwa, Shuar and mestizos). As a novelty, they combined the SAFA method with indicators related to the psychological dimension.

The SAFA framework includes the creation of a report. This is acknowledged as a unique benefit of the framework since it provides a visual representation of performance across dimensions and themes. Another novel aspect of the framework is that it includes a fourth dimension – good governance. Finally, another advantage is the framework's ability to be adapted to different agricultural and food systems. Perhaps the most serious disadvantage is that SAFA is better suited to large operations rather than small-scale operations, such as family farms, for which there exist scientific and economic limitations to its application.

TOOL FOR AGROECOLOGY PERFORMANCE EVALUATION

The tool for agroecology performance evaluation (TAPE) is an instrument for evaluating across multiple dimensions the performance of agroecology with regard to its contribution to the sustainability transition of agriculture and food systems (FAO, 2019).

Like SAFA, TAPE was created by FAO, in 2019. TAPE builds on the strengths of other methods – SAFA, RISE and MESMIS, among others. TAPE assesses agroecological systems in five dimensions of sustainability (environmental, social and cultural, economic, governance, and health and nutrition [the latter being a new dimension]) in different scales, locations and time frames, to support policymakers in specific contexts. The tool includes a characterization of the system and its description based on the ten elements of agroecology proposed by FAO. Data are obtained through a survey at the farm level and the assessment is conducted on the basis of a short list of indicators related to the SDGs.

Although the model is still in its testing phase, a number of studies have begun to examine its application. Lucantoni *et al*. (2018) applied TAPE on 3 farms in western Cuba, while Tittonell *et al*. (2010) assessed 25 farms in Patagonia, Argentina, grouping them into 3 clusters (mountain, steppe and foothills typologies).

An argument in favour of the model is its adaptability to different contexts (production systems, communities, territories, agroecological zones, etc.). Furthermore, the model includes qualitative (surveys) and quantitative data (databases) from various sources and includes disaggregation of data by age, gender and diversity of producers. However, the model includes just ten core indicators. The additional indicators are not described in depth and are more difficult to apply and assess.

3.2.2 DEDICATED METHODS

The dedicated methods include sustainability assessment approaches developed for specific contexts that are based on a list of sustainability indicators, structured within a conceptual framework. The dedicated methods are divided into methods with aggregated indicators (composite indicators) and methods with non-aggregated indicators (Soulé *et al.*, 2021).

METHODS WITH NON-AGGREGATED INDICATORS

This category of methods includes indicator sets used to assess agricultural sustainability without numerical integration (Van Passel and Meul, 2012).

A considerable amount of literature has been published to assess sustainability by employing non-aggregated sets of indicators. Examples of this kind of approach are the studies developed by Snapp *et al.* (2018) and Yegbemey *et al*. (2014). Snapp *et al*. (2018) applied this method to assess the value of maize-legume diversification and integrated soil fertility management in Malawi, using radar charts to visualize sustainability trade-offs. Yegbemey *et al*. (2014) proposed a participatory indicator-based approach for sub-Saharan Africa that allows stakeholders to select site-specific indicators, offering flexibility, but is limited by its subjectivity and inability to compare across different socioeconomic contexts.

Santiago-Brown *et al*. (2015) developed a hierarchical indicator set for viticulture to improve sustainability communication and agricultural funding allocation. While flexible and adaptable to other cropping systems, it is also limited by subjectivity in indicator selection. Recanati *et al*. (2017) introduced a framework to assess sustainability in water-limited regions, particularly in the Gaza Strip. Although flexible and regionally relevant, the approach is limited by its narrow focus on agricultural activities and its simplistic application at the regional level.

Another approach, the sustainable agrifood evaluation methodology, proposed by Peano *et al*. (2015), uses qualitative indicators to assess the sustainability of small-scale agrifood systems. Applied to ten systems in Italy, the approach includes ex post and *ex ante* assessments and involves experts and stakeholders. While adaptable to other systems, it has been criticized for focusing on qualitative indicators, excluding important quantitative measures, and selecting indicators based on data availability rather than scientific criteria.

The studies presented thus far provide evidence that non-aggregated indicators are not highly useful in analysing complex systems or when many indicators are necessary. Indicator aggregation helps reduce information overload and communicate results more effectively, though it risks losing important details and leading to misinterpretation (Jollands *et al*., 2003).

COMPOSITE METHODS

Composite indicators are mathematical combinations (or aggregations) of a set of indicators used to synthesize complex or multidimensional issues (Saisana, 2004).

Rodrigues *et al*. (2010) developed a composite index to evaluate the environmental impact of rural activities in Brazil, focusing on farms of varying sizes and activities. This approach allowed for stakeholder participation and visual representation of results but was criticized for its subjectivity and reliance on *ex ante* assessment, which is better suited for decision-making or innovation.

Dong *et al*. (2016), who created a composite sustainability scoring system for soybean farms in the United States of America, involving stakeholders throughout the process. Their method allowed farmers to assess and improve practices by comparing farms and simulating alternative scenarios to enhance sustainability.

Sharma and Shardendu (2011) designed an agricultural sustainability index to assess farm performance in India over 60 years. Although useful, this index was limited by equal weighting of variables and reliance on farmers' memory for older data. Also in India, Sajjad and Nasreen (2016) introduced the sustainable livelihood security index (SLSI) to measure sustainability in terms of ecological, economic, and social dimensions, which helped identify priority actions for policymakers.

Gómez-Limón and Sanchez-Fernandez (2010) used a combination of Principal Component Analysis (PCA) and Data Envelopment Analysis (DEA) to assess the sustainability of farms in Spain. This approach reduced data complexity while allowing for efficient sustainability assessments, though the correlation between indices raised concerns about indicator adequacy (Jollife and Cadima, 2016).

Other tools, like 4Agro by Gaviglio *et al*. (2017), aimed to address methodological challenges in sustainability assessments, such as data availability and system heterogeneity. Applied in Italian farms, 4Agro grouped farms by size, product, and geography, but faced limitations due to its reliance on primary data and farmers' participation.

Finally, Dos Santos and Ahmad (2020), developed a methodology using cluster and factorial analysis to assess agricultural sustainability across 28 EU countries, focusing on social, environmental, economic, and institutional dimensions. While useful, this method was limited by the constraints of available data, particularly environmental data.

Despite the advantages of composite indicators – such as the ability to aggregate multiple indicators and adapt to specific objectives (Bockstaller *et al.*, 2017) – they have notable limitations, including subjectivity, challenges in normalization, weighting, and aggregation (Gómez-Limón and Sanchez-Fernandez, 2010). Additionally, critics argue that many composite indicators lack clear implementation guidelines, leading to potential misinterpretation of results, especially when difficult-to-measure dimensions are ignored (Kararach *et al*., 2018). More clarity is also needed in selecting indicators with stakeholder participation (Barclay *et al*., 2018). Nonetheless, composite indicators remain a valuable tool for sustainability assessments due to their flexibility, ease of communication, and ability to engage the public and promote accountability.

MULTICRITERIA ASSESSMENT METHODS

Multicriteria assessment (MCA) methods are decision-making tools used to evaluate problems and compare alternatives on the basis of multiple criteria and competing dimensions. Multicriteria methods may provide a powerful framework for policy analysis in the context of sustainability problems, since they can be interdisciplinary or multidisciplinary (accounting for multiple dimensions), participatory (open to all stakeholders), and transparent (Munda, 2008). The next sections discuss sustainability assessment applications based on multicriteria methods.

a) Data envelopment analysis

Data envelopment analysis (DEA) is an important multicriteria assessment method for sustainability assessment. Using mathematical programming, the model evaluates the performance of individual decision-makers against best practice frontiers, which are determined according to observed actions of other decision-makers (Reig-Martínez *et al.*, 2011).

Gomes *et al*. (2009) used DEA to assess the sustainability of rice, maize, and coffee production in Brazil between 1986 and 2002, identifying factors influencing sustainability over time. The main limitation of the study is the fact that it did not account for chemical use in its evaluation.

Reig-Martínez *et al.* (2011) combined DEA with multicriteria decision-making (MCDM) to develop composite indicators for assessing farm sustainability across social, economic, and environmental dimensions, validated on rainfed crop farms in Spain.

Dong *et al*. (2015) applied DEA to evaluate agricultural sustainability in cranberry farms in Wisconsin, using principal component analysis to refine key variables and generate a composite sustainability indicator.

DEA's main strengths are its ability to handle multiple inputs and outputs and its non-parametric approach, making it flexible in data use. However, the model is sensitive to input/output selection, and its inflexibility in weight allocation is a noted limitation (Zbranek, 2013).

b) Other multicriteria methods

In addition to DEA, several other multicriteria methods have been applied to evaluate agricultural sustainability across different contexts.

Peano *et al*. (2014) used the multicriteria methodology to assess agricultural projects *ex post* and *ex ante* regarding slow-food principles (good, clean and fair) converted into criteria. The projects assessed were in Italy and Austria and the data (both quantitative and qualitative) were collected from farmers and experts.

Criteria weighting could be set equally or adjusted based on stakeholder priorities. While the participatory approach and expert involvement were strengths, the method lacked a holistic approach and had limited quantitative indicators.

Siciliano (2009) developed the social multicriteria evaluation framework to analyse the impact of the Common Agricultural Policy on farm management in Tuscany (Italy), focusing on economic, social, and environmental sustainability. The framework's strength lies in its ability to analyse problems from multiple perspectives without requiring all criteria to be converted into a single value. However, its case-specific nature limits its adaptability to different contexts.

Egea and Pérez y Pérez (2016) used the analytic network process (ANP) to study the sustainability of olive grove systems in Spain, identifying relationships between components and using pairwise comparisons to determine weights.

Lastly, the main advantage of multicriteria assessment methods is that they do not require normalization of the scores. A serious weakness of these methods, however, is that each weighting criteria has a significant effect on the final score, and since the weighting criteria are determined by the decision-maker in each case, there is a certain degree of subjectivity, which can impact the accuracy of the results (Sabaei *et al*., 2015).

MIXED MODELS

Mixed models are a compromise between composite and multicriteria methods. They are structured as decision trees in which the branches are defined according to linguistic rules (if–then) and they integrate qualitative and quantitative information. The rules can be predefined (a more objective method) or based on expert knowledge (Bockstaller *et al.*, 2017). The next sections present a review of a selection of mixed methods for sustainability assessment.

a) Multi-attribute assessment of cropping systems

The multi-attribute assessment of cropping systems (MASC) is a hierarchical decision-making support model, designed to evaluate alternative scenarios in cropping systems. Developed by Sadok *et al*. (2009), the model simplifies complex decision-making by breaking problems into smaller, more manageable components, making it especially useful for *ex ante* assessments. It incorporates 32 criteria across three sustainability dimensions (economic, social, and environmental) and allows for the inclusion of qualitative data, making it applicable at different scales, such as farm or cropping-system levels, using if–then decision rules (Arh and Blazic, 2007).

Sadok *et al*. (2009) tested the model on four cropping systems in northern France, with the input of 25 experts. More recently, Chopin *et al.* (2016) adapted the MASC model to assess *ex ante* the sustainability of banana farming systems, and Colomb *et al*. (2013) assessed the strong and weak points of organic cropping systems in a regional context.

Overall, the MASC model has clear advantages, as it includes the use of a cropping-system scale, making it possible to assess different cropping activities within a farm system. What's more, it includes more sustainability criteria than other methodologies, and it is easy for non-experts to handle thanks to the limited number of precision rules that make it possible to trace the effects of changes in one criterion for the overall assessment. The other strength of the model is its ability to handle qualitative information. However, the model carries some drawbacks, with regard to its *ex ante* perspective and if–then decision rules, as the *ex ante* assessment implies significant uncertainty. Finally, the quality rules applied in this kind of decision tree make it hard to see clearly the intrinsic sources of differences between the assessed cropping systems (Sadok et al., 2009).

b) DEXi Pest Management

DEXi Pest Management (DEXiPM), a model for multi-attribute decision-making for pest management, is based on the MASC model. It is an *ex ante* methodology consisting of 75 basic and 86 aggregated indicators to assess innovative systems (Lampridi *et al*., 2019).

Developed by Pelzer *et al.* (2012), DEXiPM addresses the limitations of the MCDA method by allowing qualitative indicators to be organized into a decision tree. It enables assessment of both current and innovative cropping systems, with fixed aggregation rules based on scientific expertise and some flexibility depending on the context. Pelzer *et al*. (2012) tested the model assessing and comparing current and innovative cropping systems of winter crops and maize in France (covering social, economic, and environmental dimensions).

Vasileiadis *et al*. (2013) applied DEXiPM to assess maize-based cropping systems in Europe and integrate social sustainability into the evaluation of innovative integrated pest-management systems. They demonstrated that DEXiPM effectively identifies impactful *ex ante* indicators, reducing the need for extensive field testing, though challenges arise at the farm scale due to additional attribute requirements. Angevin *et al.* (2017) further refined DEXiPM by introducing a common sustainability assessment framework for diverse crop production systems, organized into flexible modules with stakeholder-driven weighting. Their study evaluated pome fruit, field vegetable, and grape systems in Europe, showing how stakeholder participation improved decision-making.

In summary, the DEXiPM offers a flexible, goal-oriented approach that can assess cropping systems across various scales (cropping system, landscape, farm, and society). However, its complexity, high number of indicators, and potential lack of sensitivity due to compensation between indicators are noted limitations (Pelzer *et al*., 2012).

In summary, DEXiPM (Pelzer *et al.,* 2012).

c) Fuzzy models

Fuzzy logic can translate complex natural language statements into mathematical models where traditional mathematics fall short (Sami *et al*., 2013). In fuzzy logic, the truth value can be a real number between 0 and 1 (in contrast to Boolean logic, where truth values can only be integers: 0 or 1). By translating statements into real numbers between 0 and 1, the truth becomes partial, also known as a fuzzy truth (Novák *et al*., 1999). There are several examples in literature where sustainability was assessed through fuzzy models; these include Sami *et al*. (2013), Allahyari *et al*. (2016) and Bockstaller *et al*. (2017).

Sami *et al*. (2013) applied fuzzy inference models to assess agricultural sustainability in the Islamic Republic of Iran, considering environmental, social, and economic dimensions. While the model's simplicity and use of uncertain data were strengths, it lacked precision for monitoring and required new indexes for modifications. Allahyari *et al*. (2016) developed a sustainability assessment tool for paddy fields in Iran by ranking indicators based on expert opinions, providing a solid methodology for detailed analysis in developing countries. Bockstaller *et al.* (2017) introduced a method based on decision trees (*Construction transparente d'arbre de décision*, also known as CONTRA – its French acronym) using fuzzy sets, tested in two case studies in France to assess grassland management and viticulture/dairy production.

Research suggests that fuzzy models enable *ex ante* impact assessments and strategic implementation on farms without extensive field measurements. Their transparency and simplicity make them suitable for multicriteria assessments, reducing information loss during aggregation (Sami *et al.*, 2013).

d) Analytical hierarchy process

The analytical hierarchy process (AHP), developed by Saaty in 1980, is a method that helps organize and analyse complex decision-making problems by breaking them into a hierarchical structure of subtopics (Siekelova *et al*., 2021).

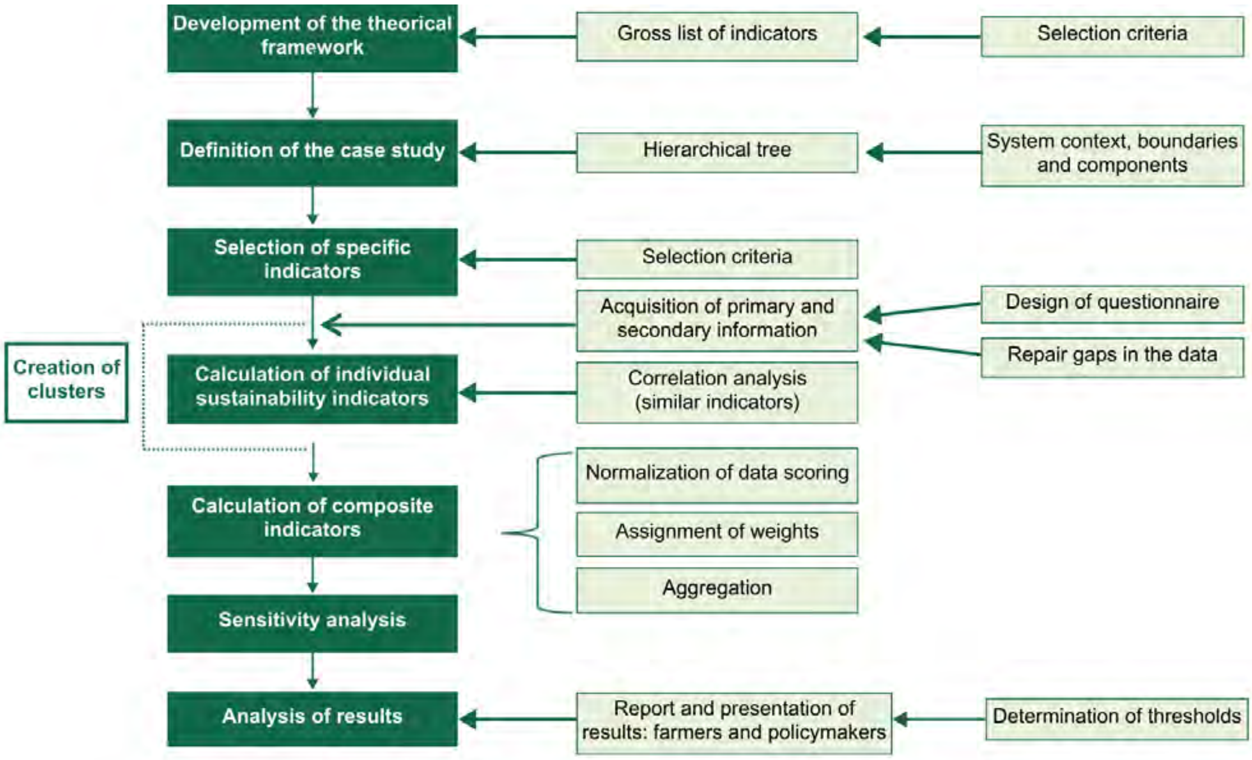
Tzouramani *et al*. (2020) applied AHP in Greece to assess farm-level sustainability. The study analysed 124 farms across four regions, focusing on permanent crops, olive trees, arable crops, and livestock, using data from agricultural databases and expert interviews.

A key advantage of AHP is its accessibility, as it doesn't require specialized knowledge to apply. It can also handle both linguistic and numerical criteria without additional modifications, making it versatile across various applications. However, AHP can be time-consuming when dealing with many criteria and alternatives, and adding or removing alternatives can disrupt previous rankings due to inconsistencies in pairwise comparisons (Siekelova *et al*., 2021).

4 A new framework for farm level sustainability assessment

This chapter describes FARMTOOLS, an indicator-based methodological framework for farm sustainability assessment. The implementation steps of the proposed framework are described in Figure 2.

Figure 2. FARMTOOLS implementation steps



Source: Author's own elaboration based on Gómez-Limón, J. A. and Sanchez-Fernandez, G. 2010. Empirical evaluation of agricultural sustainability using composite indicators. *Ecological Economics*, 69(5): 1062–1075. https://doi.org/10.1016/j.ecolecon.2009.11.027

4.1 Methodological framework

FARMTOOLS is derived from an extensive literature review and is based primarily on the IDEA, RISE, SAFA, TAPE and MOTIFS methods. These methods have been selected based on the methodological review in Chapter 3, as these methods best fit the purpose of the FARMTOOLS framework.

FARMTOOLS is adaptable to diverse farming systems, from large-scale operations in developed regions to smallholder farmers in least developed countries, when supported by cooperatives or government programmes. Policymakers can leverage FARMTOOLS to gain deeper insights into sustainability gaps and develop targeted interventions or funding strategies that drive meaningful improvements in agricultural practices.

The framework includes the possibility of creating clusters according to the socioeconomic characteristics of agricultural systems or to group farms according to their score in the different dimensions of sustainability. The creation of farm groups makes it possible to create priority action maps or classifications of farm types in need of priority action. Stakeholders can be involved in all stages of the implementation of FARMTOOLS, from the definition of the case study to the collection of data (qualitative and quantitative), to the construction of the composite indicators.

A novel aspect of FARMTOOLS is that it is based on five sustainability dimensions (economic, social, environmental, nutrition and health, and governance), which include various subthemes and their corresponding indicators, providing a broader and more comprehensive view of sustainability. The indicators are extracted from the IDEA, RISE, SAFA, TAPE and MOTIFS methods. Their linkage to the subthemes makes it easier to link them to the components of the agricultural system to be assessed.

4.2 Gross list of indicators

The default indicators included in FARMTOOLS, under each dimension of sustainability, provide standardized metrics for assessing the sustainability of agricultural systems. The economic dimension measures the long-term economic development of the agricultural system. The social dimension includes the satisfaction of basic human needs, human rights and ensuring good livelihoods. The environmental dimension refers to maintaining ecosystems and minimizing negative impacts on ecosystems. The health and nutrition dimension refers to the ability of food systems to provide sufficient energy and essential nutrients to maintain the health of the population, without compromising future generations. Finally, the governance dimension is defined as the efficiency, quality and good orientation of government intervention.

The selection of the gross list of indicators is drawn from the literature (IDEA, RISE, TAPE SAFA and MOTIFS) and from expert consultation conducted online in January-February 2022 (for aspects for which little or no scientific information is available). Specifically, the selection is based on the following criteria (Meul *et al*., 2008):

- a well-defined relationship between an indicator and the phenomenon to monitor (causality);
- a change in the situation is reflected in a value change of the indicator (sensitivity);
- the indicator value depends minimally on external factors (solidness);
- benchmarks are available to evaluate the indicator value (use of benchmarks); and
- indicator values and scores are easily interpretable (comprehensibility).

For example, indicators selected for the economic dimension include the capacity of farms to generate income (MOTIFS) and independence from agricultural subsidies (IDEA and SAFE). Social dimension indicators include sustainable employment (IDEA and SAFE) and social associations and implications (IDEA). In the environmental dimension, selected indicators include animal diversity (IDEA and MOTIFS) and crop rotation (IDEA, RISE and MOTIFS). Nutrition and health dimension indicators include dietary diversity (TAPE). Finally, in the governance dimension, the indicators include participation in decision-making (SAFA) and decision-making transparency (SAFA). (See Annex 3 for a list of the proposed indicators.)

4.3 Definition of the case study

FARMTOOLS is designed to be adapted to the agricultural system under study. In close collaboration with stakeholders, practitioners should determine the boundaries and scale of the farming system to be assessed, as well the geographic, environmental, and socioeconomic context (Van Asselt *et al*., 2014).

Hierarchical trees can be used to define the case study, and MCDM is often used to break down the agricultural system into simpler components that can be described using indicators (Chopin *et al*., 2016). The components are listed and associated with the five dimensions of sustainability (economic, social, environmental, nutrition and health, and governance). Within each component, one or more indicators are defined and measured (Yegbemey *et al*., 2014).

4.4 Selection of specific indicators

Based on the case study definition, specific indicators are selected from the gross list of indicators (Annex 3). Stakeholders should be consulted regarding the proposed indicators to determine whether they contain all relevant indicators for assessing the sustainability of the case study at farm level. Each dimension and subtopic must be defined by at least one indicator; it is not possible to leave part of the sustainability of the system unassessed. Therefore, the specific indicators selected should meet the following criteria (Van Asselt *et al*., 2014):

- relevant to the case study; and
- related directly to dimensions and subtopics.

Not all the indicators from the gross list of indicators are used in every assessment; the selection will depend on each case. However, as mentioned above, all five dimensions of sustainability must be associated with at least one indicator.

4.5 Acquisition of the data

The framework is designed to use a variety of sources (literature, questionnaires, etc.) and types of data (quantitative and qualitative), but the user should be cautious and assess the quality and availability of the data for the case study. Based on the analysis of the data, the user should choose the most appropriate method to collect data for the study of the agricultural system. It is highly recommended that stakeholders be involved in the assessment and data collection.

Data are needed in two steps of the methodological framework. First, the practitioner needs data to characterize the system to be analysed. Secondary sources, such as literature and databases, can be used to analyse the geographic, environmental and socioeconomic context of the farming system. (When determining the boundaries and scale of the farm system, it is recommended that the user work together with stakeholders, who are more involved in the reality of the case to be studied. Detailed data are not needed for this purpose.)

Second, data are needed to assess the selected indicators. When secondary data are not available, the practitioner can obtain the necessary information by collecting data directly on the farm through a questionnaire or a survey. In this case, more detailed data are required in order to obtain accurate results after calculating the indicators. However, questionnaires often yield incomplete and inconsistent answers. In these cases, the user must decide whether to accept the questionnaires with missing data for analysis. If incomplete questionnaires are accepted, the data gaps must be repaired.

Depending on the availability of the necessary data, a process of refinement of the selected indicators is often carried out.

4.6 Calculation of the individual sustainability indicators

It is very important that the indicators be calculated based on their correct use and on the availability of quality data. For each indicator, it is necessary to establish a reference value to set the desired level to be achieved. This allows the data to be normalized at a later stage. Reference values are determined by legislation and scientific studies. However, they often need to be adapted to the context of the case study. In addition, when reference values are not available, experts and stakeholders can help contextualize and establish the reference values (Gharsallah *et al.*, 2021).

Once all the indicators have been calculated, a correlation analysis is carried out to check that there is no significant correlation between the selected indicators. This step will prevent double-counting problems in the aggregation stage (Gómez-Limón and Sanchez-Fernandez, 2010).

4.7 Creation of clusters

To simplify the process, the number of cases can be reduced by creating groups of farming systems with a similar typology. Clustering farms can help to simplify the interpretation of results and better target policies. The creation of clusters is based on the identification of groups of farms that are statistically similar. The use of Principal components analysis and PSEUDO F statistics is recommended to determine the optimal number of clusters (Gómez-Limón and Sánchez-Fernández, 2010).

Other types of clustering can be carried out to determine which sets of conditions and management practices contribute most to farm sustainability. Another application can be to create role models of farm systems that have obtained the best sustainability scores. Clusters can be determined by using the procedure mentioned above to group farms according to the degree of similarity of their scores on the five dimensions of sustainability.

4.8 Calculation of the composite indicators

Composite indicators are calculated through the following steps:

DATA NORMALIZATION

As the selected indicators may use quantitative and qualitative data with different types of measurements, the indicator values must be converted into dimensionless and normalized variables so that they can be compared. Although there are many different approaches, in this framework it is suggested that the "min–max" normalization method be used. Once the normalization method is applied, the indicator values will be in a dimensionless range (0, 1) – 0 being the worst possible indicator value (least sustainable) and 1 being the best (most sustainable) (Gómez-Limón and Sánchez-Fernández, 2010). Other approaches, such as RISE, use a range of 0 (worst case) to 100 (best case), while others, such as SAFA, use percentage scores in which scores of 80 to 100 percent represent the best options while scores of 0 to 20 percent represent the worst options. (Four other categories fall between these two best and worst categories.)

The scores of the individual indicators can be used directly or aggregated to evaluate the sustainability of a subtopic or a sustainability dimension of the farming system.

ASSIGNMENT OF WEIGHTS

Weighting consists of giving a specific weight to each indicator or dimension (in case of aggregation to an overall score). There are two approaches to weighting: positive or endogenous techniques, and normative or exogenous techniques. The first approach uses statistical procedures to obtain the weights of the indicators, while the second approach applies value judgements of experts or stakeholders to determine the weighting.

In addition, the user can either give each indicator the same weight or use an exogenous technique to assign the weights. There is a wide variety of exogenous weighting techniques, including the analytic hierarchy process, direct assignment of points, swing weighting, trade-off weighting, and the simple multi-attribute rating technique. In all cases, it is advisable to involve stakeholders in the process in order to maintain the model's participatory approach (Gómez-Limón and Sánchez-Fernández, 2010). Applied to the proposed framework, it is suggested to use the direct assignment of points (also referred to as the direct scoring method), where stakeholders express their preferences by giving a score to each indicator. For each level of aggregation the sum of weights must be 100 percent (Chopin *et al.*, 2016).

AGGREGATION

This last step refers to the combination (often summing) of the weighted indicators to obtain a sustainability score that integrates the values of a set of indicators. In this case, the higher the score, the better the sustainability performance. The main methods used for the aggregation are additive methods, geometric aggregation and non-compensatory multicriteria analysis. Additive methods are very simple, as they sum the value of the indicators, which implies a full compensation of the indicators (underperforming indicators can be compensated by better ones). Geometric aggregation is less simple, as it uses multiplicative functions such as the weighted geometric mean and weighted product method (which are not fully compensatory) (Gómez-Limón and Sánchez-Fernández, 2010). Finally, non-compensatory multicriteria analysis is based on the preference of model users and focuses on the comparison of systems (Munda and Nardo, 2005).

The proposed framework advises using simple aggregation based on the sum of the values. In this case, the compensation is accepted but it is recommended that the sustainability assessment scores for each sustainability dimension and subtopic be analysed, as an overall sustainability score provides limited information. To compare the sustainability of several farming systems, it is recommended that the lowest value of the five dimensions of sustainability be used (Zahm *et al.*, 2008).

4.9 Sensitivity analysis

This step verifies the reliability of the composite indicator. Sensitivity analysis is closely related to uncertainty analysis and is often confused with it. The development of a composite indicator is linked to several uncertainties related to the outputs (scores of the composite indicator) and the inputs (methodological decisions, weights, etc.) (Saltelli *et al.*, 2020). Sensitivity analysis can help to identify which of the input uncertainties are driving the output uncertainty, and by how much. This analysis makes it possible to find which input uncertainties are significant (and, thus, may deserve more attention), and which are not important.

To carry out a sensitivity analysis, it is necessary to define which assumptions to treat as uncertain, the alternative values (or distributions) assigned to each uncertain assumption, the output(s) to be targeted (overall/individual scores), the method and the number of replications to run (Saisana *et al.*, 2005).

Simple sensitivity analyses are performed by switching one assumption at a time (varying weights, removing indicators, changing the aggregation rule, etc.). However, to properly understand the impact of uncertainties, uncertain parameters and assumptions must vary simultaneously.

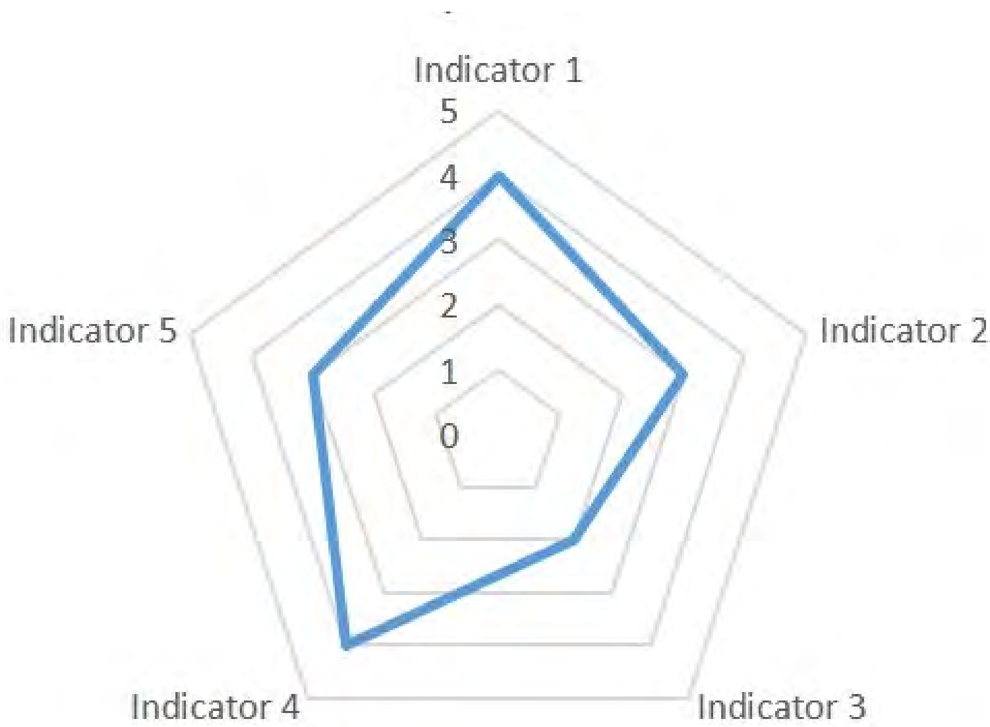
The main technique used for sensitivity analysis is the Monte Carlo method. Monte Carlo simulation produces distributions of possible outcome values by recalculating the composite indicator many times, each time randomly varying the uncertain variables (modelling assumptions, alternative data sets, etc.) (Bonate, 2001). Depending upon the number of uncertainties and the ranges specified for them, a Monte Carlo simulation could involve thousands of recalculations before it is complete. This is the technique recommended for carrying out the sensitivity analysis of the proposed composite indicator for farm sustainability assessment.

4.10 Analysis of the results

The analysis of the results is the last step of the proposed methodological framework for farm sustainability assessment. Three aspects are key when analysing and presenting the results: visualization, determination of thresholds and reporting.

Visualization. For a complex issue such as sustainability, good communication of the results obtained in the assessment is crucial. Creating polygons/radar graphs is a good way to visualize the results of the sustainability assessment. Polygons/radar graphs (Figure 3) show each dimension or subtopic with a black line that connects each to its performance.

Figure 3. Sample polygon: level of performance



Source: Author's own elaboration.

Determination of thresholds. Thresholds are usually defined by minimum or maximum values or a range of acceptable values for each indicator. As with reference values, the threshold values can be taken from scientific literature and legislation. Thresholds should be adapted to the context of the study and discussed with experts and stakeholders (Gharsallah *et al*., 2021).

Another technique for determining thresholds is the reference group of comparable farms, where 10 percent of the best-performing farms score 100 and 10 percent of the worst-performing farms score 0 (Meul *et al*., 2008).

Final report. The final report should summarize the assessment, including the definition of the case study (context, boundaries and components of the system), data sources, reference and threshold values, composite indicator results, and the visualization of sustainability scores using polygons. The report should also identify areas for improvement. Furthermore, it should describe the strengths and weaknesses of the system (the farms or groups of farms assessed) and can also identify relations between dimensions or subtopics.

5 Conclusions

This report presents the technical proposal for FARMTOOLS, a framework for assessing sustainability performance at farm level. It has been developed under the framework of the project FARMTOOLS "Design of Farm Business Optimization Tools in the Context of Economic and Environmental Crises" (project number 351488), funded by the Food and Agriculture Organization of the United Nations (FAO) and implemented by the Universidad Politécnica de Madrid.

The technical proposal is derived from an extensive literature review. First, the most relevant studies on sustainability assessment were selected according to the scale of analysis (only farm scale), type of publication (papers published in peer-reviewed scientific journals or by relevant international organizations), scope (covering the social, economic, and environmental dimensions), and date of publication (papers published in the last 15 years). In total, 42 papers were selected and analysed in depth to obtain an overview of the foremost methods of farm sustainability assessment. Second, all identified methods were analysed and compared. Special emphasis was placed on the implementation of the methods, their application in case studies, and their main features and innovations.

The methodological review revealed that each method has its advantages and disadvantages, and that there is no one-size-fits-all approach. The development and application of sustainability assessment methods requires a thorough understanding of the problem and adaptation to local contexts.

The framework proposed in this report has been conceived as a novel indicator-based framework that includes five dimensions of sustainability (economic, social, environmental, nutrition and health, and governance). It is intended to be flexible, so as to be adaptable to various agricultural contexts and different levels of data and resource availability, and simple enough for general use. It offers the possibility of involving stakeholders in all steps of the process, from defining the case study to constructing the composite indicators. It also allows for creating clusters according to the socioeconomic characteristics of the agricultural system or grouping farms according to their scores in the different dimensions of sustainability. This means that the framework can be used to create priority action maps or to identify farm types in need of priority action.

The proposed framework can improve agricultural decision-making and ultimately promote change towards more sustainable and productive agriculture. It allows for the identification of the most vulnerable farming systems in terms of environmental, economic, social, health or governance sustainability issues. Thus, it facilitates addressing specific regions and targeting strategies especially suited for their sustainability context, aiming at the achievement of key agriculture-related SDGs (SDG 1, SDG 2, SDG 8, SDG 12 and SDG 13). The proposed framework aims to profit from and contribute to existing databases and mapping tools, such as typologies of rural microregions, and to provide FAO with a prioritization tool that can contribute to ongoing initiatives, such as the Hand-in-Hand Initiative.

The framework can be used by farmers, when supported by cooperatives or government programs, for monitoring and improving their sustainability at farm level, and by policymakers, investors and donors to support responsible and sustainable investment and to design actions to improve sustainability. It has already been applied in Ecuador to assess the sustainability performance of cocoa farms. Further details are available in the forthcoming FAO Technical Study, *"Implementation of an Indicator-Based Framework for Farm Sustainability Assessment in Ecuador."*

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Annexes

Annex 1. Sources reviewed in the bibliometric analysis

Table A1. List of reviewed studies

Study	Sustainability dimensions	Peer reviewed	Scale of analysis	Geographic application
Implementing Minkowski fuzzy screening, entropy, and aggregation methods for selecting agricultural sustainability indicators (Allahyari *et al.*, 2016)	Economic, social, and environmental	Yes	Field level	Iran (Islamic Republic of)
Assessing the sustainability of crop production systems: Toward a common framework? (Angevin *et al.*, 2017)	Economic, social, and environmental	Yes	Field level	Europe
Assessing the Sustainability of Small Farmer Natural Resource Management Systems. A Critical Analysis of the MESMIS Programme (1995–2010) (Astier *et al.*, 2012)	Economic, social, and environmental	Yes	Agrifood systems	Latin America
Assessing sustainability of different forms of farm organization: Adaptation of idea method to rubber family farms in Thailand (Biret *et al.*, 2019)	Economic, ecological, and socioterritorial	Yes	Farm level	Thailand
A tool to design fuzzy decision trees for sustainability assessment (Bockstaller *et al.*, 2017)	Economic, social, and environmental	Yes	Agricultural systems	France
Ex-ante sustainability assessment of cleaner banana production systems (Chopin *et al.* 2016)	Economic, social, and environmental	Yes	Farm level	Guadeloupe
Stockless organic farming: Strengths and weaknesses evidenced by a multicriteria sustainability assessment model (Colomb *et al.*, 2013)	Economic, social, and environmental	Yes	Farm level	France
Assessing the sustainability performance of organic farms in Denmark (de Olde *et al.*, 2016)	Economic, social, and environmental	Yes	Farm level	Denmark
Sustainability of European agricultural holdings (Dos Santos and Ahmad, 2020)	Economic, social, environmental, and institutional	Yes	Farm level	Europe
Measuring farm sustainability using data envelope analysis with principal components: The case of Wisconsin cranberry (Dong *et al.*, 2015)	Environmental and social	Yes	Farm level	Wisconsin, United States of America
Assessing sustainability and improvements in US Midwestern soybean production systems using	Economic, environmental, and community sustainability	Yes	Farm level	United States of America

Study	Sustainability dimensions	Peer reviewed	Scale of analysis	Geographic application
a PCA-DEA approach (Dong *et al.*, 2016)				
Sustainability and multifunctionality of protected designations of origin of olive oil in Spain (Egea and Pérez y Pérez, 2016)	Economic, sociocultural and environmental	Yes	Farm system	Spain
Sustainability Pathways: Evaluación de la sostenibilidad para la agricultura y la alimentación (SAFA) (FAO, 2014)	Good governance, environmental integrity, economic resilience and social well-being	No	Food and agriculture supply chains	Worldwide
TAPE Tool for Agroecology Performance Evaluation 2019- Process of development and guidelines for application. Test version (FAO, 2019)	Environment and climate change, health and nutrition, society and culture, economy and governance	No	Farm/household and community/territorial levels	Developing countries
A tool for the sustainability assessment of farms: Selection, adaptation and use of indicators for an Italian case study (Gaviglio *et al.*, 2017)	Economic, social, and environmental	Yes	Farm/local scale	South Milan Agricultural Park, Italy
Empirical evaluation of agricultural sustainability using composite indicators (Gómez-Limón and Sanchez-Fernandez, 2010)	Economic, social, and environmental	Yes	Farm level	Spain
Efficiency and sustainability assessment for a group of farmers in the Brazilian Amazon (Gomes *et al.*, 2009)	Socio-agronomic	Yes	Farm level	Brazilian Amazon
Sustainability assessment of smallholder farms in developing countries (Goswami *et al.*, 2017)	Economic, social, and ecological	Yes	Farm level	Developing countries
MOTIFS: A monitoring tool for integrated farm sustainability (Meul *et al.*, 2008)	Economic, social, and ecological	Yes	Farm level	Flanders, Belgium
A methodology for the sustainability assessment of agri-food systems: An application to the slow food presidia project (Peano *et al.*, 2014)	Economic, social, ecological, quality, and cultural	Yes	Agrifood systems	Italy and Austria
Evaluating the sustainability in complex agri-food systems: The SAEMETH framework (Peano *et al.*, 2015)	Sociocultural, agri-environmental, and economic	Yes	Small-scale agrifood systems	Italy
Assessing innovative cropping systems with DEXiPM, a qualitative multi-criteria assessment tool derived from DEXi (Pelzer *et al.*, 2012)	Economic, social, and environmental	Yes	Arable cropping systems	France

Study	Sustainability dimensions	Peer reviewed	Scale of analysis	Geographic application
Trading off natural resources and rural livelihoods. A framework for sustainability assessment of small-scale food production in water-limited regions (Recanati *et al.*, 2017)	Economic, social, and environmental	Yes	Farm and regional level	Gaza Strip
Ranking farms with a composite indicator of sustainability (Reig-Martínez *et al.*, 2011)	Economic, social, and environmental	Yes	Farm level	Campos County, Spain
Integrated farm sustainability assessment for the environmental management of rural activities (Rodrigues *et al.*, 2010)	Landscape ecology, environmental, sociocultural, economic, management and administration	Yes	Cropping systems	Brazil, various zones
MASC, a qualitative multi-attribute decision model for *ex ante* assessment of the sustainability of cropping systems (Sadok *et al.*, 2009)	Economic, social, and environmental	Yes	Cropping systems	Picardy, France
Assessing farm-level agricultural sustainability using site-specific indicators and sustainable livelihood security index: Evidence from Vaishali district, India (Sajjad and Nasreen, 2016)	Ecological security, economic efficiency and social equity	Yes	Farm level	India
Assessing the sustainability of agricultural production systems using fuzzy logic (Sami *et al.*, 2013)	Social, environmental, and economic	Yes	Agricultural production systems	Iran (Islamic Republic of)
Sustainability assessment in wine-grape growing in the New World: Economic, environmental, and social indicators for agricultural businesses (Santiago-Brown *et al.*, 2015)	Economic, environmental, and social	Yes	Agricultural business or region	Australia, Chile, New Zealand, South Africa, United States of America
Assessing farm-level agricultural sustainability over a 60-year period in rural eastern India (Sharma and Shardendu, 2011)	Economic, social, and ecological	Yes	Farm level	India
Social multicriteria evaluation of farming practices in the presence of soil degradation. A case study in Southern Tuscany, Italy (Siciliano, 2009)	Financial, environmental, and social	Yes	Farm level	Southern Tuscany
Maize yield and profitability trade-offs with social, human and environmental performance: Is sustainable intensification feasible? (Snapp *et al.*, 2018)	Production, economics, environment, social and human condition	Yes	Farm level	Central Malawi

Study	Sustainability dimensions	Peer reviewed	Scale of analysis	Geographic application
Unheated soil-grown winter vegetables in Austria: Greenhouse gas emissions and socio-economic factors of diffusion potential (Theurl *et al.*, 2017)	Good governance, environmental integrity, economic resilience, and social well-being	Yes	Farm and regional level	Austria and Italy
Assessing sustainability performance at the farm level: Examples from Greek agriculture systems (Tzouramani *et al.*, 2020)	Economic, social, and environmental	Yes	Farm scale	Greece
A protocol for evaluating the sustainability of agri-food production systems - A case study on potato production in peri-urban agriculture in the Netherlands (Van Asselt *et al.*, 2014)	Economic, social, and environmental	Yes	Agrifood production systems	Netherlands (Kingdom of the)
Sustainable value assessment of farms using frontier efficiency benchmarks (Van Passel *et al.*, 2009)	Economic, social, and environmental	Yes	Farm/company level	Flanders, Belgium
Multilevel and multi-user sustainability assessment of farming systems (Van Passel and Meul, 2012)	Economic, social (lack of data), and environmental	Yes	Sector level and farm level	Flanders, Belgium
Sustainability of European maize-based cropping systems: Economic, environmental and social assessment of current and proposed innovative IPM-based systems (Vasileiadis *et al.*, 2013)	Economic, social, and environmental	Yes	Cropping systems	Denmark, Hungary, Italy, Netherlands (Kingdom of the) and Spain
A new method for assessing the sustainability of land-use systems (I): Identifying the relevant issues (Walter and Stützel, 2009a)	Physical (geobiochemical) and social (economic, political and social)	Yes	Agrifood systems	Northwest Germany
A new method for assessing the sustainability of land-use systems (II): Evaluating impact indicators (Walter and Stützel, 2009b)	Economic (not assessed but possible), social (not assessed but possible) and environmental	yes	Agrifood systems	Northwest Germany
Novel participatory indicators of sustainability reveal weaknesses of maize cropping in Benin (Yegbemey *et al.*, 2014)	Economic, social, and environmental	Yes	Farm level	Benin
Assessing farm sustainability with the IDEA method - From the concept of agriculture sustainability to case studies on farms (Zahm *et al.*, 2008)	Economic, socioterritorial, and ecologic	Yes	Farm scale	France

Source: See References.

Annex 2. Summary table of the methods

Table A2. Established frameworks

Method	Description	Advantages	Limitations	Cited
Life cycle assessment (LCA)	Life cycle assessment is a technique for assessing the environmental aspects associated with a product over its life cycle	• Allows for comparison between systems or against a threshold, facilitating decision-making.	• Targets environmental impacts, leaving aside socioeconomic aspects. • Does not analyse all the dimensions of sustainability, giving a partial sustainability assessment. • Complex framework as it considers all the life and process chain of a product, which requires considerable data.	Theurl *et al*. (2017); Walter & Stützel, (2009b); Van Cauwenbergh *et al*.(2007); Muralikrishna & Manickam (2017)
Guidelines for indicator selection	Guidelines for the selection of the most relevant indicators in order to facilitate the decision-making process for policymakers	• Process of selecting indicators is more transparent.	• Wrong use of the framework leads to loss of objectivity and transparency. The criteria used to select the indicators may influence the outcome of the sustainability assessment. (Involving the stakeholders in selecting the indicators can help overcome this limitation.)	Van Asselt *et al*. (2014); Goswami *et al*. (2017); Dasgupta *et al*. (2021)
***Marco para la evaluación de sistemas de manejo de recursos naturales incorporando indicadores de sustentabilidad* (MESMIS, Framework for the evaluation of natural resource management systems using sustainability indicators)**	Identifies anthropogenic changes in a system based on sustainability standards	• Its flexible structure can be adapted to diverse systems. • Approach is participatory, interdisciplinary and multi-institutional.	• Its flexible nature can lead to neglecting relevant aspects of the system. • Complex systems require long and costly assessment.	López-Ridaura *et al*. (2002); Astier *et al*. (2012)
Monitoring tool for integrated farm	Visual monitoring tool used for the aggregation	• The participation of stakeholders and the	• Indicators are selected based on the availability of data rather than their	Meul *et al*. (2008); Van Passel *et al*. (2009);

Method	Description	Advantages	Limitations	Cited
sustainability (MOTIFS)	of indicators of various themes, which creates benchmarks for the rescaling of the indicator values	simplicity of the tool make it easy to apply.	scientific relevance.	Lampridi *et al*. (2019)
Sustainability assessment of food and agriculture systems (SAFA)	SAFA guidelines provide a protocol for assessing sustainability. Themes define universal sustainability goals and are broken down into subthemes that define objectives which are specific to food and agricultural supply chains	• Assesses performance across dimensions and themes. • Can be adapted to different agricultural and food systems. • Includes a new dimension of sustainability: good governance.	• Not well suited to small-scale operations, such as family farms.	FAO (2014)
Tool for agroecology performance evaluation (TAPE)	TAPE is a participatory tool to assess the multidimensional performance of agroecology for a transition towards sustainable agricultural and food systems	• Analyses five dimensions of sustainability (economic, social, environmental, health and nutrition, and good governance) for a variety of contexts (production systems, communities, territories, agroecological zones, etc.). • Built from the strengths of existing frameworks. • Includes qualitative (surveys) and quantitative data (databases) from various sources. • Disaggregation of data by age, gender and diversity of producers.	• Includes just ten core indicators. The additional indicators are not described in depth and are more difficult to apply and assess.	FAO (2019)
Response-inducing sustainability evaluation (RISE)	RISE is an interview-based method for a holistic assessment of the	• Applied to a wide variety of themes and subthemes. Aggregates different types of	• Difficult for auditors to decide when a survey answer should be "yes" and when it should be "partially".	de Olde *et al*. (2016)

Method	Description	Advantages	Limitations	Cited
	sustainability of farming operations. The evaluation is based on ten indicators that reflect environmental, economic and social aspects	data: qualitative data and quantitative farm data, regional and master data (global reference data), covering a wide variety of themes. • Direct input of data from other tools, such as greenhouse gas calculations. • Possibility to assess a wide variety of themes and subthemes.	• Need to find appropriate reference values.	
Indicateurs de durabilité des exploitations agricoles (IDEA, Farm sustainability indicators)	IDEA is a method designed as a self-assessment framework for farmers. It provides operational content for the assessment of agricultural sustainability	• Analyses differences in sustainability between production systems.	• Must be adapted to local context and to the specific agricultural system. • Based on the European context and requires adaptation for application to developing countries.	Zahm *et al*. (2008); Biret *et al*. (2019)

Source: See References.

Table A3. Dedicated methods

a. Non-aggregated set of indicators

Method	Description	Advantages	Limitations	Cited
Indicators sets	Methods and tools contain indicator sets used to assess agricultural sustainability without a numerical integration	• Simplicity. • There is no loss of information.	• Too many indicators can compromise the legibility of the information. • In complex systems, aggregation may be necessary to organize the data and to reveal succinct views and interrelationships.	Snapp *et al*. (2018); Yegbemey *et al*. (2014); Santiago-Brown *et al*. (2015); Recanati *et al*. (2017); Peano *et al*. (2015); Dos Santos & Ahmad, (2020); Jollands *et al*. (2003)

b. Composite methods

Method	Description	Advantages	Limitations	Cited
Composite Index	Composite indicators are mathematical combinations (or aggregations) of a set of indicators which serve to synthesize complex or multidimensional issues.	• The aggregation of multiple sustainability indicators into composite indicators or indices make it easier to understand, as well as allowing this concept to be operationalized. • Allows for the adaptation of sustainability metrics to the specific objectives of the assessment. • Facilitates engagement with the general public, promotes accountability, facilitates comparison.	• The main problem is its subjectivity as it is dependent on normalization, weighting and the aggregation method.	Rodrigues *et al*. (2010); Dong *et al*. (2016); Sharma & Shardendu (2011); Sajjad & Nasreen, (2016); Gómez-Limón & Sanchez-Fernandez (2010); Gaviglio *et al*. (2017); Jollife & Cadima (2016); Dos Santos & Ahmad, (2020); Bockstaller *et al*. (2017); Barclay *et al*. (2018)

c. Multicriteria methods

Method	Description	Advantages	Limitations	Cited
Data envelopment analysis (DEA)	Technique based on mathematical programming that allows for benchmarking the performance of individual decision-making units against	• The DEA approach can deal with a variety of value and physical data and provides a built-in method of data standardization, as decisional units	• Limited flexibility in the selection of weights. • Sensitive to the selection of inputs and outputs.	Gomes *et al*. (2009); Reig-Martínez *et al*. (2011); Dong *et al*. (2015); Zbranek, (2013)

Method	Description	Advantages	Limitations	Cited
	frontiers of best practices based on the observed behaviour of other units	are ranked from 0 to 1, according to their level of efficiency. • Can handle multiple inputs and outputs simultaneously.		
Other multi-criteria methods	Methods that support decision-making based on multiple competing criteria and dimensions	• Analyses the problem at hand considering the different points of view of various disciplines. • Does not require normalization of the scores.	• Each weighting criteria has a significant effect on the final score.	Peano *et al*. (2014); Siciliano (2009); Egea & Pérez y Pérez, (2016); Sabaei *et al*. (2015)

d. Mixed methods

Method	Description	Advantages	Limitations	Cited
Multi-attribute assessment of cropping systems (MASC)	Hierarchical multi-attribute decision support model designed for the *ex ante* assessment of cropping systems to address the need of in-field, alternative-scenario evaluation	• Includes the use of cropping system scale, allowing for the assessment of different cropping activities within a farm system. • Easy to handle by non-experts. • Precision rules make it possible to trace the effects of changes in one criterion for the overall assessment.	• Quality rules make it difficult to investigate the intrinsic sources of differences between the cropping systems assessed. • Assessments from an *ex ante* perspective inevitably result in significant uncertainty.	Chopin *et al*. (2016); Sadok *et al*. (2009); Colomb *et al*. (2013); Arh & Blazic (2007)
DEXi Pest Management (DEXiPM)	The DEXiPM model is based on the MASC model. It is an *ex ante* methodology consisting of 75 basic and 86 aggregated indicators to assess innovative systems	• Considers a broad range of aspects of sustainability. • This assessment approach is goal-oriented and is more subjective. • Allows *ex ante* and *ex post* assessment and evaluation at different scales. • Flexible and dynamic framework adaptable to the level of information available on the systems under assessment.	• Complexity of the model and lack of sensitivity. • Basic indicators are difficult to estimate because of their subjectivity (especially social sustainability). • Compensation between indicators can contribute to lack of sensitivity of the model.	Angevin *et al*. (2017); Vasileiadis *et al*. (2013); Pelzer *et al*. (2012); Lampridi *et al*. (2019)
Fuzzy models	Fuzzy logic can translate sophisticated statements from natural language into a mathematical formalism in defined situations where	• Allows the *ex ante* assessment of impacts. • Allows for the implementation of strategies on the farm without extensive field measurements.	• Modification of the model requires a precise choice of new indexes. The information not easily available.	Sami *et al*. (2013); Allahyari *et al*. (2016); Bockstaller *et al*. (2017); Novák *et al*. (1999)

Method	Description	Advantages	Limitations	Cited
	traditional mathematics are ineffective	• Can trace results, reducing the loss of information in the aggregation procedure.		
Analytical hierarchy process (AHP)	Method for organizing and analysing complex decisions, using math and psychology developed by Saaty (1980)	• No special knowledge is required to apply the method, unlike other methods of multicriteria decision-making. • The method can combine criteria defined linguistically or numerically without any additional modifications. • Wide range of potential applications.	• When decision-making problem contains many criteria and alternatives, the process can be time consuming. • Adding a new alternative or removing an old one from the model, the preferential order of other alternatives can change without changing the values of pairwise comparisons with regards to individual criteria or their preferences.	Tzouramani *et al*. (2020); Siekelova *et al*. (2021)

Source: See References.

Annex 3. Gross list of indicators, by dimension

Table A4. Economic sustainability dimension

Name	Framework
Added value	RISE, MOTIFS, TAPE
Autonomy	IDEA
Agricultural subsidies independence	IDEA
Capital productivity	MOTIFS, TAPE
Cash flow turnover ratio	RISE
Community investment	SAFA
Crop productivity	RISE, TAPE
Degree of indebtedness	RISE
Diversification of production	IDEA
Economic viability	IDEA
Economic vulnerability	RISE
Efficiency	IDEA, MOTIFS
Farm ability to generate income	MOTIFS, TAPE
Internal investment	SAFA
Labour productivity	MOTIFS, TAPE
Liquidity reserve	RISE, SAFA
Livelihood security	RISE
Livestock productivity	RISE, TAPE
Local procurement	SAFA
Long-ranging investment	SAFA
Profitability	SAFA
Related activities	IDEA
Resilience	TAPE
Return on asset	MOTIFS
Return on equity	MOTIFS
Risk management	SAFA
Stability of market	SAFA
Stability of production	SAFA
Stability of supply	SAFA
Transferability	IDEA
Usage of debt service limit	RISE
Value of production	MOTIFS

Notes: IDEA – Indicateurs de durabilité des exploitations agricoles (Farm sustainability indicators); MOTIFS – monitoring tool for integrated farm sustainability; RISE – response-inducing sustainability evaluation; SAFA – sustainability assessment of food and agriculture systems; TAPE – tool for agroecology performance evaluation.

Source: Authors' own elaboration.

Table A5. Social sustainability dimension

Name	Framework
Accessibility to space	IDEA
Association and social implications	IDEA
Capacity development	SAFA
Child labour	SAFA
Collective work	IDEA
Cooperation	IDEA
Decent work	TAPE
Employment relations	SAFA
Enhancement of building and landscape heritage	IDEA
Entrepreneurship	MOTIFS
Exposure to pesticides	TAPE
Fair access to means of production	SAFA
Financial situation	RISE
Forced labour	SAFA
Freedom of association and right of bargaining	SAFA
Indigenous knowledge	SAFA
Isolation	IDEA
Labour intensity	IDEA
Landscape and territory	IDEA, MOTIFS
Non-discrimination	SAFA
Occupation + education	RISE
Personal freedom + values	RISE
Processing of non-organic waste	IDEA
Professional pride	MOTIFS
Quality of life	IDEA, SAFA
Quality of the products	IDEA
Responsible buyers	SAFA
Rights of suppliers	SAFA
Rural buildings	IDEA, MOTIFS
Safety at work	RISE, SAFA
Salaries and income level	RISE, TAPE
Services, multi-activities	IDEA
Short food supply chain	IDEA
Social relations	RISE
Social services	MOTIFS
Support to vulnerable people	SAFA
Sustainability of the employment	IDEA
Training	IDEA
Women's empowerment	TAPE, SAFA
Work	IDEA
Working times	RISE
Youth employment opportunity	TAPE

Notes: IDEA – *Indicateurs de durabilité des exploitations agricoles* (Farm sustainability indicators); MOTIFS – monitoring tool for integrated farm sustainability; RISE – response-inducing sustainability evaluation; SAFA – sustainability assessment of food and agriculture systems; TAPE – tool for agroecology performance evaluation.

Source: Authors' own elaboration.

Table A6. Environmental sustainability dimension

Name	Framework
Air quality	MOTIFS, SAFA
Alternative water resources use	MOTIFS
Ammonia emissions	RISE
Animal diversity	IDEA, MOTIFS, TAPE
Animal health	SAFA
Animal well-being	IDEA, SAFA
Annual crop diversity	IDEA, MOTIFS, TAPE
Biological soil quality	MOTIFS, TAPE, SAFA
Carbon sequestration	TAPE, SAFA
Crop rotation	IDEA, MOTIFS, RISE
Cropping patterns	IDEA
Dimension of fields	IDEA
Diversity of agricultural production	RISE
Diversity of associated vegetation	IDEA, TAPE, SAFA
Ecological buffer zones	IDEA, RISE
Energy dependence	IDEA, RISE, MOTIFS
Energy intensity of agricultural production	RISE, SAFA
Environmental and landscapes safeguard	IDEA, RISE
Fertilization	IDEA, MOTIFS
Fodder area management	IDEA
Genetic diversity	SAFA
Greenhouse gas balance	RISE, TAPE, SAFA
Habitat diversity	MOTIFS
Intensity of agricultural production	RISE
Land degradation	SAFA
Measures to protect natural heritage	IDEA, RISE
Nitrogen (N) and Phosphorus (P) self-sufficiency	RISE
Nitrogen (N) surplus	MOTIFS
Nitrogen balance	RISE, MOTIFS
Organic matter management	IDEA
Pesticides	IDEA, MOTIFS
Phosphorus (P) balance	RISE, MOTIFS
Physical soil quality	MOTIFS
Plot management	IDEA, MOTIFS, RISE
Risk of water quality	RISE, MOTIFS, TAPE, SAFA
Safeguard of animal and vegetal diversity	IDEA, TAPE
Share of sustainable energy carriers	RISE, MOTIFS
Soil compaction	RISE

Name	Framework
Soil erosion	RISE
Soil health	TAPE
Soil management	IDEA, RISE
Soil organic matter supply	RISE, MOTIFS
Soil phosphorus (P) content	MOTIFS
Soil pollution	RISE
Soil potassium (K) content	MOTIFS
Soil quality pH	MOTIFS
Soil reaction	RISE
Stocking rate	IDEA
Sustainable use of materials	IDEA
Tree crop diversity	IDEA, MOTIFS, TAPE
Veterinary treatments	IDEA
Waste management	RISE, SAFA
Water-resource management	IDEA, RISE, MOTIFS, TAPE
Water supply	RISE
Water-use intensity	RISE
Water withdrawal	SAFA

Notes: IDEA – *Indicateurs de durabilité des exploitations agricoles* (Farm sustainability indicators); MOTIFS – monitoring tool for integrated farm sustainability; RISE – response-inducing sustainability evaluation; SAFA – sustainability assessment of food and agriculture systems; TAPE – tool for agroecology performance evaluation.

Source: Authors' own elaboration.

Table A7. Nutrition and health sustainability dimension

Name	Framework
Contribution to world food balance	IDEA
Dietary diversity	TAPE
Food quality	SAFA
Food security and nutrition	TAPE, SAFA
Food sovereignty	SAFA
Health	RISE, SAFA
Reception, hygiene and safety	IDEA

Note: IDEA – *Indicateurs de durabilité des exploitations agricoles* (Farm sustainability indicators); RISE – response-inducing sustainability evaluation; SAFA – sustainability assessment of food and agriculture systems; TAPE – tool for agroecology performance evaluation.

Source: Authors' own elaboration.

Table A8. Governance sustainability dimension

Name	Framework
Accountability	SAFA
Civic responsibility	SAFA
Conflict resolution	SAFA
Ethics	SAFA
Grievance procedures	SAFA
Legitimacy	SAFA
Participation	SAFA
Remedy, restoration and prevention	SAFA
Resource appropriation	SAFA
Responsibility	SAFA
Rule of law	SAFA
Secure land tenure (or mobility for pastoralists)	SAFA
Stakeholder dialogue	SAFA
Transparency	SAFA

Note: SAFA – sustainability assessment of food and agriculture systems.

Source: Authors' own elaboration.

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