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Methodologies for Assessing Sustainability in Farming Systems

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Abstract

Development of composite indicators is considered an important approach for evaluating sustainable development. For agriculture, different indicators have been developed such as Delphi, IDEA, MESMIS, MOTIFS, RISE, or SAFE. For its construction, usually bivariate and multivariate statistical techniques were employed. These are pragmatic tools used to simplify the description of complex systems by the use of three functions: to simplify, to quantify, and to communicate easily. Criteria for indicator selection include policy relevance, validity, accessibility, and measurability. However, operational evaluation of agricultural sustainability presents problems, because it requires analyzing the future production of goods and services, which need to be observed on a reasonable time horizon, and other difficulties involve interpreting the combination of indicators required for such analyses. This chapter realizes a review of these methodologies and its applications.

Keywords: sustainable development, indicators, index, organic, natural resources

1. Introduction

The meaning of sustainability and sustainable development is different. Neufeldt [1] mentioned that sustainability is the ability to “keep in existence; keep up; maintain or prolong.” Hildebrand [2] suggested that it may be interpreted as the length of time that a system can be maintained. Monteith [3] added the possible interaction of changes in input and output levels. And according to the Brundtland report, sustainable development is defined as “development

that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" [4]. The formalization of this concept was completed by three pillars—social, environmental, and economic—described in the World Summit on Sustainable Development in 2002 [5].

According to Hamrin [6], natural resources and the environment "constitute the ultimate foundation upon which all future economic activity must be construed. From this, it follows that future economic progress will be increasingly dependent on the sustained integrity of the resource and environmental base." The economic crisis shows that maintaining economic growth is an essential objective accepted and growth has been the most important policy goal across the world; it is the reason why it is difficult to find a balance between sustainability and the economic growth [7].

Social sustainability requires that the cohesion of society and its ability to work towards common goals are maintained. Social sustainability (social values, identities, relationships, and institutions) is probably the most important and critical long-term "pillar" of sustainable development for survival of civilization as shown in the study of past (and contemporary) societies [8, 9].

Environmental sustainability seeks to protect the sources of raw materials ensuring that the sinks for human wastes are not exceeded to prevent harm to humankind [10]. This conceptualization fits into the resource-limited ecological framework and "limits to growth" described by Meadows et al. [11]. OECD [12] considered criteria like regeneration (renewable resources should be used efficiently and their use should not be permitted to exceed their long-term rates of natural regeneration), substitutability (non-renewable resources should be used efficiently and their use limited to levels which can be offset by substitution with renewable resources or other forms); assimilation (releases of hazardous or polluting substances into the environment should not exceed their assimilative capacity); and irreversibility.

There is a recognition that the three pillars of sustainable development need to be complemented by institutional, cultural, or ethical dimensions and including governance, efficiency, motivation, values, and other factors that may be important for sustainable human prosperity. It is essential to maintain the ecosystem and nature's services to assure the human well-being. Sustainability science must research the most significant driving forces, impacts, and their causal relationships and identify the relevant indicators to the points in the system where management actions would be most effective. Compiling many separate indicators cannot provide an adequate measure of the systems sustainability. But modeling systems help to explore resilience and tipping points or developing alternative scenarios to anticipate vulnerabilities in the natural, social, and economic dimensions. Indicators at the individual level are relevant to the changes in personal motivation and their behavior and essential for a sustainable society [13].

The aim of this paper is to review the main methodologies for assessing sustainability in farming systems.

2. Sustainable agriculture

Conventional agriculture is characterized as a system with intensive use of capital, large-scale, highly mechanized agriculture with monocultures of crops and extensive use of artificial fertilizers, herbicides, and pesticides, with intensive animal husbandry [14]. This has led to an increase in the use of fertilizers, synthetic pesticides, antibiotics, hormones, and fossil fuels and consequently led to an increase in environmental problems [15]. The problems associated with “conventional agriculture” were perceived as unsustainable [16]. These impacts, such as depletion of non-renewable resources, soil degradation, environmental effects of agricultural chemicals, inequity, declining rural communities, loss of traditional agrarian values, farm worker safety, decline in self-sufficiency, and decreasing number and increasing size of farms, reflect the goal of promoting alternatives.

The definition of “sustainable agriculture” is an activity that permanently satisfies a given set of conditions for an indefinite period of time [17]. Sustainable agriculture has been described as a term encompassing several ideological approaches including organic farming, biological agriculture, ecological agriculture, biodynamic agriculture, regenerative agriculture, permaculture, and agroecology [16, 18–20]. Neher [21] considered it as an approach or a philosophy that integrates land stewardship with agriculture, where land is managed with respect to allow a future for next generations. This philosophy guides the application of prior experience and the latest scientific advances to create integrated, resource-conserving, equitable farming systems [22].

A sustainable agricultural system is often defined as one that fulfills a balance of several goals including some expression of maintenance or enhancement of the natural environment, provision of human food needs, economic viability, and social welfare through time [17]. This multidimensional character inherent in the concept of sustainable development requires from the triple perspective of profitable operation, fair and equitable distribution of the generated wealth, and its compatibility with the maintenance of natural ecosystems [23].

For agriculture with alternative practices, Beus and Dunlap [24] listed values like community, independence, decentralization, diversity, and harmony with nature. Social values such as equity, self-sufficiency, preservation of agrarian culture, and preference for small owner-operated farms have been incorporated into definitions of sustainability [22, 25].

Excessive chemical input levels degrade natural resources through accumulation, while inadequate levels degrade resources through exhaustion. Zandstra [26] and Stinner and House [27] in sharp contrast described sustainability as a function of chemical input levels.

In general, the society accepted that organic production may contribute to mitigate environmental problems. Organic farming practices help to promote the sustainable land use and improve environment conservation, animal welfare, and products’ quality [28–30]. As a general principle, this organic agriculture should be managed in a precautionary and responsible manner to protect the health and well-being of future generations and the environment [31].

Sustainable land use management is necessary to shorten the gap between planning practice and research regarding landscape [32–34].

3. Methodologies for assessing sustainability in agricultural systems

The methodological problems imposed by the temporal nature of sustainability have hindered the development of approaches for its characterizing. Sustainability involves future outcomes that cannot be observed in the time frame required for intervention [35, 36].

Environmental sustainability is the maintenance of natural resources. These can be expressed as environmental objectives: water, soil, and air quality and maintenance of biodiversity. At the farm level, an agricultural system is sustainable if it conserves the natural resources provided by its ecosystem [10, 37, 38].

In order to maintain the production, it would be useful to follow a method to evaluate the degree of approximation between different systems and identify aspects to improve on each farm. This method should be broad and multidimensional [39, 40] and should address the management of animals, soils and vegetation, as well as environmental, economic, and social aspects. They should be expressed through indicators so as to compare different farms in a region or country and analyze the evolution over time [41].

Spohn [42] identifies two main approaches for sustainability assessment:

- The “bottom-up” approach, which requires systematic participation to understand the framework as well as the key sustainable development indicators.
- The “top-down” approach, which enables to define the overall structure for achieving the sustainability, and subsequently, it is broken down into a set of indicators.

There have been developed a large number of sustainability assessment tools to gain insight into the sustainability performance of farms. These tools generally integrate a wide range of subjects and indicators to develop a holistic view on farm-level sustainability and are used for different purposes, such as monitoring, certification, consumer information, farm advice, and research [43–46]. Moreover, after a sustainability assessment, additional efforts are needed to discuss the assessment outcomes with farmers and other stakeholders and translate these into meaningful decisions for change [43, 44, 47].

Creating a tool requires collaboration between researchers and farmers; input from farmers needs to be accepted as being complementary to traditional scientific knowledge [48]. Sustainability indicators are often developed by scientists, expressed in technical language. It is commonly accepted that if the stakeholders, who will ultimately benefit from indicators, are involved in indicator conceptualization and development, then it is far more likely that they would use and appreciate the results [49, 50]. One of the main roles of indicators is communication with stakeholders. Hence, several authors [48, 51] agree that the participation and consultation of farmers is a key element in building and developing indicators. However, different types of stakeholders can interpret indicators differently, due to different values,

interests, or cultural and academic context. Most of the literature on stakeholder participation associated with sustainability indicators focus on participation in the design and development of indicator systems or in data collection for indicator calculation [52]. According to Jackson et al. [53], a useful indicator must produce results that are clearly understood and accepted by scientists, policy makers, and general public [54].

At another related level, self-assessment approaches used by local communities are examples of complementary approaches to the more traditional use of indicators for measuring and communicating sustainability-related issues. Community-based monitoring refers to a range of activities through which concerned citizens gather and record systematic observations about social or environmental conditions, often in collaboration with academia, industry, government, or community institutions [55]. Through participatory monitoring and evaluation, research in the late 90s has revolved around finding ways to help different people to identify clearly their information needs and acceptable forms of assessing information [56]. Stakeholders' own assessment of sustainability performance could be used to make qualitative comparative analysis with the formal technical assessments that are provided by indicators. As an indirect way of evaluating the strengths and weaknesses of the technical indicator sets and concluding about its overall utility, an evaluation of sustainability indicators by stakeholders can be used. Significant gaps between indicator data and stakeholders' perceptions can point to a failure in fulfilling that role. The credibility of sustainability self-assessment and the related procedures and outcomes analysis is a relatively underexplored issue, but it could be of particular importance [57].

Sustainability indicators are a tool that can be used by farmers at the farm or field level to assess the effects of managerial changes [58]. Many indicators are purely theoretical, in which modeling, equations, and simulations are used to provide an evaluation and cannot be used directly as a decision tool by farmers. At the farm level, complex tools that require a lot of information and expert knowledge to provide environmental estimates are generally not suitable. Many indicators for other kinds of assessment or monitoring are transferred to agriculture to let farmers assess and evaluate farming systems [59].

As Van de Fliert and Braun [60] attest, farmers have a critical role to play in assessing sustainable agriculture because their responsibilities for managing natural resources are increasing. Zhen and Routray [61] proposed that assessments should be closely linked to the context of specific farming systems. Several frameworks that assess sustainability include the development of indicators [38, 62, 63]. According to the context, the framework can change with different end-users and it should incorporate characteristics that can be generally applied under different conditions [38].

Girardin et al. [64] reported that the environmental impacts of an agricultural practice can be compared with reference values. These reference values can be a target value, defined as an optimal level, or as the minimal level required for sustainability [63]. Reference values provide guidelines to improve farm systems.

To deal a challenge with measurement for sustainability and its dimensions, a variety of methods or agri-environmental indicators have been developed [43, 44, 51, 65–69]. For instance, some researchers focused on investigated environmental phenomena related to farming systems and/

or farming practices [43, 44, 51, 61, 70–73]. The indicator accounting methods in the literature have usually been proposed for specific farming sectors, such as arable farms (i.e., method AEI by Girardin et al. [64] evaluating the impact of practices on agroecosystem and its environment); crops, livestock, and forestry (i.e., method LCAE by Rossier [74] or SD by Pointereau et al. [75] evaluating the environmental impact); and for specific target groups (i.e., method IFS by Vilain [76] or MOP by Vereijken [77]) such as farmers, farm advisers, policy makers, or researchers [70, 78, 79].

Agroecological studies have recognized the importance of analyzing environmental impacts as an aspect for measuring environmental sustainability in agriculture [38, 64, 69, 78, 80]. Different environmental objective groups (or attributes) were assessed in these studies. Notably, the Agro-Ecological System Attributes (AESAs) and the Statistical Simulation Modeling (SSM) approaches covered three environmental objective groups. The Response Inducing Sustainability Evaluation (RISE) and Scenario Based Approach (SBA) incorporated only two environmental objective groups. Some agroecological sustainability indicators have been formulated considering any environmental objective group. For instance, Farmer Sustainability Index (FSI), Sustainable Agricultural Practice (SAP), Sustainability Assessment of the Farming and the Environment (SAFE), Environmental Sustainability Index (ESI), and Multi-scale Methodological Framework (MMF) methods [81].

4. Indicators for assessing sustainability

An indicator is a variable that reflects or explains other variables that are more difficult to understand or quantify [82]. Indicators are a pragmatic tool used to simplify the description of complex systems. They can be used individually, as part of a set, or aggregated within a set to increase understanding by end-users [83]. Indicators are only as good as the data behind them [13]. The three functions of an indicator are to simplify, quantify, and communicate easily. At the farm level, indicators may be the best approach for assessing sustainability directly and assessing the environmental status of farm resources [59].

Indicators simplify, quantify, and analyze the complex and complicated information [84]. When the indicators are defined, they have to be measured by quantitative and qualitative techniques. The main difficulties related to obtaining the indicators are their selection, interpretation, and use. They can be used to determine a trend to have a notion of what is acceptable or to establish a baseline [7, 85, 86]. The existence of a target is of key importance, regardless of the type of target. Even a vague, qualitative target may be an important policy driver. The benefit of specific, quantitative, time bound targets is then straightforward; the indicators can be linked to these and interpreted clearly on a distance-to-target basis. Targets can be based on international treaties, agreements, or derived from environmental and public health standards developed by international organizations, national governments, or expert opinion (i.e., 2015 United Nations climate change conference), and they represent an ideal state [7]. Stieglitz et al. [87] mentioned that humans need an assessment of how far they are from sustainable targets.

The indicators are adopted by countries and corporations because of their ability to condense the enormous complexity of the dynamic environment to a manageable amount of meaningful information [88].

The selection of sustainability indicators is essentially a political process [89, 90]. This implies reconciling “expert-led” and “community-led” perspectives on sustainable development priorities [91]. OECD [92] included criteria for indicator selection as follows:

- Policy relevance: It should address issues considered of importance for policy making.
- Validity: It may be viewed from a variety of perspectives, including those of scientists, farmers, rural residents, and consumers. Therefore, a valid indicator must be able to reconcile the need for sound scientific analysis with a requirement to be recognized as legitimate by other non-scientist.
- Accessibility: The selection of an indicator must match to the scale that is appropriate to those decision-makers avoiding relevance at only a particular scale.
- Measurability: To monitor policy impact, the importance is the availability or easy acquisition of data.

There have been consistent efforts at international level to identify appropriate sustainability indicators. The United Nations Commission on Sustainable Development (UNCSD) has derived a list of 58 indicators for all countries to use. Booyesen [93] defined the following general dimension of measurement for the classification and evaluation of indicators:

- Aspects of sustainability measured by indicators.
- Methods for development of indexes (quantitative/qualitative, subjective/objective, cardinal/ordinal, unidimensional/multidimensional).
- Indicators comparing sustainability measure across “time-series” or “cross-section,” absolute or relative manner.
- Measuring sustainability in terms of input (“means”) or output (“ends”).
- Clarity and simplicity in its content, purpose, method, comparative application, and focus.
- Availability of data.
- Flexibility for allowing change, purpose, method, and comparative application.

The accuracy and credibility related with the evaluation of sustainability indicators are an essential aspect of their development process. The progress towards a more sustainable agricultural production can only be made when the objectives defined by different stakeholders can be translated into practical measures.

A major aspect of the design of indicators is the use of participatory processes. Expert participation provides a preliminary validation of the indicator set. Compromises between feasibility, practicability, and relevance of measurements should be considered including spatial and

temporal scales. The farmers validate the tool by evaluating their own results. Through this validation, reference values will need to be established as farmers adopt new practices [59].

5. Compound indexes

The construction of composite indicators involves selection of various methods at different stages of development process [94]. Development of composite indicators is considered to be a unique approach for evaluating sustainable development. Composite indices can be constructed with or without weights depending on its application. Indices are very useful in focusing attention and often simplify the problem [95]. The selection of the appropriate methods depends on the data and the scope of the study. After aggregation of indicators, an index requires to be checked for robustness and sensitivity.

There is a critical need to develop indicators to assess the relative degree of sustainability of the production systems, especially those throughout the rural sector of the developing world [62]. This is important for the Natural Resource Management Systems (NRMS) in the peasant context, because despite being highly resilient, diverse and based on the use of renewable local natural resources, have been undervalued on the basis of criteria that focus on short-term economic benefits. Its complexity has been alluding to the tight interactions among the different activities related to natural resource management and their repercussion in the satisfaction of a multiplicity of economic, environmental, and social objectives [96, 97].

For constructing a composite index, policy goal has to be clearly defined [93]. When empirical analysis is used for selection, bivariate and multivariate statistical techniques can be employed. Bivariate analysis measures the correlation between all pairs of variables using correlation matrices, while multivariate analysis assesses the strength of any set of variables to measure any other variable, using discriminant, principal component, and factor analyses. The objective of these techniques is to determine the number of key variables that influence the composite index [98].

For performing the scaling for composite indexing purposes, Booysen [93] defined that the use of standard scores (z and t values) can be employed for composite indexing, it can be transformed in the form of ordinal response scales for surveys results, or it can be scaled on conventional linear scaling transformation method.

Weighting system and method employed in aggregating component scores plays a predominant role for development of composite index [93]. Multivariate techniques provide relatively better option for weight selection. Some of the key methods of aggregation employed are principal components analysis, factor analysis, distance to targets, expert's opinion (budget allocation), and analytic hierarchy process. Principal component analysis is one of the widely used multivariate analysis tools for weighting of components based on the proportion of variance. Once the weights have been assigned to each indicator and this is transformed into component score, these scores are aggregated into a composite score [93]. Sensitivity analysis along with proper validation should be done on composite indices [99]. Based on the validation results, indices need to be improved and adjusted. Validation is normally performed by using either item

analysis or external validation [93]. There is always a requirement for demonstrating proper evidence through the reliable results while using composite index [100].

Using composite indices does not solve the problem, as there are controversies for defining the weight attached to each indicator. Methodological frameworks are needed for the selection of appropriate indicators and in the integration and transformation of the information to set the basis for the design of more sustainable alternatives. Conway [101] and Garcia [102] suggested that for an interdisciplinary analysis it has to produce insights that significantly transcend those of the individual participating disciplines. Systems theory holds that certain principles stand for all systems regardless of its hierarchical level [101, 103]. Identifying a set of central systemic attributes (or properties) that holds across disciplines or scales is therefore fundamental to keep the evaluation of sustainability and the derivation of indicators theoretically consistent.

The development of evaluation frameworks and indicators that make explicit the environmental, economic, social, and cultural advantages and disadvantages of the different NRMS let to improve not only the system's productivity or profitability but also the stability, resilience, reliability of resources management, adaptability, equity, and self-reliance [62].

To provide useful indicators based on benchmarking, trend analysis, and decoupling, Kovanda and Hak [104] developed Material Flow Analysis (MFA), and other attempts to conceptualize sustainable resource management were developed based on the idea of '*carrying capacity*' [105] to express the idea of biophysical limit to use of resources. Wackernagel and Rees [106] developed the Ecological Footprint (EF) indicator based on the amount of biologically productive land and water area required to support a population at its current level of consumption. EF is used to estimate environmental sustainability at national and global level. And the Eco-Index Methodology [107] measures the impact of different products, services, and lifestyles. It takes care of entire life cycle data for assessing the EF conversion factors for most of the key components. The ecological footprint (as measured using global average yields) is normalized by the application of equivalence factors. **Table 1** presents some of the environmental indices developed through the time.

Index	Description	Reference
Ecological Footprint (EF) indicator	Footprint is calculated based on either compound or component or combination of these methods	[106]
Living Planet Index (LPI)	It tries to assess the overall state of the Earth's natural ecosystems, which includes human pressures on natural ecosystems arising from the consumption of natural resources and the effects of pollution	[108]
Eco-Index Methodology	Utilizes "bottom-up approach" methodology	[107]
Environmental Sustainability Index (ESI)	ESI scores are based upon a set of 20 core indicators each of which combines 2–8 variables for a total of 68 underlying variables. Its permits cross-national comparisons of environmental progress	[109, 110]
Environmental Performance Index (EPI)	It aims to evaluate a set of environmental issues monitored through 6 policy categories	[111]
Environmental Vulnerability Index (EVI)	This comprises 32 indicators of hazards, 8 indicators of resistance, and 10 indicators that measure damage	[112]

Table 1. Some environmental indices used.

Rockstrom et al. [113] have introduced the concept of *planetary boundaries*. It is based on the knowledge that the Earth’s subsystems react in a nonlinear way and often are particularly sensitive around the threshold levels of variables such as CO₂ concentration. The authors identified nine processes and thresholds associated to an unacceptable environmental change: climate change, rate of biodiversity loss (terrestrial and marine), interference with the nitrogen and phosphorus cycles, stratospheric ozone depletion, ocean acidification, global freshwater use, change in land use, chemical pollution, and atmospheric aerosol loading.

The degree of complexity with which each indicator is obtained, for example through field measurements, mathematical models, and simulation models, also presents drawbacks in the comparison between systems evaluated by different methodologies. Many of the mentioned indicators lack the capacity to predict the state and the variation of the human system with the natural system, having to be looked at together with other indicators to obtain those properties, complicating the understanding of the results [114].

6. Methods to evaluate sustainability in farming systems

Also for agriculture and livestock systems, different indicators have been developed (Table 2). Some indicator-based farm monitoring tools are visual integration tools, aggregating scores of a set of sustainability indicators into radar graphs [66] or bar graphs [129]; others are numerical

Method	Description	Reference	Examples
Delphi	This technique is normally used to solve complex problems or generate strategies. It was adapted in agriculture to consult experts and to build and select the indicators	[48, 115]	Dairy farm sustainability in Quebec [59]
MESMIS (Marco para la Evaluación de Sistemas de Manejo incorporando Indicadores de Sustentabilidad; in English: Management Systems Assessment Framework Incorporating Sustainability Indicators)	The method does the characterization of the systems, the identification of critical points, and the selection of specific indicators for the environmental, social, and economic dimensions of sustainability. The information obtained by means of the indicators is integrated through mixed (qualitative and quantitative) techniques and multicriteria analysis	[62, 116]	Extensive livestock farming in Spain [117] Low input maize systems in Central México [118]
IDEA (<i>Indicateurs de Durabilité des Exploitations Agricoles</i> ; in English: Agricultural Sustainability Indicators)	It assesses whole-farm sustainability with agri-ecological (18 indicators), socio-territorial (18 indicators), and economic (6 indicators) scales	[119]	Small ruminants in Liban [120] Sheep farming systems in Morocco [121]
RISE (Response-Inducing Sustainability Evaluation)	This tool is also designed to be used with all types of production and evaluates three aspects of sustainability with a set of 12 indicators. Each indicator includes a state measure and a driving-force measure	[79, 122]	Dairy farms in China [79] Tea farms in Southern India [47] Armenian dairy farms and agriculture [123]

Method	Description	Reference	Examples
SAFE (Sustainability Assessment of Farming and the Environment Framework)	This is based on the goods and services provided by agricultural ecosystems, resulting in the primary level of the hierarchy, the principles that are correlated with the three dimensions of sustainability: economic, social, and environmental	[38, 124]	Belgian farms of Dairy, Poultry, Beef and Crop production [124]
MOTIFS (Monitoring Tool for Integrated Farm Sustainability)	It allows to monitor farm progress towards integrated sustainability, taking into account economic, ecological, and social aspects	[125]	Flemish dairy farms [126]
OLPI (Organic Livestock Proximity Index)	Nine indicators integrated in a global index: Nutritional management, Sustainable pasture management, Soil fertility and contamination, Weed and pest control, Marketing and management, Disease prevention, Breeds and reproduction, Animal welfare, and Food safety	[41]	Dairy Goat in Southern Spain [41] Dairy systems in Mexico [127]
SASM (Sustainable agricultural spatial model)	Take into consideration the land use, geomorphology, and the five factors of sustainability: productivity, security, protection, economic viability, and social acceptability. Mathematical formula expressing sustainability index as a result of the various criteria	[128]	Agriculture in Northern Sinai [128]

Table 2. Methods for evaluate sustainability in farming using composite indicators of agricultural sustainability (CIAS).

integration tools, aggregating values into a single composite index [83]. Clark and Dickson [130] identified saliency, credibility, and legitimacy as three characteristics that determine the effectiveness and success of an assessment tool. The relevance or value of an assessment tool is the use in decision-making. Credibility is authoritativeness of the information and conclusion of the tool. Finally, legitimacy relates to the perceived fairness and openness of the assessment process to political constituencies.

Hardi and Zdan [131] described the “Bellagio Principles” as guidelines for practical assessment of progress towards sustainable development. The assessment should reflect a view of the linkages between the social, environmental, and economic aspects. Essential elements like equity and disparity, economic development, and ecological conditions should be considered. The process of developing the assessment tool should be open, with an effective communication and a broad participation; it should be a continuous, iterative, and adaptive process that provides ongoing support in the decision-making process. An effective model expresses its credibility with the potential users’ confidence and the information derived from it. When occur the translation of the experience of model validation to indicator validation, it is important to consider two aspects: an evaluation of the indicator’s accuracy and an evaluation of its credibility [126].

Nevertheless, a conceptualization of agricultural sustainability presents problems with regard to its operational concretization. First, sustainability requires analyzing the future production

of goods and services by agriculture, a requirement that need to be observed on a reasonable time horizon. Secondly, it is difficult to identify what specific demands agriculture needs to satisfy in order to be sustainable. The greatest difficulty involves interpreting the combination of indicators required for such analyses. Applying various methods of aggregation, the combinations of multidimensional indicators into indices or composite indicators were the contributions of van Calster et al. [132], Hajkowicz [133], and Qiu et al. [134], among others. Composite indicators are an opportunity to identify which aspects of agricultural sustainability are relevant in practice and these are called CIAS (composite indicators of agricultural sustainability) (Table 2).

In the context of multicriteria decision-making, most applications require criteria to be weighted according to importance [135]. The literature shows a plethora of techniques available to build sustainability indices. Some guidance regarding the construction of composite indicators consider a selection of relevant indicators based on strict quality criteria and accurate data gathering to calculate empirical values of these indicators. Before any aggregation, transforming base indicators into dimensional variables (normalization) is required. For this purpose, the use of multiple attribute utility theory and reference values is suggested [23, 93]. According to the importance for each dimension/indicator, the composite indicator had the assignment of weighting. Although there exist a wide variety of functional forms that permit indicators to be aggregated, the use of indices should be done with caution in all cases. All such attempts must be regarded as partial representations of a complex reality. Individual treatment of different agricultural systems allows introducing methodological differences such as the choice of indicators for the evaluation of the empirical sustainability of each case study and the individual treatment of the results [23].

The *Delphi technique* was used to consult experts or advisers (i.e., researchers in different areas of expertise, farmers, and stakeholders from different backgrounds) to build and select the indicators. Indicators were selected and developed through a series of consecutive steps using a combination of bottom-up and top-down approaches. According to King et al. [48], combining both approaches is necessary and provides good results. This technique is normally used to solve complex problems or generate strategies [136]. The main features of the technique are its anonymity, to reduce the influence of “super-experts,” and its contribution to the objectivity of the results [137, 138].

The *MESMIS* (for its acronym in Spanish—Marco para la Evaluación de Sistemas de Manejo de recursos naturales incorporando Indicadores de Sustentabilidad) has an operative structure: Characterization of the systems, identification of critical points, and the selection of specific indicators for the environmental, social, and economic dimensions of sustainability. These information are integrated through mixed (qualitative and quantitative) techniques and multicriteria analysis to obtain a value judgment about the resource management systems and to provide suggestions and insights aimed at improving the socio-environmental profile [62]. The framework is based on the following premises:

- Sustainability is defined by attributes of NRMS: productivity, stability, reliability, resilience, adaptability, equity, and self-reliance.

- Sustainability evaluations are only valid for: a specific management system in a given geographic location; a previously circumscribed spatial scale; and a previously determined time period.
- The evaluation of sustainability is a participatory process requiring an evaluation team with an interdisciplinary perspective. The team should include external evaluators and internal participants (farmers, technicians, community representatives, and others involved).
- Sustainability can be seen through the comparison of two or more systems. The comparison can be made cross-sectionally or longitudinally.

The *IDEA method* is used widely in Europe and assesses a farm sustainability with agro-ecological (18 indicators), socio-territorial (18 indicators), and economic (6 indicators) scales [139].

Response-Inducing Sustainability Evaluation (RISE) is an indicator-based sustainability assessment tool developed by Häni et al. [79]. Its aim is to provide a holistic evaluation of sustainability at the farm level and support the dissemination of sustainable practices. RISE has been applied in over 2500 farms in 56 countries [140]. RISE 2.0 assesses the sustainability performance of a farm for 10 themes (soil use, animal husbandry, nutrient flows, water use, energy and climate, biodiversity, working conditions, quality of life, economic viability, and farm management) and 51 subthemes. The sustainability performance of each subtheme is based on an aggregation of various indicators. These indicators are normalized for each subtheme and can include comparisons between farm and reference data. The score at the theme level is based on the average of the scores of the 4–7 subthemes included in each theme. Scores on theme and subtheme level range from 0 to 100 and are visualized in a polygon.

A hierarchical framework based on the goods and services provided by agricultural ecosystems is the base of the *SAFE method* (*Sustainability Assessment of Farming and the Environment Framework*), resulting in the hierarchy, the principles that are correlated with the three dimensions: economic, social, and environmental [38].

The *Monitoring Tool for Integrated Farm Sustainability* (MOTIFS) allows monitoring farm progress towards integrated sustainability, taking into account economic, ecological, and social aspects [125]. This tool offers a visual aggregation of indicator scores into an adapted radar graph, defining to rescale indicator values into scores between 0 (indicating a worst-case situation) and 100 (indicating assumed maximum sustainability). This allows for a mutual comparison of the indicators for different sustainability themes.

MOTIFS is a sustainability monitoring and management tool, and it allows positioning the strong and weak aspects of a farm; hence it can be used to perform a SWOT analysis (strengths, weakness, opportunities, and threats). It has major assets that could be incorporated in any indicator-based system. It can provide information to farmers for helping them to take action and make decisions. Also, it can guide through the process of assembling and understanding from information and data [126].

Different studies report indicators that have been used to analyze farms' sustainability [141–144] or differences between organic and conventional farms [145, 146]. Considering the sustainability of organic farming and agroecology, there are few methods proposed for evaluating the possibilities on the conversion to organic farming. The *Organic Livestock Proximity Index (OLPI)* is a methodology proposed by Mena et al. [41] and Nahed et al. [127] based on the multicriteria approach for weighting and aggregating multidimensional information. The OLPI of each farm was the sum of its weighted indicator values. The weighting coefficient assigned to each indicator (between 0 and 1) was defined as a function of: its importance according to the principles of organic livestock farming and agroecology and the difficulty in fulfilling the requirements of the European standards on organic production. In this sense, the indicators for assignment of the weights are nutritional management, marketing, soil fertility and contamination, weed and pest control, breeds and reproduction, and animal welfare.

The global OLPI for all case study farms is the average of the indicators. Weights of indicators are based on the importance conferred to them by the experts and are transformed to a percentage scale. As the weighting coefficients must be adjusted in accordance with specific local criteria, OLPI should not be considered if it is used to compare farms of different regions [41]. Some methods based on fuzzy measures have been used in the field of subjective multicriteria evaluation, because the theory of fuzzy logic provides a mathematical means to capture the uncertainties associated with human cognitive processes [147, 148], but in spite of their immense value, fuzzy integrals are difficult to apply to real situations [135]. Mena et al. [41] considered the main advantage of the OLPI method over fuzzy logic in multicriteria analysis is that it is easy to calculate. Once the method proposed has been applied to many farms, the researchers will have a precise idea of the relationship between different criteria and conditioning factors, and therefore, it can be used for decision-making.

Sustainable agricultural spatial model (SASM) integrates five factors (productivity, security, protection, economic viability, and social acceptability) using geographic information system (GIS), analytical tools for the purpose of combating and tackling sustainable agricultural constraints, and optimum land use planning [128].

In the end, the sustainability of agroecosystems depends on their basic characteristics and how, why, and through which variables are affected within each dimension. Convenience in the analysis of agroecosystems should not be viewed from an anthropocentric point of view but rather in a broader (holistic) way that favors the sustainability of production systems and that takes into account the hierarchy and complexity of agricultural systems. The use of the property as a unit of study is satisfactory to the extent that the interactions of the different activities carried out are considered and evaluated, along with externalities, complementarity, and interference with adjacent farm activities [149].

7. Conclusions

Productivity, security, protection, viability, and acceptability are the main factors of sustainable land management. But, implementing sustainability remains a hard event in many agricultural

situations, and the concept of sustainability needs to integrate a comprehensive assessment of ecological, economic, and social dimensions to achieve sustainable agriculture.

Sustainability evaluation is a multidimensional issue involving huge amounts of complex information. Therefore, perfect evaluation is uncommon; in this sense, there is a need to systematically reduce the complex information to a more concentrated form while constructing the pyramid of information aggregation, at the base of which are raw data and at the top the indexes.

The first generation sustainability indexes do not incorporate interrelations between the components of a system. Examples are environmental indicators, as CO₂ emissions, deforestation or erosion. The second generation use composed indicators, normally with four dimensions: economic, social, productive, and environmental. Now, there are coming the third generation, indicators that it is necessary to build. They correspond to binding synergistic or transversal indicators, which simultaneously incorporate several attributes or dimensions of sustainability.

The assessment of sustainability needs to continue exploring in agriculture systems an integrated approach, and in the future, the set of multidimensional indicators (economic, ecological, social, and technical indicators) will be evaluating both separate parts of the system and their relationships.

Abbreviations

NRMS	Natural Resource Management Systems
EF	Ecological Footprint
MOTIFS	Monitoring Tool for Integrated Farm Sustainability
SWOT	strengths, weaknesses, opportunities, and threats
OLPI	Organic Livestock Proximity Index

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