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PROGRAMA DE PÓS-GRADUAÇÃO EM ADMINISTRAÇÃO

A MULTI-CRITERIA MODEL FOR ASSESSING THE SUSTAINABILITY OF FAMILY FARMING

DISSERTAÇÃO DE MESTRADO

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Co-Orientadora: Prof.a Dr.a Vanessa Batista Schramm

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BRUNO CICCIÙ

"**A MULTI-CRITERIA MODEL FOR ASSESSING THE SUSTAINABILITY OF FAMILY FARMING**"

Dissertação apresentada ao Programa de Pós-Graduação em Administração (PPGA-UFCG) como pré-requisito para obtenção do título de Mestre em Administração.

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À minha esposa Ana Simara, a mais linda flor no caminho da minha vida, um raio de luz que brilha como o eterno sol, ternura infinita que transborda num rio de amor.

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ABSTRACT

This study aims to propose a multi-criteria model to assess family agricultural sustainability. To achieve this objective, three scientific papers were developed. The 1st paper performs a literature review on the use of multi-criteria decision making/aid (MCDM/A) methods for assessing agricultural sustainability, focusing on verifying the evolution of this area over the last two decades. Data were analyzed through bibliometric and content analyses which have been performed using Bibliometrix and Nvivo tools. The 2nd paper aims to propose an integrated framework based on MESMIS and Delphi methodologies to derive family farming sustainability indicators with regional validity. The proposed framework was used as input for a multi-criteria model that has been developed and implemented in the 3rd paper. The 3rd paper aims to develop a non-compensatory MCDM/A model aiming at assessing the sustainability performance related to smallholder family farms in a given region. The study presents managerial, theoretical, and social contributions. In the theoretical context, it contributes to an advance in knowledge of the MCDM/A method related to the study of family farming. As for managerial contributions, it can be used by farm managers and policymakers as a guidance in the decision-making process, while in the social context it offers the possibility for the family farms to improve their sustainability performance with positive consequences for them as well as for the society as a whole.

Keywords: Agricultural sustainability, Family farming, Multi-criteria methods, MESMIS framework

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RESUMO

Esse estudo tem como objetivo propor um modelo multicritério para avaliar a sustentabilidade da agricultura familiar. Para alcançar esse objetivo, foram desenvolvidos três artigos científicos. O primeiro artigo realiza uma revisão de literatura sobre o uso de métodos multicritério na avaliação da sustentabilidade agrícola, visando destacar a evolução desta área de conhecimento nas últimas duas décadas. Os dados foram tratados por meio de uma análise bibliométrica e de conteúdo as quais foram realizadas por meio dos softwares Bibliometrix e Nvivo. O segundo trabalho tem como objetivo propor um framework integrado baseado nas metodologias MESMIS e Delphi para derivar indicadores de sustentabilidade da agricultura familiar que tenham validade regional. O framework proposto foi utilizado como input para um modelo multicritério de apoio à decisão desenvolvido e implementado no terceiro artigo. O terceiro artigo visa desenvolver modelo multicritério non-compensatório para avaliar o desempenho sustentável dos pequenos agricultores familiares em uma determinada região. O estudo apresenta contribuições gerenciais, teóricas e sociais. Do ponto de vista teórico, contribui para o avanço do conhecimento na área dos métodos multicritério correlatos ao estudo da agricultura familiar. Pelo que concerne as contribuições gerenciais, ele pode ser usado como guia no processo de tomada de decisão de gerentes de fazendas e formuladores de políticas, enquanto no contexto social oferece a possibilidade de a agricultura familiar aumentar o seu desempenho sustentável com consequências positivas para os agricultores assim como para a sociedade como um todo.

Palavras-chave: Sustentabilidade agrícola, Agricultura familiar, Métodos multicritério, MESMIS framework

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LIST OF ABBREVIATIONS AND ACRONYMS

AHP	Analytic Hierarchic Process
ANP	Analytical Network Process
ARGUS	The German acronym for "Allocation module for computer-aided generation of environmental strategies for emissions"
CONTRA	The French acronym for "design of transparent decision trees"
EESC	European Economic and Social Committee
EVAMIX	Evaluation of Mixed data
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
IBGE	The Brazilian Institute of Geography and Statistics
IFAD	International Fund for Agricultural Development
INCRA	National Institute for Colonization and Agrarian Reform
MELCHIOR	Méthode d'Élimination et de Choix Includent les relations d'Ordre
MCDM/A	Multi-Criteria Decision Making/Aid
NAIADE	Novel Approach to Imprecise Assessment and Decision Environments
NGO	Non-Governmental Organization
OECD	Organization for Economic Co-operation and Development
ORESTE	Organisation, Rangement, et Synthèse des données rationnelle
QUALIFLEX	Qualitative Flexible multicriteria method
SDGs	Sustainability Development Goals
UN	United Nations

CONTENTS

CHAPTER 1

INTRODUCTION

1. Introduction

Agricultural development has an extremely important role in the global economy. According to the World Bank, agriculture represents one of the most powerful tools to end extreme poverty, feed an estimated population of 9.7 billion people by 2050, and boost shared prosperity (The World Bank, 2021a). Considering this, agriculture can be considered a cornerstone of human existence and national development, especially for Brazil, which has been becoming ever more one of the main agricultural countries in the world.

According to Embrapa (2020), Brazilian agriculture is recognized as highly competitive and a generator of jobs, wealth, food, fiber and bioenergy for Brazil and other countries. It is one of the sectors that most contributes to the growth of the national GDP, which corresponds to 21% of the sum of all the wealth produced, a fifth of all jobs and 43.2% of Brazilian exports, reaching 96.7 billion dollars in 2019. Even considering situations of global crises, such as the current COVID-19 pandemic, data indicate that in Brazil, food production from agriculture will show the highest growth rate among the largest food producers and consumers in the world (Zia et al., 2019).

However, according to Porto (2012), it is necessary to emphasize that the hegemonic agrarian model in Brazil is based on monocultures for export, which are intensive in mechanized technologies and the use of pesticides. This model of agrarian development and its production and consumption processes, based on the "green revolution" techniques – that is, alteration in the genetics of seeds, application of pesticides, highly mechanized production, monoculture – has been generated serious socio-environmental problems, because the high technology allied to high productivity and the uncontrolled use of pesticides has been contributed to the rural exodus, the concentration of income, the loss of the landscape aesthetics and environmental quality, the decrease of biodiversity, thus not being considered as sustainable and long-lasting (Veiga, 2001).

By virtue of these collateral effects that conventional agriculture has been causing, and the importance that the role of agricultural activities occupies, public opinion is becoming even more sensitive to a paradigm shift that can lead to the progressive abandonment of unsustainable practices and the formulation of agricultural systems more in line with environmental preservation and socially useful.

According to Ikerd (1993), sustainable agriculture must preserve its productivity and utility for society in the long term. This implies that agricultural activities must be environmentally sound, resource-conserving, economically viable, and socially acceptable. In other words, sustainable agriculture must incorporate the logic of the production system, ecological cycles, the reduction of the use of the external inputs, social justice in the distribution of work and its results, the increase of genetic and biological diversity, knowledge and values of the local community, and the rationalization of production to eliminate waste and the inappropriate use of resources. Agricultural sustainability, therefore, includes the consideration of economic, social, and environmental issues associated with agriculture (Talukder, 2016).

Meanwhile, achieving and maintaining environmental, economic, and social sustainability simultaneously is a very difficult task because different stakeholders are involved and each one of them emphasizes different goals. Stakeholders such as farmers, governments, NGOs, experts, scientists, local and international businesses play a very important role in the agricultural sustainability since they have different perspectives about it, and consequently they place different emphases on the various goals of sustainability.

In addition, agricultural sustainability is also characterized by an interdisciplinary approach, by virtue of the fact that it encompasses a wide array of areas of knowledge such as biophysical, social, environmental, economic, politics, mathematic, among others. The integration well-done of this knowledge can improve the sustainability of agricultural systems (vanLoon et al., 2005).

It is interesting to note also that sustainable agriculture has become a very important point taken seriously into consideration by the SDGs. Goal number 2 of the SDGs – that is, ending hunger, achieving food security and improved nutrition, and promoting sustainable agriculture – emphasizes, in fact, the need to achieve a sustainable form of agriculture (BRASIL, 2021). In this context, family farming is widely considered as the most sustainable form of agricultural production system (Fuller et al., 2021). The definition of family farm varies across countries and context. There are around 36 definition of family farming in literature, and all of these definitions share several characteristics, above all the role of the family labor and the role of the family in managing the farm operation, as well as agricultural operations as dominant source of family income (Graeub et al., 2016). Family control over production is thus primary in these definitions.

Based on these findings, the UN defines a family farm as any type of agricultural, fishery or forest production where a family is central (FAO and IFAD, 2019). In addition, in his turn, Abramoway (1998) argues that family farming is in which the management, property, and most of the work derive from individuals who have blood or marriage ties between them.

Furthermore, according to the author, family farming is a social sector around which it is possible to build an ambitious project of development.

In line with these findings, FAO (2019) argue that family farming offers a unique opportunity to ensure food security, improve livelihoods, better manage natural resources, protect the environment, and achieve sustainable development in rural areas. Thanks to their wisdom and care for the heart, family farmers are the agents of change we need to achieve zero hunger, a more balanced and resilient planet, and the sustainable development goals. In agreement with this, Veiga (2001) states that the rural development without productive specialization, but characterized by economic diversification, based on family farming, can be considered as ideal from the point of view of sustainability. Souza (2002) corroborates this finding, pointing out that family farming, being able to operate on a smaller scale and to combine vegetal and animal production, becomes ideal for the establishment of more sustainable agricultural practices. According to the author, family farming can adapt more easily to economic practices whose benefits are long-term, breaking with the economic immediacy of the contemporary market.

In light of these issues, therefore, it would be worthwhile to evaluate the extent to which family farming can be considered sustainable. In other words, can family farming truly guarantee healthy and safe foods for all people, being simultaneously economically viable, environmentally sound, and socially useful? Aiming at fulfilling this question, it is interesting to dispose of models, methods and techniques that allow assessing the sustainability of family farms.

However, to assess the sustainability of family farms, it is necessary also to operationalize its construct, which, because of its nature, remains very conceptual and sometimes very difficult to be applied in practice. Toward this goal, researchers around the world and various stakeholders have been working together to translate this concept into a more operational framework, using indicators, indexes or methods based on them.

There are, in literature, a wide range of methods that have been developed over the years aiming at assessing the agricultural sustainability, few of them have been projected exclusively for the assessment of family farming (for instance the MESMIS framework, acronym for Indicator-based Sustainability assessment Framework), while the majority have been adapted and employed for this task. Among these last ones, it is worthwhile mentioning the RISE (Response-Inducing Sustainability Evaluation) that has been defined by Cândido et al. (2015)

as idoneous for the sustainability assessment of smallholders family farms, even though in disadvantages with regard to MESMIS.

Another important framework to assess family farming, is the Multiscale Methodological Framework (MMF) (López-Ridaura et al., 2005), which allows the assessment of peasant agriculture sustainability at different levels (farm, community, municipality, sub-region, region). The MMF has been developed using the MESMIS as a base, but, conversely, takes into consideration only 5 sustainability attributes (Productivity, Stability, Resilience, Reliability, and Adaptability). In addition, we can cite other important methods used to evaluate the sustainability of family farming, such as the Sustainability Assessment of Farming and the Environment (SAFE), and Monitoring Tool for Integrated Farm Sustainability (MOTIFS). All the methods above mentioned use a set of indicators to assess the sustainability of the system under analysis but don't permit the aggregation process of indicators into a single index.

In general, an indicator is a quantitative or qualitative measure derived from a series of observed facts that can reveal relative positions in a given area (OECD, 2010). According to Marzall and Almeida (2000), assessing sustainability implies the use of a set of indicators whose quantity depends on the principles of sustainability taken into consideration. The aggregation of these individual indicators into a single composite item constitutes an index. An index should ideally measure concepts that cannot be captured by a single indicator (for instance competitiveness, industrialization, sustainability, etc.).

Always according to OECD (2010), there are pros and cons in the use of indices. On the positive side, indices can summarize complex multidimensional realities and facilitate decision making; they are easier to interpret than a set of many separate indicators; if mathematically well-constructed, they can concentrate the information carried by all indicators singularly. On the negative side, instead, if the construction process is not transparent, mathematically robust, or lacks conceptual principles, they can lead to simplistic conclusions and misleading interpretations.

For this reason, according to Feil and Schreiber (2016), the construction of a sustainability index needs solid scientifical methods in each of its steps, that is: (i) normalization; (ii) weighting; (iii) aggregation; (iv) index formation; (v) sensitivity and uncertainty analysis. The first three steps are more critical by mathematical point of view. Normalization is a process that allows to bring to the same measure variables that are measured on different scales, making them comparable. If the normalization process is not done, the aggregate result may lack mathematical meaning. The weighting process emphasize the contribution of variables (indicators) in generating the results, assigning them importance in the analysis. Aggregation, on the other hand, is a process that condenses the information from the indicators into a single item.

Different aggregation methods exist that differ based on the amount of information lost in the process. Therefore, the use of different aggregation methods results in different indexes. According to Talukder et al. (2017), the aggregation types commonly applied are: (i) the additive aggregation (arithmetic mean); (ii) the geometric aggregation (multiplication), and (iii) multi-criteria methods. Meanwhile, despite being used in a wide range of areas of knowledge for decades, the MCDM/A methods in assessing agricultural sustainability are still a novelty, and, therefore, they need improvement (Talukder, 2016). This is even more true when it comes to assessing the sustainability of family farming. Moreover, most of the studies present in the literature, facing the sustainability assessment of agricultural systems (including family farming) using MCDM/A methods, almost always adopt compensatory methods, which make it possible to compensate for low performance in one dimension of sustainability with high performance in another dimension (Cicciù et al., 2022).

Although many authors agree with the conceptual difference between strong sustainability (where trade-offs between dimensions are not possible) and weak sustainability (which admits trade-offs between dimensions) (Deytieux et al., 2016; Munda, 2008), in this work, the adoption of compensatory rationality in the assessment of sustainability is considered a conceptual error, because according to Schramm et al. (2020), it doesn't make sense that environmental and social aspects be compensated by economical ones. As a result, it can be stated that non-compensatory methods are the most appropriate for assessing sustainability in general, and consequently also agricultural sustainability.

Considering what has been exposed, the study will be guided by the following research question: **how to assess family agricultural sustainability using a set of reliable indicators having regional validity in an MCDM/A model that is mathematically robust and avoids trade-offs between the dimensions of sustainability?**

1.1. Objectives

1.1.1. Main objective

In order to answer the research question, the present study aims to propose a set of indicators and a non-compensatory multi-criteria model aiming at assessing family agricultural sustainability in the Brazilian Semiarid Region.

1.1.2. Specific objectives

(i) To perform a literature review on the use of multi-criteria methods for assessing agricultural sustainability

(ii) To propose an integrated framework aiming at deriving family farming sustainability indicators having regional validity.

(iii) To develop a non-compensatory MCDM/A model in order to assess the sustainability performance related to smallholder family farms in the Brazilian Semiarid Region.

1.1.3. Motivation

Family farming constitutes the predominant form of agricultural production in both developed and developing countries, producing over 80% of the world's food in value terms (FAO & IFAD, 2019), in fact most farms across the world are family farms (Van Vliet et al., 2015; Graeub et al., 2016). When it comes to Brazilian country, according to the Agricultural Census (IBGE, 2021), 76.8% of Brazilian rural establishments fit the family farming model. The contribution of family farming to agricultural production is not small, as 38% of the value of production and 34% of the total revenue of Brazilian agribusiness comes from this sector

Various worldwide initiatives such as the International Year of Family Farming occurred in 2014, and the recent UN resolution which recognized 2019-2028 as the International Decade of Family Farming, point out that the social, economic, and environmental contribution of family farming is highly perceived not only by the international institutions but also by the stakeholders and public opinion around the world.

Looking in the Paraiba state, it is possible to highlight that the importance of family farming is present both in terms of income generation and employment. In relation to employment, 73.4% of the 424.116 people employed in agriculture in Paraiba are absorbed in family establishment which are responsible for 44.5% of the income of all agrarian establishments of the state.

These data, point out that the family farming sector in Brazil has acquired, over time, fundamental importance because, in addition to being able to provide environmental benefits, it can trigger a whole series of social benefits such as the generation of jobs, increased production and supply of food consumed by Brazilian people, reduced rural exodus, and finally the introduction of virtuous circles in local economies such as in Paraiba state. This view has encouraged researchers from universities and research centers to study to what extent the family farming can be considered sustainable. In this context, it is necessary to have models, methods and techniques that allow to measure and assess the extent to which agricultural practices adopted in a given family farming system can be considered more or less sustainable.

In general, sustainability assessment is used as a policy tool for planning and decision making. According to Guijt and Moiseev (2001), sustainability assessment is mainly used: (i) as an input for strategic planning and decision making; (ii) as a source of information for monitoring, assessing and analyzing impacts; (iii) as a source of information for developing sustainability reports; (iv) as a tool to raise awareness.

In 2020, the Brazilian government has designed a very interesting law proposal (PL n. 4478/2020), currently being evaluated in the Chamber of Deputies, which aims to implement the System of Assessment and Certification of Environmental compliance, Social and Governance (SISASG) whose objective is to assess and further to certificate the sustainable performance of agrarian production, from the small farmers to the large intensive companies. The purpose of this law proposal is to encourage sustainable practices in agriculture as a whole and to give more international visibility to Brazilian agriculture.

By virtue of this new context, sustainability assessment of agricultural systems acquires more prominent importance, and considering the supremacy of family farming in Brazilian territory, the need to have an effective and efficient assessment model of family farming sustainability is evident.

2. Theoretical background

2.1. Agricultural sustainability

Since 1960, agriculture has been a central concern in sustainability because of its impacts on food production, its pervasive use of natural resources, and its effects on the environment. This concern led to the development of the idea of sustainable agriculture that initially focused on the environmental dimension and later has improved including economic and social dimensions (Talukder, 2016).

In many studies, it is widely accepting the consensus that sustainable agriculture is able to ensure the future food demand through some practices such as reduced tillage, integrated pest management, crop rotation, efficient water use, wild habitat enhancement, and improving community well-being, among others.

Moreover, agricultural sustainability is a complex and dynamic concept, that is specific to time and space (Gómez-Limón & Riesgo, 2010), as a consequence its application is constantly being developing and improved. There is in literature a wide range of agricultural sustainability definitions, and the choice of one of them defines what dimensions should be selected and considered, what criteria, and consequently the way in which the sustainability assessment will be undertaken.

Schaller (1993), points out that the term sustainable agriculture has become a popular code word for an environmentally sound, productive, economically viable, and socially desirable agriculture. According to the author, the concept of agricultural sustainability does not lend itself to a precise definition, partly because it implies a way of thinking as well as of using farming practices, and because the last ones cannot be specified as final answer. One of the most operational definitions of agricultural sustainability has been offered by FAO (2013), according to which agricultural sustainability is defined as human activities to produce food and fiber in a manner that ensures the well-being of the present and future community without diminishing the surrounding ecosystems' capacity and ensuring environmental integrity, social well-being, resilient local economies, and effective governance.

The concept of agricultural sustainability involves various issues both at macro and micro scales. Macro sustainability take into consideration the consumption of resources at national and global level, international trade and environmental regulations, greenhouse gas production, regulatory legislation, equity in food supplies between nations and preserving environmental and social values in global rural society.

Micro sustainability, instead, take into consideration issues related to the productivity of individual farmer, such as availability of financial and physical resources, financial viability of farmers, ability to grow crops in a safe manner, equity with the local community (Talukder, 2016).

The application of agricultural sustainability requires a great effort because its concepts are very complex in terms of local, national, or global scale. In applying these concepts seven concerns can be distinguished: (i) integration of capitals; (ii) maintaining resilience, adaptation, and transformation; (iii) ensuring system performance; (iv) involving stakeholders; (v) mixing interdisciplinary views; (vi) integration of scales; (vii) practicing good governance.

The integration of capitals refers to the need of natural, human, social, financial, and physical capitals that are indispensable to manage agricultural sustainability.

Resilience is, likely, the most important attribute in order to achieve and maintain agricultural sustainability. This term has been coined by Holling (1973), according to who, resilience is a concept to help understand the capacity of ecosystems with alternative attractors to persist in the original state subject to perturbations. One of the most cited definition of resilience was provided by Walker et al. (2009), according to which resilience is the capacity of a system to absorb disturbance and reorganize while undergoing changes so as to still retain essentially the same function, structure, and identity.

Across the years, various definitions of resilience have been provided. According to Talukder (2016), resilience refers to the ability of people, household, communities, countries, and systems to mitigate, adapt to, and recover from shocks and stresses such as floods, water shortage, lack of agricultural inputs (for instance fertilizer, seeds, etc.), economic crises, and geopolitical crises - such as actually happens due to the conflict between Russia and Ukraine – in order to reduce chronic vulnerability. Urruty et al. (2016), in their turn, define resilience as the capacity of socio-ecological systems to adapt and transform in response to unfamiliar, unexpected and extreme shocks. In other words, they study resilience through the way that socio-ecological systems persist and innovate when facing unknown perturbations. In line with these findings, Folke et al. (2010) argue that resilience is the ability of agricultural systems to respond to changes, to reorganize their structures, to anticipate future changes and to take advantage of new opportunities.

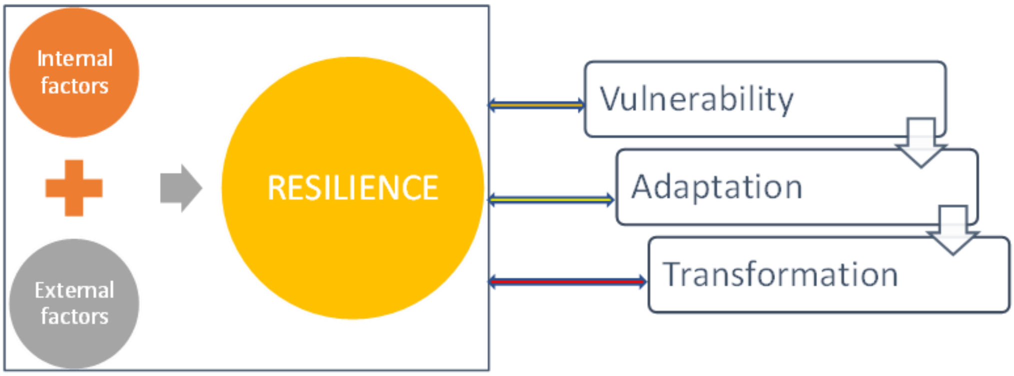
In light of these definitions, it is clear that the lack of resilience can lead the agricultural system to an irreversible collapse (EESC, 2013).

Resilience, in addition, is not an isolated concept, but it works in an interlinked structure in which are considered also internal and external factors of agriculture in managing vulnerability, as well as adaptability and transformability. It can be considered internal factors, some issues such as soil properties, availability of water, temperature, farmers' skills and knowledge, farmers' economic conditions, women's participation, and equity, among others. While external factors are those that cannot be controlled directly by farmers such as globalization, governmental policy, political agenda, investments, shortage of rainfall, etc.

The vulnerability can be seen as the state of susceptibility to harm from exposure to stresses associated with environmental, social, and economical changes, and from the absence of the capacity of adaptation to it. Thus, vulnerability refers to a state of fragility, a disposition of agroecosystem to be hurt (Urruty et al., 2016). By means of knowledge of internal and external factors, it is possible to identify the vulnerability of the agricultural system.

Once the vulnerability was identified and recognized, an adaptation process must be undertaken, which permits to manage all the risks associated with the vulnerability. And finally, the adaptation process leads to a transformation process which re-establishes the equilibrium and feeds the resilience of the system. Figure 1 shows the whole interaction.

Figure 1: Factors affecting resilience of agricultural systems



Source: Adapted from (Talukder, 2016)

An agricultural system is interlinked also with other systems (economic system, social system, environmental system) and each system needs inputs from other ones to be productive and performant, because in isolation no one can produce anything. Therefore, an agricultural system can be considered as sustainable when it protects and helps to improve the economic, social, and environmental systems of agriculture in a circular way. That is which characterizes the so-called system integrity.

Agricultural sustainability, furthermore, widely depends on stakeholders' perspectives and policies. Stakeholders such as farmers, government, NGOs, experts, academics, and advocacy groups, influence the direction of activities that lead to more or less agricultural sustainability (Pope et al., 2000). For these reasons, it is interesting and necessary to include stakeholders' participations in all sustainability assessment processes. Moreover, this allows a mix of interdisciplinary views which provide a more in-depth image of the agricultural system under analysis.

The concern related to the integration of scales refers to the fact that agricultural sustainability, as a phenomenon, can be study across a spectrum of scales, that is, through different spatial, temporal, quantitative, or analytical dimensions. The lack of a right integration of these scales can lead to wrong policies, management approaches and assessment to help agricultural sustainability.

Finally, a good governance is fundamental to achieve the agricultural sustainability. Indeed, governance represents a binding force among the various stakeholders and dimensions involved in agricultural sustainability, providing policies, norms, regulations, technology support, and access to knowledge.

It is widely accepted that family farming is the most sustainable form of agriculture across the world. According to Abramoway (1998), much more than an economic and social segment clearly delimited, family farming is defined as a value. The support that family farming gets, stems from the consequences that its development can provide, that is better living conditions, sustainable development, and eradication of poverty. More than this, the author argues that family farming is seen as a social sector able to counterbalance the tendency of our society to depreciate the rural mean as a place in which it is possible to build new and better life conditions with respect to the "civilized" urban areas. This is even more true in developing countries such as Brazil.

2.2. The family farming in the Brazilian context

As it is largely known, agriculture in general and family farming specifically are considered the most essential activities in the world. Further to producing food, family farming is linked to nutrition security, preservation of agro-biodiversity, and sustainable use of natural resources. The World Bank report recognized the importance of small and mid-sized land holdings in the countries with the highest indices of porty, and, specifically for the Brazilian case, the relevance of small farmer in the creation of employment, and the production of food and agro-industrial products (The World Bank, 1994).

Meanwhile, in Brazil, over time, family farming played a secondary and subordinate role to large-scale agribusiness, which has been favored by agricultural policies designed to modernize and ensure its reproduction. Moreover, infrastructures and rural credit programs have always favored cash crop production over food crops (Petrini et al., 2016).

This situation began to change with the creation of Pronaf (National Program for Strengthening Family farming) in 1996. This revolutionary program signaled, for the first time, public concerns about family farming, and since then policy makers viewed family farming as an important generator of employment and income. Since then, Brazilian government has formulated various public policies becoming Brazil, among other developing countries, that which stimulates more production in the family farming sector.

The Brazilian law nº 11.326/2006 provides a formal definition of family farming. According to this law, family farms should meet all the following criteria: (i) don't exceed the maximum area of landholding for the municipality or county where the farm is located; (ii) to use, predominantly, the labor of its own family within the economic activities of their establishments; (iii) to have a family income mainly from economic activities tied to establishment itself; (iv) to manage their establishment with its family.

However, notwithstanding the wide range of definitions provided so far, the concept of family farms in Brazil is still far to be clear, specially concerning its dimensions, and its economic scope. According to Souza (2002), family farming can be seen as a generical category because the association between family work and property takes different forms concerning the organization and the production objectives over time and space. The author points out that developing a definition that takes into consideration the complexity with which modern family farming manifests is an arduous task, as it doesn't only involve the type of working relationship within it. In reality, economic dimensions are also involved as well as political-administrative too.

A definition based only on family work doesn't enough to meet, for instance, issues related to financing, supply policy, and agrarian reforms. Criteria such as the income earned, economic scope, and number of employees must be taken into account. Meanwhile, family farming is generally considered synonymous with "little" agriculture, in opposition to a prosperous agriculture or to a rural capitalist family farming that doesn't depend on incentives or government credits. One of the main contributions of rural studies was to demonstrate that is not the size that defines the family farm, but the centrality of the family in the management and ownership of property, and these elements distinguish it from the commercial farmers or business establishments.

Therefore, the definition of family farming provided by the law nº 11.326/2006 presents some limitations, especially with regard to the attempt to assign a size to family farms, and in addition for doesn't take into account the possibility to use external work and the recruitment of permanent external employers.

According to Souza (2002), considering family farming only as a poor activity is merely an imposition of a socio-cultural belief, in fact the author argues that different forms of family farms exist corroborating the findings of FAO/INCRA (1994). Thus, there are the large and medium-sized family properties classified as companies; small properties classified as consolidated family businesses, which make use of high technology, have credit, and are focused on the demands and logic of marketplace; family business in transition that have a greater diversity of crops, use low technology, and begins to be market oriented; and finally, peripheral or subsistence family farms that don't use technology and is absolutely non-market oriented. The last one is characterized by a very low rate of instruction and a high rate of poverty.

These findings point out that the focus of the Brazilian government must be the intermediate category with the aim of consolidating it, while specific agrarian and social policies needed to be prepared for the peripheral family farms. The objective should be the support for an integrated global development of family establishments, through the education and training and/or rural technical assistance, the adoption of an agro-industrial based production, and the stimulation of sustainability practices.

In order to support these intentions, MCDM/A methods can be used as guidance for a broad range of users, from family farm managers to policymakers, that who aim to improve the sustainable performance of family farm production units.

2.3. Agricultural sustainability assessment and MCDM/A methods

Given the urgent need for increasing agricultural sustainability in the world comprehensive responses are required to understand the complex dynamics between social, economic, and environmental sustainability. Agricultural sustainability assessment constitutes one of these responses (Talukder & Blay-Palmer, 2017).

Effective and comprehensive assessment methods can reconcile the complex concepts involved in interpreting and applying agricultural sustainability at different scales from local to global, aiming to increase the attention to social, environmental and economic resilience and good governance in agricultural systems (Talukder, 2016).

However, it is very difficult to capture the systemic complexity of agricultural sustainability through assessment because sustainability is a theoretical concept linked to durability, and putting it into practice often proves to be very challenging (Gaviglio et al., 2017).

Agricultural sustainability assessment is an important process for promoting the concept of sustainable agricultural systems since it incorporates sustainability principles into agricultural policy planning and decision making (Astier et al., 2012). The purpose of agricultural sustainability assessment is to provide decision makers with an evaluation instrument to help determine which actions should or shouldn't be taken in attempt to move toward sustainable agriculture.

Despite the real utility of these instruments, achieving a shared method or approach for assessing agricultural sustainability is probably a utopian goal for three main reasons. Firstly, an agricultural system is a very complex system that can vary across time and space by virtue of the social and cultural features of a given region and by virtue of local agricultural priorities and practices. Secondly, sustainability is a dynamic concept and consequently its features, such as dimensions and variables, can be extended and improved over time. Thirdly, sustainability has a relevant subjective component that could lead to a loss of its effectiveness.

As a consequence, a wide range of methods have been developed in the last three decades for assessing agricultural sustainability at different levels (spatial applicability) that is, international, national, regional, farm, or product level. According to (Talukder & Blay-Palmer, 2017) there are more than 120 assessment tools used around the world for assessing agricultural sustainability. Some methods are classified as non-holistic, that is, through them only one aspect of sustainability is assessed – for instance LCA (Life Cycle Analysis) – and some others are classified as holistic methods (such as SAFE, MESMIS, MMF, MOTIFS, IDEA, among others) that is they take into consideration the three pillars of sustainability. Further, some methods are expert-driven (top-down), while some are only stakeholders-driven (bottom-up). Some methods are based on indicators, and some are based on indexes.

The complexity of agricultural sustainability requires holistic methods in order to understand the dynamic interactions between agriculture, economy, society and environment which use different scales. Understanding the interconnections across these scales is important for better planning agricultural sustainability because the information, policies and action associated with each scale affect sustainability issues at other scales (vanLoon et al., 2005).

Existing holistic methods have some limitations such as, don’t generate aggregate results, generating aggregated results without considering stakeholders’ opinions, and/or assessing complex agricultural systems without taking into consideration the interconnections and interdependencies between the different scales. Therefore, it exists an opportunity to identify a framework that can help to overcome these above-mentioned problems. MCDM/A can be helpful in this regard, moreover, according to Talukder et al. (2018), the use of MCDM/A methods in assessing agricultural sustainability is relatively new.

MCDM/A consists of a branch of operational research/management science and allows methods that facilitate decision making (such as sorting, ranking, and selection) in the presence of many conflicting criteria. In MCDM/A, a decision making finds the best scenario that suits the goal among a set of alternatives. Generally, MCDM/A approach follows several phases. It starts by defining objectives, after which the criteria are chosen to measure the objectives and then alternatives are specified. Once the criteria and alternative are fixed, the criteria are translated into commensurable units through the use of indicators. Successively, weights are assigned to reflect the importance of each indicator and each criterion. In the last phase, mathematical algorithms are used for ranking or choosing an alternative.

According to Almeida (2013), these methods can be classified in different ways. Regarding the approach, MCDM/A methods can be classified as compensatory and not compensatory. The selection of the right approach depends on the decision maker's preference structure and on the type of rationality he/she considers in the context of the study. Compensatory methods allow trade-offs between attributes, that is, an unfavorable disadvantage or value in one attribute can be compensated by a favorable advantage or value in another attribute.

Another very common classification found in the literature for MCDM/A methods considers three main types of methods: single synthetizing criterion methods, outranking methods, and interactive methods (Vincke, 1992). To the first group belong the methods based on the deterministic additive model, such as AHP (Analytic Hierarchy Process), MACBETH (Measuring Attractiveness by a Category Based Evaluation Technique), SMART (Simple Multi-Attribute Rating Technique), FITradeoff (Flexible Interactive Tradeoff). To the second group belong, instead, the family of ELECTRE methods (ÉLimination Et Choix Traduisant la REalité), and PROMETHEE methods (Preference Ranking Organization Method for Enrichment Evaluations), which are characterized by a non-compensatory approach. Finally, to the last group belong the multi-objective programming methods which are mostly interactive methods.

MCDM/A methods combines and aggregates economic, social, and environmental indicators in order to quantify sustainability in a holistic manner and prioritize the sustainability performance of agricultural systems through incorporating stakeholder inputs in the form of weighting. This allows an integrated assessment and handles data from the three pillars of sustainability.

3. Research method

This thesis used the model of scientific articles as foreseen in the regulation of the Programa de Pós-Graduação em Administração of Federal University of Campina Grande (PPGA-UFCG). To achieve the main objective the research was divided into two steps:

exploratory and descriptive. In the exploratory step, a paper was developed, which allowed analyzing how research using MCDM/A methods for assessing agricultural sustainability has evolved over the last three decades. This paper gave the basis for the descriptive step of the research in which two papers have been undertaken (2nd article and 3rd article). Table 1 summarizes the research design.

Table 1: Research design. Source: The author (2021)

RESEARCH CLASSIFICATION	Qualitative and quantitative, cross sectional, exploratory, descriptive		
RESEARCH PROBLEM	How to assess family agricultural sustainability using a set of reliable indicators having regional validity in a multi-criteria model that is mathematically robust and avoids trade-offs between the dimensions of sustainability?		
MAIN OBJECTIVE	To propose a set of indicators and a non-compensatory multi-criteria model aiming at assessing family agricultural sustainability in the Brazilian Semiarid Region		
PAPERS	**SPECIFIC OBJECTIVES**	**DATA COLLECTION**	**DATA PROCESSING AND ANALYSIS**
MCDM/A METHODS FOR ASSESSING AGRICULTURAL SUSTAINABILITY: A LITTERATURE REVIEW	*To perform a literature review on the use of multi-criteria methods for assessing agricultural sustainability*	*Web Of Science*	*Bibliometric analysis, Content analysis (Bibliometrix, Nvivo, Excel)*
A FRAMEWORK TO DERIVE FAMILY FARMING SUSTAINABILITY INDICATORS AT A REGIONAL SCALE	*To propose a framework to derive a set of exhaustive indicators for assessing family farming sustainability indicators having regional validity*	*Documents consulting, semi-structured interviews with stakeholders and experts, field observations*	*Content analysis, MESMIS framework, Delphi method (Atlas.ti, SPSS)*
DEVELOPMENT OF A MODEL FOR EVALUATING FAMILY FARMING SUSTAINABILITY BASED ON A NON-COMPENSATORY AGGREGATION OPERATOR	*Developing a non-compensatory MCDM/A model to assess and manage the sustainability performance related to smallholder farming systems production in the BSR*	*Documents consulting, workshops with experts and stakeholders, Web of Science, Google Scholar*	*De Borda method*

The 1st paper (the publication's proof is on Appendix III) performs a literature review on the use of MCDM/A methods for assessing agricultural sustainability, focusing on verifying the distribution of papers according to year, journal, and countries; to identify the most productive authors in the area, the most frequently used MCDM/A methods and their characteristics, the type of system (spatial applicability) and the type of agriculture in which these methods are being performed, the methodological approaches and assessment types, the dimensions used in each method; and to present methodological and theoretical advances as well as emerging topics. The review database is comprised of 41 papers that are published between 1999 and 2021.

The 2nd paper (the submission proof is on Appendix IV) aims to propose a framework to derive family farming sustainability indicators having regional validity. The framework is based on the MESMIS methodology and uses content analysis to derive indicators, thereafter a modified Delphi methodology is employed to validate them. Data collection has been undertaken using documents consulting, semi-structured interviews with stakeholders and experts, as well as field observations. The developed framework has been used to derive family farming sustainability indicators in the Brazilian semiarid region and successively was employed as input for a multi-criteria model that was developed and implemented in the 3rd paper.

The 3rd paper (the submission proof is on Appendix V) aims to develop a non-compensatory MCDM/A model aiming at assessing and managing the sustainability performance related to smallholder farming system production in a given region. The model has been applied to assess the sustainability of 10 family farms located in the Paraiba state.

3.1. Thesis structure

This thesis will be organized into six chapters. Chapters 2, 3 and 4 will present the first, second, and third papers, respectively. Each paper will follow the rules of the respective journal in which it will be submitted, and the list of references cited in those papers will be presented in the reference list at the end of this document, with the remaining references cited throughout the document. Chapter 5 will present the final remarks with the main results, contributions, limitation of the research, and suggestions for future works.

CHAPTER 2

FIRST PAPER

Multi-criteria decision making/aid methods for assessing agricultural sustainability: a literature review

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ABSTRACT

This paper aims to perform a literature review on the use of multi-criteria methods for assessing agricultural sustainability, focusing on the distribution of papers according to year, journal, and countries, the most productive authors, the most frequently used multi-criteria methods and their characteristics, the type of system and the type of agriculture in which these methods are being performed, the methodological approaches and assessment types, and the sustainability dimensions considered. The data collection has been carried out through the Web of Science™ platform on September 3rd, 2021. After a refinement process, 41 papers were selected. The descriptive analysis was carried out through Bibliometrix tool, while content analysis was performed using Nvivo. The descriptive analysis shows that from 2016 to 2021 the scientific production addressing multi-criteria methods to assess agricultural sustainability started to grow markedly in a very rapid matter, reaching an average of 6 papers per year. France and China are the most scientifically productive countries. The content analysis points out that the most used multi-criteria method is the AHP that was used 11 times. The outranking methods, instead, were used only 3 times. In 68% of the papers the Triple Bottom Line was used as dimensions, and in 41% of the papers the spatial applicability was the farming system. The results highlight that there aren't many MCDM/A methods for assessing agricultural sustainability, and most of them are compensatory. These results point out that the use of multi-criteria methods in assessing agricultural sustainability is still underexplored and can be improved.

Keywords: Multi-criteria methods, Decision support, Agricultural systems, Sustainability

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1. Introduction

Agriculture development plays an important role in the global economy. As a source of livelihood for an estimated 86% of rural people, agriculture is one of the largest and most important economic activities, being crucial to economic growth: in 2018, it accounted for 4% of global gross domestic product (GDP) and in some developing countries, it can account for more than 25% of GDP (Agriculture and Food, 2021). Moreover, according to the World Bank, agricultural development is one of the most powerful tools to end extreme poverty, boost shared prosperity and feed a projected 9 billion people by 2050 (The World Bank, 2021b).

Currently, the number of challenges the agricultural sector faces is enormous including market globalization, production of healthy foods, biofuels, environmental concerns, social concerns, and changes in legislation at the global and local scales (Sadok et al., 2009a). As consequence, these challenges require a change of paradigm to switch from the current conventional agricultural systems, which is characterized by unsustainable practices, to new agricultural systems, which should adopt environmental and social friendly practices jointly with a responsible management of natural resources.

In this new context, the concept of agricultural sustainability emerges and consequently the need for assessing the sustainability of agricultural systems at international, national, regional, farming, and cropping level. A critical issue in this process is to understand the concepts of sustainability in the context of agriculture development and to reflect this on the instrument used for assessing the sustainability of agricultural systems, aiming to provide a reliable source of information that truly reflects what do happens in practice. The quality of this information is the key issue for the success of policies, practices, and programs for moving to a new paradigm of agricultural systems.

Notwithstanding, the term sustainable agriculture has been introduced since the Brundtland Report held in 1987, the meaning of this concept is still far from clear, and according to Lichtfouse (2011), there is no consensus among most researchers about its dimensions. Different definitions of sustainability have been provided for the agricultural sector (Hansen, 1996; Rigby & Cáceres, 2001; Smith & McDonald, 1998). According to (Ikerd, 1993), sustainable agriculture should be capable of maintaining its productivity and usefulness to society in the long term. Considering different points of view, we conclude that sustainable agriculture should be environmentally sound, resource-conserving, economically viable, and socially acceptable, that is, it should be based on the triple economic, social, and environmental. Therefore, these three dimensions should be considered in the assessment of the sustainability of agricultural systems. According to Talukder (2016), the economic dimension is related to the capacity of farmers to produce enough food to maintain the economic viability of agriculture and feed themselves and their community; social dimension refers to the equity and quality of life of farmers, consumers, and members of the community; and environmental dimension includes the enhancement of the environmental quality of the landscape and the conservation of natural resources base.

According to Bockstaller et al. (2009), translating the concept of sustainability, considering a multi-dimensional perspective, into a more operational framework is the motivation for the work of various researchers and extension agents. In the last three decades, a wide variety of methods have been developed to assess agricultural sustainability. Most of them present their evaluation in numerical form and generate scores for each dimension separately, and the results are displayed in both numerical and graphical form. Some methods generate aggregated results, but without considering the stakeholder's opinions; as for this issue, Sadok et al. (2009a) argue that an assessment method must handle the complexity of the agricultural sustainability concept, whilst taking personal and subjective views concerning the relative importance of priorities into account.

Given the characteristics of the problem, Multi-Criteria Decision-Making/Aid (MCDM/A) methods seem to be a powerful analytical tool for assessing agricultural sustainability. Multicriteria methods are operators to aggregate multicriteria evaluation of alternatives, that is, evaluation of alternatives according to a set of criteria, some of which conflict with each other. The goal in MCDM/A is to identify the best alternative considering all criteria simultaneously. This kind of analysis guarantees a transparent, structured, rigorous and objective evaluation of options (Hajkowicz, 2008). Although MCDM/A methods have been extensively applied to evaluate sustainability in many different sectors, they are relatively new in the study of agriculture.

Deytieux et al. (2016) provide a literature review based on a sample of 56 papers covering a period of 20 years from 1996 to 2015, which aims to compare the various methodologies used to assess the sustainability of cropping systems. In their analysis, the authors have classified the methods used into four categories: (i) simple descriptive statistics, such as graphical plots, scoreboards, statistics synthesizing data distribution, correlation tests or tests of comparison; (ii) multidimensional statistics, such as multiple correspondence analysis and clustering analysis; (iii) linear model-based methods, such as variance analysis or multivariate linear regression; (iv) other methods, not necessarily based on statistics. Only three MCDM/A methods were reported in this study, and they were grouped into the last category.

Sadok et al. (2009a) provide a comparative literature review of the main families of MCDM/A methods, aiming to elaborate a framework for the selection of the most appropriate MCDM/A methods for ex-ante assessment of the sustainability of cropping systems. The literature review considers a timespan of 25 years from 1982 to 2007 and considers the most important taxonomies on MCDM/A methods that have been undertaken in this period. Further, a synthesis of these taxonomies, carried out by the authors, reveals that most MCDM/A methods fall into one of the following three categories: Multi-Attribute Utility-based methods, outranking methods, and mixed methods. The mixed-methods can be divided into two further groups: (i) outranking approaches handling qualitative or mixed information, such as REGIME, QUALIFLEX, ORESTE, EVAMIX, MELCHIOR, and ARGUS; and (ii) decision rule-based approaches, such as MASC, DEX, and DEXiPM. Finally, the authors suggest a framework to undertake a comparative assessment of these methods using the criteria suggested by Munda et al. (1994) aiming to select the most appropriate method to assess the agricultural sustainability at the cropping system level.

Lampridi et al. (2019) examined 38 papers considering a timespan from 2009 to 2019, whose goal was to investigate the most frequently used methodologies to assess the sustainability of crop cultivation at the farm level. The methods were classified into five major categories based on the main scope of the assessment: (i) life cycle assessment methods; (ii) environmental methods; (iii) economic methods; (iv) multi-criteria methods; (v) indicators methods. Concerning the group "multi-criteria methods", this includes not only MCDM/A methods but all the methods that employ multicriteria assessment for the evaluation of agricultural systems. Among them, the study points out that the most frequently used are the Principal Component Analysis (PCA) (4 papers), the Data Development Analysis (DEA) (4 papers), and the DEXiPM (4). In the sequence MASC (3), DEX (2), AHP (2), CONTRA (1), NAIADE (1), Social Multi-Criteria Evaluation (SMCE) (1), and ANP (1).

The above studies focused on the evaluation of agricultural sustainability at the cropping system level, that is, the lowest spatial applicability of the assessment tools. Moreover, only the study by Sadok et al. (2009a), focused the review on the use of MCDM/A methods for agricultural sustainability assessment, while the other two studies searched for more general approaches and the consequence of which is that some important MCDA/M based approaches may have been left out of the reviewed sample.

Considering these findings, this paper aims to know the advances in the specialized literature on the development of MCDM/A-based approaches for assessing agricultural sustainability. For this, a literature review was performed on the use of MCDM/A methods for assessing agricultural sustainability, focusing on verifying the distribution of papers according to year, journal, and countries; to identify the most productive authors in the area; to identify the most frequently used MCDM/A methods and their characteristics; to identify the type of system (spatial applicability) and the type of agriculture in which these methods are being performed; to identify the methodological approaches and assessment types; to identify the dimensions used in each method; and to present methodological and theoretical advances and emerging topics. The review database is comprised of 41 papers that are published between 1999 and 2021.

The paper is organized as follows: Section 2 presents the methodology used in this study; Section 3 presents a descriptive and content analysis of the papers; Section 4 shows the discussion of the findings; and finally, the conclusions are presented in Section 5.

2. Research methodology

The methodology adopted in this study is a systematic literature review, which, according to Seuring and Müller (2008) aims to summarize existing research by identifying patterns, themes, and issues; then, it helps to identify the conceptual content of the field and can contribute to theory development. In this work, a five-step process was adopted to perform the literature review. The whole process is shown in Figure 1 below:

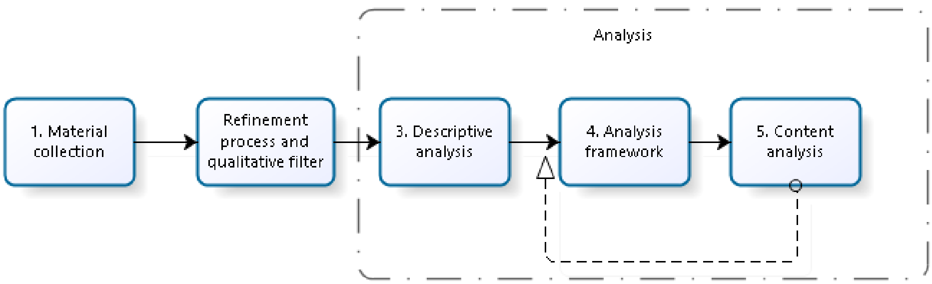

Figure 1: The literature review process

1 Material collection: the material to be collected is defined and delimitated. Furthermore, the unit of analysis is defined.

2 Refinement process and qualitative filter: to consider only the papers aligned with the scope of the research, the collected material was filtered through a set of criteria that delimit the boundary of the study.
3 Descriptive analysis: descriptive analysis has been performed to understand the evolution of the area, by assessing formal aspects of the material, which will provide the background for subsequent theoretical analysis.
4 Analysis framework: Through a previous reading of the papers and based on the existent theory, this step aims to build a framework formed by some structural dimensions and analytical categories that were extended and improved through further content analysis.
5 Content Analysis: the material is analyzed according to the structural dimensions and analytic categories. This should allow the identification of relevant issues and interpretation results. Moreover, this step provides a feedback loop to the analysis framework's step, aiming at the revision of structural dimensions and analytical categories.

3. Material collection

The data collection has been carried out through the Web of Science ™ platform since it is the world leading scientific research platform (Li et al., 2018) and the most reputable and comprehensive in the most diverse areas of knowledge (Bhardwaj, 2016). The period from 1990 to 2021 has been selected as temporal cut of the research because agricultural sustainability has gained momentum since the United Nations Conference on Environment and Development, held in Rio de Janeiro in 1992 (Talukder, 2016; Yli-Viikari, 1999). However, the period of review starts from papers that were published from 1999, when the first paper on this topic was published (considering the chosen base). Table 1 shows the parameters used in this research which has been performed on September 3rd, 2021.

Parameters	Input
Search query	(((TS=("multi-objective*" OR "multi objective*" OR "multi criteri*" OR "multi attribut*" OR multi-criteri* OR multi-attribut* OR multicriteri* OR multiattribut* OR MCDA* OR MCDM* OR AHP OR ANP OR TOPSIS OR DEMATEL OR PROMETHEE OR ELECTRE OR VIKOR OR DEA OR TODIM OR BWM OR SAW OR COPRAS OR FUCOM OR WASPAS OR MAUT OR SMART OR OWA)) AND (TS=("sustainab*" OR "sustainab* performanc*" OR "sustainab* ind*" OR "sustainab* dimensio*" OR "triple bottom line" OR "TBL" OR "social dimension*" OR "economic dimension*" OR "environmental dimension*" OR “Governance Dimension”))) AND (TS=("agribusiness*" OR "rural industr*" OR "rural compan*" OR "rural organization*" OR “rural system*” OR "agricultural industr*" OR " agricultural compan*" OR " agricultural organization*" OR “agricultural system*” OR “agroecosystem*”)))
Indexes	Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI), Arts and Humanities Citation Index (A&HCI), and Emerging Sources Citation Index (ESCI).
Document Type	“Article” or “review”
Timespan	1990-2021
Languages	English or Portuguese

Table 1: Parameters used for the search in Web of Science ™

3.1. Refinement process and qualitative filter

Initially, the database returned 355 publications. These publications have been submitted to a refinement process meeting the following criteria: (i) document type: early access, proceeding papers, book chapter, data papers and retracted publications documents were excluded from the database because they usually don’t undergo such a thorough review before publication, and therefore, only article and review document type have been selected; (ii) languages: only papers developed in English or Portuguese have been selected. After this first refinement process, 12 papers have been removed resulting in 343 papers that were analyzed.

Subsequently, a qualitative filter was also applied, through the analysis of titles, abstracts, and keywords of publications in order to select only papers aligned with the established scope of the study, that is: (i) the papers should present a new MCDM/A approach to assessing agricultural sustainability or present the application of an existing approach; (ii) the papers should aim to assess the agricultural sustainability at different levels (agricultural systems, farming systems and/or cropping systems), and/or the sustainability of processes, practices, strategies, and policies adopted in a given level; (iii) papers that focus only on environmental performance evaluation should be removed. After this second refinement process, 302 papers have been removed from the database resulting in 41 papers that were analyzed. The following topic presents how the data analysis was performed.

4. Results

The analysis was conducted into two steps: descriptive and content analysis, which was supported by the framework created in step 4 of the process. Descriptive analysis was carried out to describe the performance of scientific publishing. This analysis has been performed using as support the open-source R-tool Bibliometrix. Then, in a second phase, the content analysis was performed to identify, among data, the structural dimensions, and the analytical categories, which have been derived either deductively or inductively, and for which the software NVivo was used as a supportive tool.

4.1. Descriptive analysis

Figure 2 shows the distribution of the papers over the years, from 1999 to 2021. The first paper that proposes an MCDM/A approach for assessing agricultural sustainability has been published in 1999. From 1999 until 2015, the publication's production has been very low, with an average of 0.7 papers per year. However, from 2016, the scientific production started to grow markedly in a very rapid matter, reaching an average of 6 papers per year; this significant increase in the number of publications from 2016 is likely due to the occurrence of the United Nations Conference on Sustainable Development (UNCSD), also known as Rio 2012, Rio+20, or Earth Summit 2012. The years with the highest scientific production were 2018 and 2019 with 7 papers, although the following year there was a drop of approximately 42%, in 2020 and 2021 the scientific production remained stable with an average of 5 papers per year.

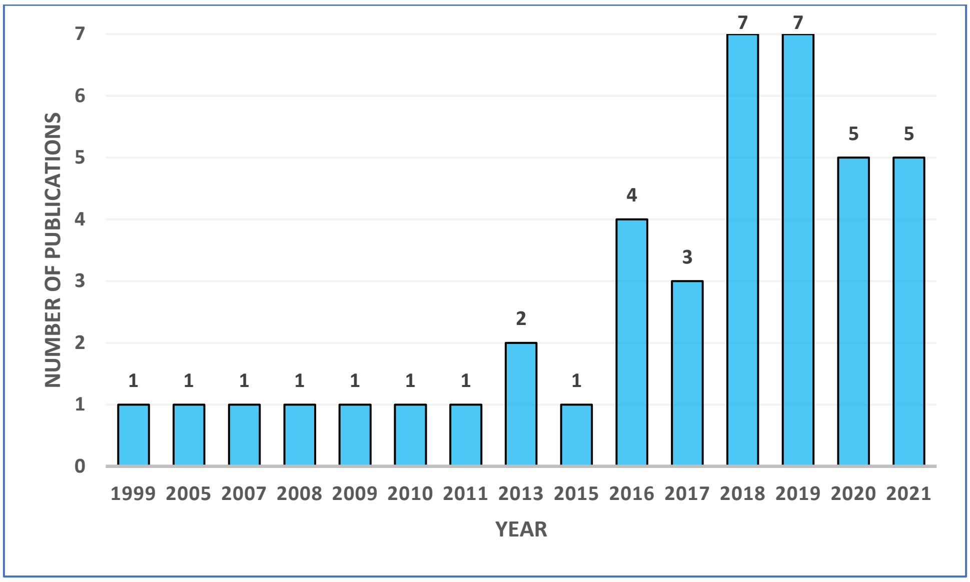

Figure 2: Distribution of publications per year

The papers are distributed in 24 different journals, among which, according to Bradford's law, the core group is composed of four sources, that is: Agricultural Systems (with 4 documents, 9.8%), Ecological Indicators (with 4 documents, 9.8%), Sustainability (with 4 documents, 9.8%), and Agricultural Water Management (with 2 documents, 4.9%). Figure 3 shows the distribution of reviewed papers according to journals.

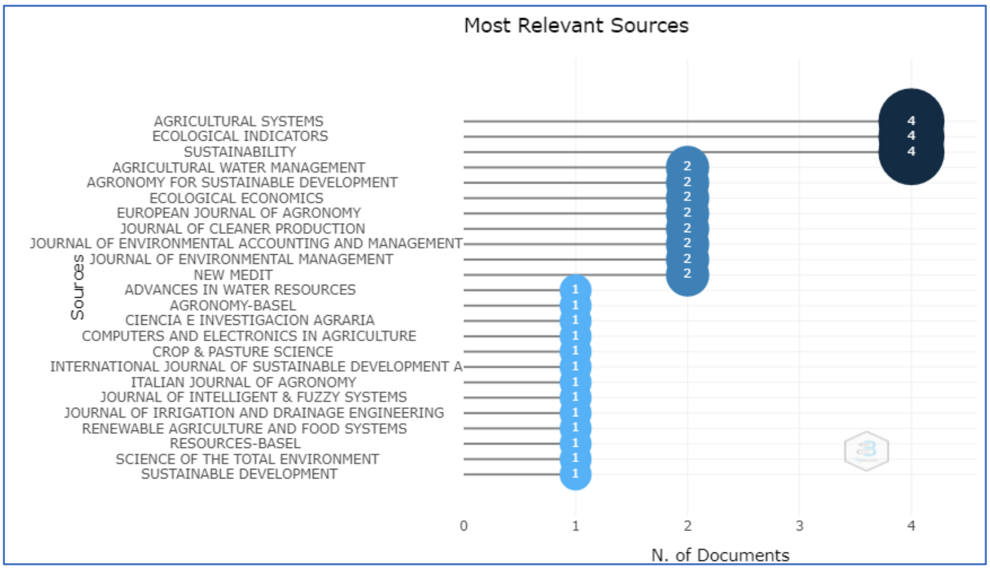

Figure 3: Distribution of the papers according to journals

Regarding the most productive authors, Angevin (France) and Talukder (Canada) are the most productive authors, with 4 papers included in the Web of Science database, followed by Bergez (France), Bockstaller (France), Dore (France), Hipel (Canada), Li M. (China), Parra-Lopez (Spain), Singh (USA), Vanloon (Canada) (3 papers each). Finally, in the third position, there is the group composed by Colomb (France), Craheix (France), Fu (China), Furst (Germany), Guichard (France), Li TX (China), Liaghati (Iran), Liu (China), Messean (France), and Mwambo (Germany) (2 papers each). Figure 4 shows the top 20 most productive authors.

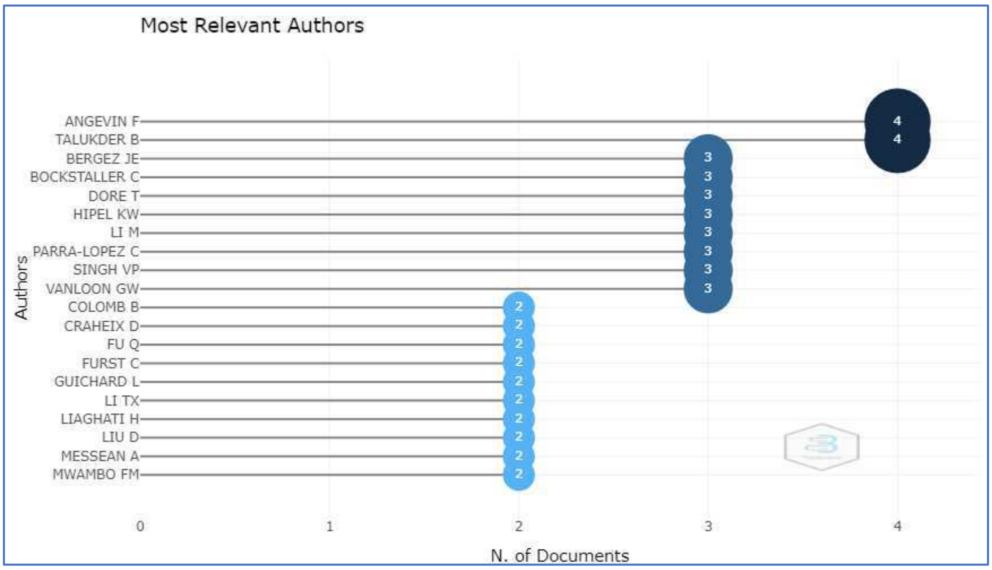

Figure 4: Most productive authors

Regarding the countries' scientific production, China and France are the most productive countries with 6 papers published, followed by Spain with 5, and Canada with 4. Figure 5 below, shows the distribution of the papers according to the countries, considering either the single country publication or the multiple country publication.

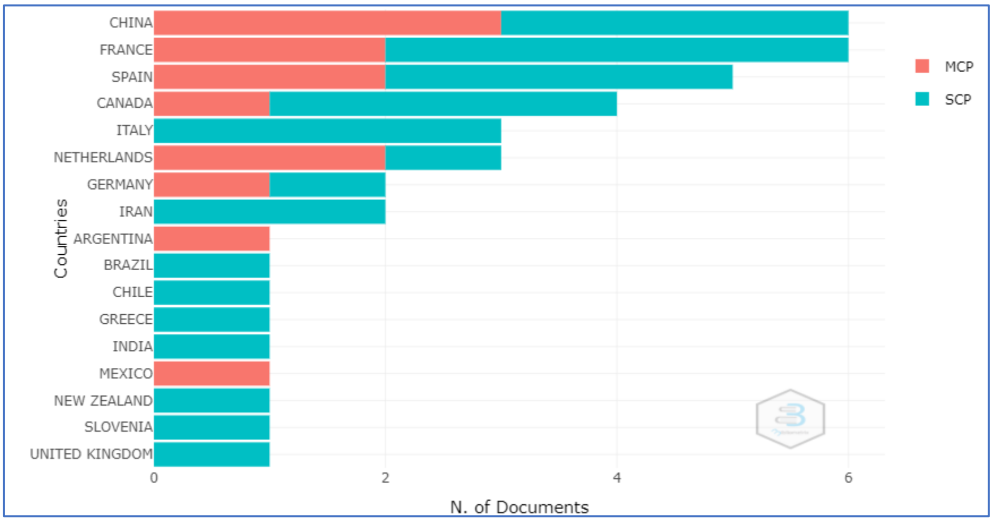

Figure 5: Distribution of the papers according to the countries

In the next topic, the content analysis has been performed, according to the proposed structural dimensions and analytical categories.

4.2. Content analysis

4.2.1. Applied methods

The papers were organized into two main classes: (i) approaches based on a single method, and (ii) approaches based on the integration of techniques. Considering the use of one method applied individually, the AHP (Analytic Hierarchic Process) is the most frequently applied method with 11 occurrences (~39%) (See Table 2).

The mixed methods, specifically the decision-rule-based approaches, are the second most used methods, with 7 occurrences (25%). These approaches are based on qualitative attributes, whose values are usually string values rather than numbers, that are aggregated using a discrete function defined in terms of decision rules ("IF-THEN-ELSE"), often organized in the form of decision trees or decision tables. Particularly, MASC (Multi-Attribute Assessment of the Sustainability of Cropping systems) was employed in the studies of (Pelzer et al., 2017), (D. Craheix et al., 2016), and (Sadok et al., 2009b). Other decision-rule-based approaches employed as single methods: DEXiPM (Decision Expert Integrated Pest Management) (Viguier et al., 2021), Biodurum_MCA (Biodurum Multi-Criteria Analysis) (Iocola et al., 2021), DEXi-CSC (Decision Expert integrated-Center for Sustainable Cropping) (Hawes et al., 2019), and DEX (Decision Expert) (Damien Craheix et al., 2015).

Other MCDM/A methods that are being used in single method-based approaches are: MAVT (Multi-Attribute Value Theory) with 3 occurrences (~7%); DEA (Data Envelopment Analysis) with 2 occurrences; a fuzzy version of DEA (Fuzzy-DEA) have been applied in the study of (Mu et al., 2018); the outranking methods ELECTRE II (ELimination Et Choix Traduisant la RÉalité) and ELECTRE TRI were used in the studies of (Talukder, Blay-Palmer, et al., 2017) and (Maydana et al., 2020), whereas PROMETHEE II (Preference Ranking Organization METHod for Enrichment of Evaluation) was employed by (Talukder & Hipel, 2018).

The optimization techniques appear in a wide set of papers. Multi-Objective Linear Fractional Programming (MLFP) has been used as a single method in the study of (Lara & Stancu-Minasian, 1999) which is also the first MCDA/M method appearing in the selected timespan. Marta-Costa (2010) in her study propose an integration between the NISE method (Non-Inferior Set Estimation) with Compromise Programming. Multi-objective programming appears integrated with Compromise Programming also in the study of Bazzani et al. (2021). Studying irrigated agriculture, Salazar et al. (2005) use an integration between Linear Programming and the Range of Value method (Multi-objective programming). Goal Programming was integrated with the Emergy Analysis method (EMA) to assess the sustainability of the dairy sector in the study of Kocjančič et al. (2018). Li, Zhou, et al. (2020) propose an approach based on the integration between multi-objective programming, Crop Ecological Footprint (CEF), and fuzzy method. A fuzzy-stochastic multi-objective mixed-integer nonlinear programming was integrated with the Stewart method by Yue & Guo (2021) aiming at an optimization model for sustainable land use. Li, Fu, et al. (2020) use a mixed-integer multi-objective nonlinear programming incorporating a fuzzy method to develop an approach for the optimal allocation of agricultural water and land resources under uncertainties. Li et al. (2019) propose a model based on stochastic multi-objective programming integrated with the fuzzy set theory and with the Random Boundary Interval concept aiming at an optimal allocation of land resources in agriculture. Aiming the optimization of the agricultural industrial structure to improve its sustainability and benefits, Zhou, Y.W. and Fan (2018) propose a model based on the integration between multi-objective programming and genetic algorithm.

Regarding the integration of the multi-criteria methods with other techniques, DEA has been combined with Emergy Analysis in two papers: Mwambo, Fürst, Martius, et al. (2021) and Mwambo, Fürst, & Martius, (2021). The MASC method was used combined with a meta-heuristic method based on a genetic algorithm in the study of Bergez (2013). Finally, the AHP method was combined with the AMOEBA method to develop an agricultural sustainability index proposed by Liu et al. (2007).

Figure 6 shows the frequency in which the methods were used in both single and integration-based techniques approaches.

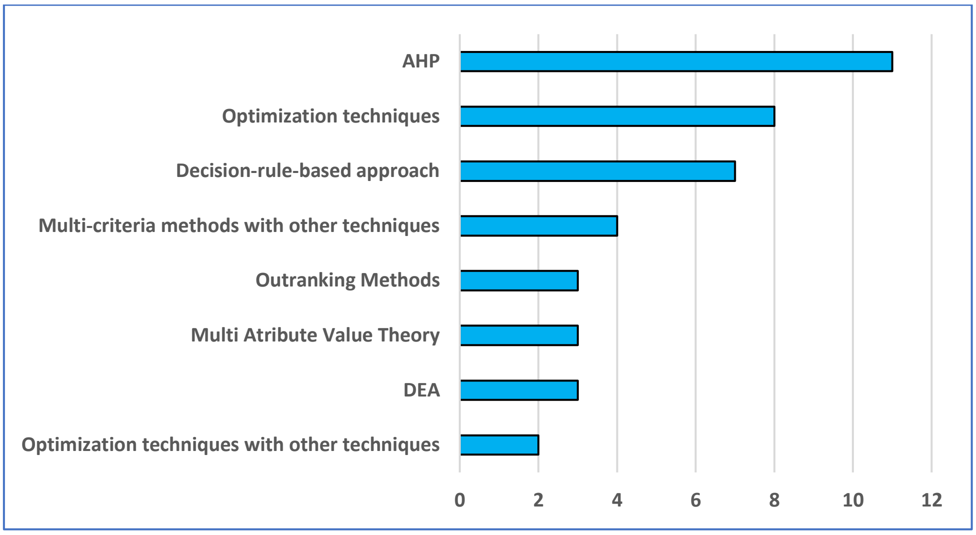

Figure 6: Occurrences of applied methods. Source: Research data (2021)

In the next topic, the data source has been analyzed.

4.2.2. Data source

The data source points out the origin of data that feed the assessment models used in the papers to evaluate agricultural sustainability. Primary data includes information that arises directly from the field studied, through some tools such as farm survey, lab analysis, field observation. Secondary data includes information arising from public documents, farm reports, statistical yearbooks, and relevant government agencies. Finally, the expert's judgment is information that arises directly from the specialist's opinions. In 18 papers (~44%) the evaluation of the indicators was based on both primary and secondary data. In 10 papers (~24%) secondary data was used as a source. Primary data have been employed in 8 papers (~20%). In three papers (~7%) the evaluation of indicators was based on secondary data and expert's judgment. Finally, only two papers (~5%) use a combination of primary data, secondary data, and expert's judgment.

The next topic addresses the dimensions used in the assessment models for assessing agricultural sustainability.

4.2.3. Dimensions used in the assessment models

Regarding the dimensions of sustainability used in the various approaches, the data gathered show that a pattern exists. In fact, in 28 papers (~68%) the classic sustainability tripod constituted from economic, social, and environmental dimensions have been used for assessing agricultural sustainability. In 4 papers (~10%) the classic Triple Bottom Line (TBL) was incremented with other dimensions.

Srinivasa Rao et al. (2019) in their study, added the institutional dimension which is essentially considered as a binding force for the other dimensions of the classical sustainability tripod. This dimension is considered a great dimension including governance and politics as subdimensions. Politics encompasses an array of solutions and rules provided by the state and aiming at the satisfaction of general or collective interest. Governance, instead, can be described as a shared responsibility of representatives from the state, the market, and society dealing with economic, social, and environmental problems. Through this point of view, governance encompasses politics and, moreover, this concept is used when the state no longer has the necessary authority or means to produce a political position that adequately represents the general or collective interest. This is especially true for the contrasting and complex agricultural sustainability issues.

Li, Zhou, et al. (2020) in their study, added resources utilization. In this context, resources utilization refers to the ability of agricultural systems to avoid the overconsumption of resources offered by nature (water, and nonrenewable resources above all). In turn, the environmental dimension refers only to the negative impact of farmer's pollution in its different forms.

Four dimensions have been used also in the study of Parra-López et al. (2008), that is, environmental, economic, socio-cultural, and technical. In this case, the socio-cultural dimension takes into consideration either the social issue or the cultural one such as the respect of the traditions and local cultural values, while the technical dimension deals with the help of technology in the dissemination of sustainability.

Finally, Renwick et al. (2019) use the following dimensions: financial, market, knowledge, regulation, social, and environmental. Financial and market dimensions can be considered as subdimensions of the economic dimension. Regulation dimension points out the compliance with regulations and laws that public institutions provide, while knowledge dimension refers to the ease of access to technical knowledge that business requires.

In 5 studies (~12%) only two dimensions of the classical sustainability tripod have been used, the economic and the environmental dimensions. In conclusion, the 4 studies listed below used a modified TBL in which one or more classic dimensions have been substituted from other dimensions.

The economic, environmental, and water use dimensions appear in the study of Salazar et al. (2005). Water use points out the ability of the agricultural system to use water most efficiently, that is, avoiding waste as long as possible. The water use dimension appears also in the study of Lara & Stancu-Minasian (1999), jointly with economic and social dimensions.

Economic, environmental, and resources utilization have been used as dimensions in the study of Yue & Guo (2021).

Olguín et al. (2019) in their study propose the use of four dimensions, that is, economic, environmental, technical, and political. The political dimension represents the support service, subsidies, and investments that farmers receive from public institutions, while the technical dimension deals with the help of technology in the dissemination of sustainability.

An overview of these findings is presented in Figure 7, where the approaches were divided into four groups: approaches using the classical TBL, approaches using the TBL added with other dimensions, approaches using a modified TBL (in which one or more classic dimensions are substituted from other dimensions), approaches using two dimensions only.

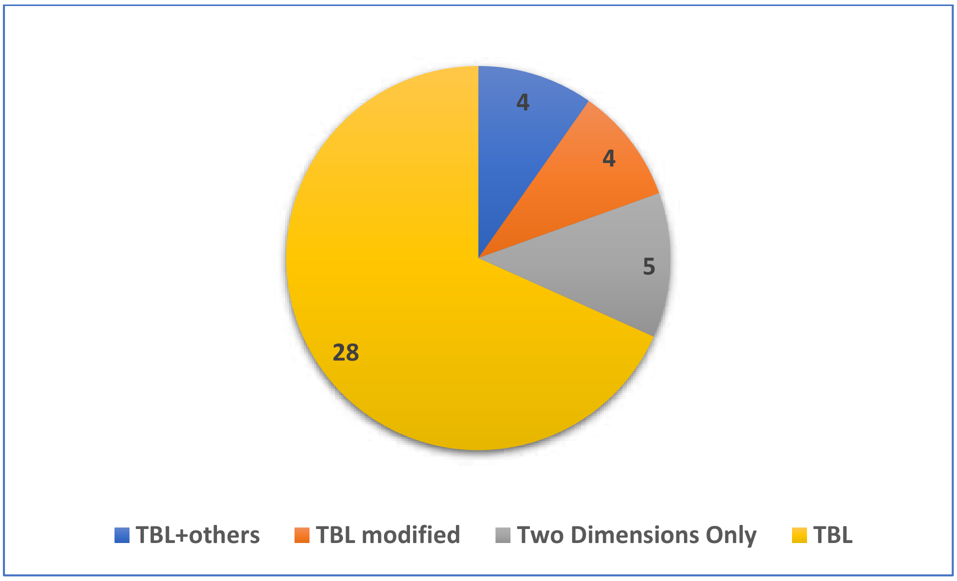

Figure 7: Overview of dimensions used in the approaches. Research data (2021)

4.2.4. Methodological approaches and assessment types

All the applied methods performed to assess agricultural sustainability can use one or both of the following methodological approaches: top-down or bottom-up. In the top-down approach, choices are made by a small group of designers composed of experts, while in the bottom-up approach, choices are made mainly by a larger group of potential users, including stakeholders. Results show that most of the methods applied for assessing agricultural sustainability at different spatial applicability (that is, cropping systems, farming systems, and agricultural systems) use a top-down methodological approach. Indeed, the top-down methodological approach was used in 29 papers (~71%). In contrast, only 3 studies (~7%) adopt a bottom-up methodological approach, and 9 papers (~22%) use an integrated top-down and bottom-up approach.

Regarding the assessment types, two groups have been found: ex-ante assessment, which is used for assessing non-existent systems generated by simulation under experts; and ex-post assessment, which is used for assessing already existent real systems. The ex-post assessment is the most used and it appears in 32 papers (~78%), while the ex-ante assessment was employed in 4 papers (~10%). Finally, 4 papers (~10%) employed a mixed ex-ante and ex-post assessment, whereas 1 paper (~2%) did not specify the type of assessment.

The next topic addresses the spatial applicability of the sustainability assessment.

4.2.5. Spatial applicability of the sustainability assessment

Agricultural sustainability can be assessed at different levels, that is: cropping system, farming system, and agricultural system.

The cropping system is the smaller agricultural unit that can be assessed. According to Sebillotte (1978), a cropping system is defined by the nature of the crops and their sequence, and crop management, seen as a logical and ordered sequence of agricultural techniques applied to each of these crops, including the choice of cultivars. Fresco and Westphal (1988) define a farming system as a decision-making unit comprising the farm household, cropping systems, and livestock system that transforms land, capital, and labor into useful products that can be consumed or sold. The set of cropping systems and farming systems present in a given region, give rise to an agricultural system.

The data gathered in this work, show that most of the papers (17 papers, ~41%) assess the sustainability at the farming system level. Agricultural sustainability has been assessed at the cropping system level in 10 papers (~24%). Finally, in 13 papers (~32%) the sustainability was assessed at the agricultural system level. In the study by Iocola et al. (2021), sustainability was assessed both at the cropping system level and at the farming system level. Figure 8 shows an overview of the findings.

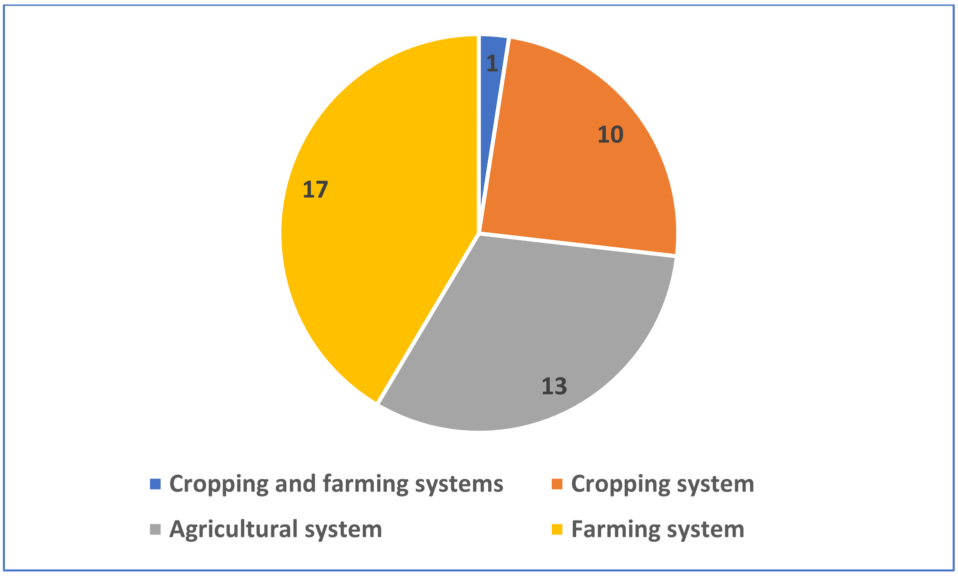

Figure 8: Spatial applicability of the sustainability assessment. Research data (2021)

The following topic appraises the type of agriculture considered in the assessment.

4.2.6. Type of agriculture

The various approaches highlighted in this review have performed the sustainability assessment in different types of agriculture, which, as it is known, can vary in a broad range of alternatives. Conventional agriculture is the most considered type, being addressed, alone, in 13 papers (~32%), and jointly with different forms of alternative agriculture in 19 papers (~46%). Conventional agriculture mainly aims at a maximum financial return, and this demands intensive practices based on monoculture, mechanization, and high levels of inputs such as energy, fertilizers, and pesticides.

In contrast, alternative agriculture refers to a wide range of agriculture types adopting practices that aim to reach not only financial results but also environmental and social ones. Alternative agriculture doesn’t use conventional methods and gathers a lot of different agriculture types such as organic agriculture, biodynamic agriculture, integrated agriculture, conservation agriculture, whose meaning will be explained below.

Conservation agriculture was addressed in 1 paper (~2%). This type of agriculture is based on the following three principles: (i) minimal or no mechanical soil disturbance, (ii) diversified crop rotations, and (iii) permanent soil cover (consisting of a growing crop or a dead mulch of crop residues).

Organic agriculture alone has been considered only in 3 studies (~7%). This type of agriculture avoids the usage of synthetic inputs and genetically modified organism, minimizes pollution of air, soil, and water, and optimizes the health and productivity of interdependent communities of plants, fisheries, animals, and people (Hossain, 2012).

Integrated agriculture has been addressed alone in 1 paper and jointly with organic agriculture in 1 study. Integrated agriculture may be considered as an intermediate agriculture between conventional and organic. In fact, integrated agriculture should produce a corresponding financial output, but another aim is minimum input of fertilizer, pesticides, and machinery to avoid pollution of the environment and save non-renewable resources (Vereijken, 1986).

Conventional agriculture has been also addressed with a wide range of alternative agriculture types. Maydana et al. (2020) in their study address both conservation and conventional agriculture. Conventional agriculture has been addressed with organic agriculture in 7 papers (~17%), with integrated agriculture in 1 paper, with organic and integrated agriculture in 6 papers (~14%), with various alternatives practices in 3 papers, and with organic and biodynamic agriculture solely in 1 paper. Unlike other alternative agriculture types, biodynamic agriculture seeks to promote soil fertility by administering special herbal preparation to fields and compost heaps a specific time of year, which are intended to concentrate or build cosmic, ethereal, and astral forces that shape animal and plant growth, enliven the soil and promote decay. Therefore, organic, astral, and spiritual practices seem to characterize biodynamic agriculture.

Finally, three papers (~8%) did not specify the type of agriculture considered in the assessment approach. An overview of these findings is displayed in Figure 9 that shows the frequencies in which each type of agriculture was addressed.

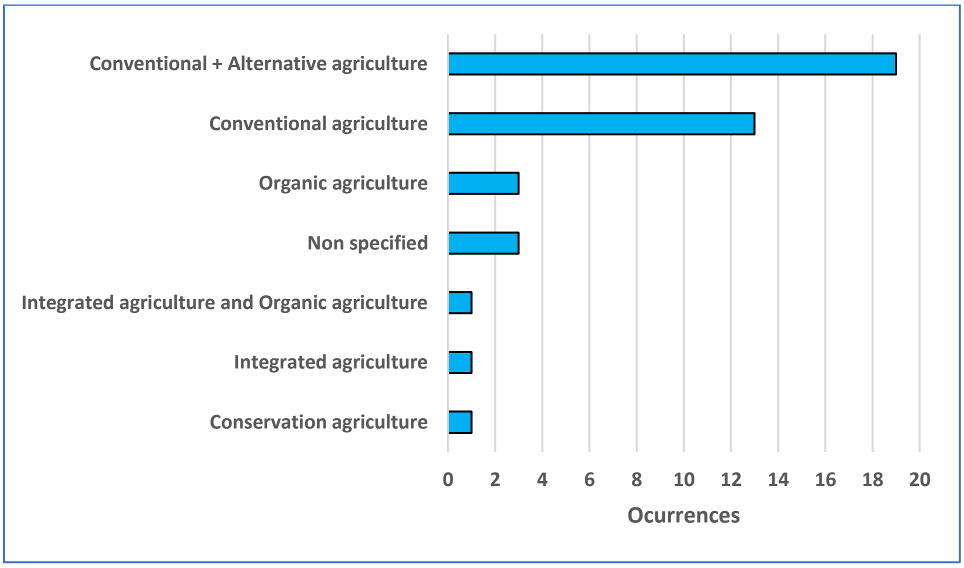

Figure 9: Type of agriculture considered in the assessment. Source: Research data (2021)

Table 2 shows the analysis framework and provides a summary of the structural dimensions and analytical categories performed.

Structural Dimensions	Great Analytical Categories	Analytical Categories	References
Applied Methods	Approaches based on a single method	AHP	(Rodríguez Sousa et al., 2020), (Tzouramani et al., 2020), (Srinivasa Rao et al., 2019), (Olguín et al., 2019), (Abdallah et al., 2018), (Parra-López et al., 2008), (Tran et al., 2018), (Sajadian et al., 2017), (Renwick et al., 2019), (Olveira et al., 2016), (Veisi et al., 2016)
		Decision-rule-based approaches	(Pelzer et al., 2017), (D. Craheix et al., 2016), (Sadok et al., 2009b), (Viguier et al., 2021), (Iocola et al., 2021), (Hawes et al., 2019), (Damien Craheix et al., 2015)
		Multi Atribute Value Theory	(Troiano et al., 2019), (Talukder et al., 2018), (Talukder et al., 2016)
		DEA	(Gerdessen & Pascucci, 2013), (Picazo-Tadeo et al., 2011), (Mu et al., 2018)
		Outranking Methods	(Talukder, Blay-Palmer, et al., 2017), (Maydana et al., 2020), (Talukder & Hipel, 2018)
		Optimization techniques	(Lara & Stancu-Minasian, 1999), (Marta-Costa, 2010), (Bazzani et al., 2021), (Salazar et al., 2005), (Yue & Guo, 2021), (Li, Fu, et al., 2020), (Li et al., 2019), (Zhou, Y.W. and Fan, 2018)
	Approaches based on the integration of techniques	Optimization techniques with other techniques	(Kocjančič et al., 2018), (Li, Zhou, et al., 2020)
		Multi-criteria methods with other techniques	(Mwambo, Fürst, Martius, et al., 2021), (Mwambo, Fürst, & Martius, 2021), (Bergez, 2013), (Liu et al., 2007)

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Data source		Primary data	(Viguier et al., 2021), (Iocola et al., 2021), (Rodríguez Sousa et al., 2020), (Maydana et al., 2020), (Tzouramani et al., 2020), (Hawes et al., 2019), (Troiano et al., 2019), (Sajadian et al., 2017)
		Secondary data	(Srinivasa Rao et al., 2019), (Mwambo, Fürst, & Martius, 2021), (Mu et al., 2018), (Veisi et al., 2016), (Gerdessen & Pascucci, 2013), (Bergez, 2013), (Parra-López et al., 2008), (Bazzani et al., 2021), (Li, Zhou, et al., 2020), and (Li et al., 2019)
		Primary and secondary data	(Olguín et al., 2019), (Talukder & Hipel, 2018), (Talukder et al., 2018), (Abdallah et al., 2018), (Tran et al., 2018), (Renwick et al., 2019), (Mwambo, Fürst, Martius, et al., 2021), (Talukder, Blay-Palmer, et al., 2017), (Pelzer et al., 2017), (Olveira et al., 2016), (Damien Craheix et al., 2015), (Picazo-Tadeo et al., 2011), (Marta-Costa, 2010), (Liu et al., 2007), (Salazar et al., 2005), (Lara & Stancu-Minasian, 1999), (Yue & Guo, 2021), and (Li, Fu, et al., 2020)
		Secondary data and expert's judgment	(Sadok et al., 2009b), (Kocjančič et al., 2018), and (Zhou, Y.W. and Fan, 2018)
		Primary data, secondary data, and expert's judgment	(D. Craheix et al., 2016) and (Talukder et al., 2016)
Dimensions		Triple Bottom Line	(Viguier et al., 2021), (Iocola et al., 2021), (Rodríguez Sousa et al., 2020), (Maydana et al., 2020), (Tzouramani et al., 2020), (Mwambo, Fürst, & Martius, 2021), (Abdallah et al., 2018), (Tran et al., 2018), (Sajadian et al., 2017), (Mwambo, Fürst, Martius, et al., 2021), (Talukder, Blay-Palmer, et al., 2017), (Pelzer et al., 2017), (D. Craheix et al., 2016), (Talukder et al., 2016), (Olveira et al., 2016), (Veisi et al., 2016), (Damien Craheix et al., 2015), (Gerdessen & Pascucci, 2013), (Bergez, 2013), (Picazo-Tadeo et al., 2011), (Sadok et al., 2009b), (Liu et al., 2007), (Li, Fu, et al., 2020), (Kocjančič et al., 2018), (Zhou, Y.W. and Fan, 2018), (Talukder & Hipel, 2018), (Talukder et al., 2018), and (Troiano et al., 2019)
		Triple Bottom Line + others	(Srinivasa Rao et al., 2019), (Li, Zhou, et al., 2020), (Renwick et al., 2019), (Parra-López et al., 2008)
		Triple Bottom Line modified	(Salazar et al., 2005),(Lara & Stancu-Minasian, 1999),(Yue & Guo, 2021),(Olguín et al., 2019)
		Two dimensions only	(Hawes et al., 2019), (Mu et al., 2018),(Marta-Costa, 2010), (Bazzani et al., 2021), and (Li et al., 2019)

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Methodological approaches		Top-down	(Viguier et al., 2021), (Maydana et al., 2020), (Tzouramani et al., 2020), (Srinivasa Rao et al., 2019), (Mwambo, Fürst, & Martius, 2021), (Abdallah et al., 2018), (Sajadian et al., 2017), (Renwick et al., 2019), (Mwambo, Fürst, Martius, et al., 2021), (Mu et al., 2018), (Pelzer et al., 2017), (D. Craheix et al., 2016), (Olveira et al., 2016), (Veisi et al., 2016), (Gerdessen & Pascucci, 2013), (Picazo-Tadeo et al., 2011), (Marta-Costa, 2010), (Sadok et al., 2009b), (Parra-López et al., 2008), (Liu et al., 2007), (Salazar et al., 2005), (Lara & Stancu-Minasian, 1999), (Bazzani et al., 2021), (Li, Zhou, et al., 2020), (Yue & Guo, 2021), (Li et al., 2019), (Li, Fu, et al., 2020), (Kocjančič et al., 2018), and (Zhou, Y.W. and Fan, 2018)
		Bottom-up	(Iocola et al., 2021), (Hawes et al., 2019), and (Troiano et al., 2019)
		Top-down + bottom up	(Rodríguez Sousa et al., 2020), (Olguín et al., 2019), (Talukder & Hipel, 2018), (Talukder et al., 2018), (Tran et al., 2018), (Talukder, Blay-Palmer, et al., 2017), (Talukder et al., 2016), (Damien Craheix et al., 2015), and (Bergez, 2013)
Assessment types		Ex-ante	(Viguier et al., 2021), (Marta-Costa, 2010), (Sadok et al., 2009b), and (Salazar et al., 2005)
		Ex-post	(Rodríguez Sousa et al., 2020), (Maydana et al., 2020), (Tzouramani et al., 2020), (Srinivasa Rao et al., 2019), (Hawes et al., 2019), (Olguín et al., 2019), (Troiano et al., 2019), (Mwambo, Fürst, & Martius, 2021), (Talukder & Hipel, 2018), (Talukder et al., 2018), (Abdallah et al., 2018), (Tran et al., 2018), (Sajadian et al., 2017), (Renwick et al., 2019), (Mwambo, Fürst, Martius, et al., 2021), (Mu et al., 2018), (Talukder, Blay-Palmer, et al., 2017), (D. Craheix et al., 2016), (Talukder et al., 2016), (Olveira et al., 2016), (Gerdessen & Pascucci, 2013), (Picazo-Tadeo et al., 2011), (Parra-López et al., 2008), (Liu et al., 2007), (Lara & Stancu-Minasian, 1999), (Bazzani et al., 2021), (Li, Zhou, et al., 2020), (Yue & Guo, 2021), (Li et al., 2019), (Li, Fu, et al., 2020), (Kocjančič et al., 2018), and (Zhou, Y.W. and Fan, 2018)
		Ex-post + ex-ante	(Iocola et al., 2021), (Pelzer et al., 2017), (Damien Craheix et al., 2015), (Bergez, 2013)
		Non specified	(Veisi et al., 2016)

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Spatial applicability		Cropping system	(Viguier et al., 2021), (Hawes et al., 2019), (Olguín et al., 2019), (Mwambo, Fürst, Martius, et al., 2021), (Pelzer et al., 2017), (D. Craheix et al., 2016a), (Bergez, 2013), (Sadok et al., 2009b), (Salazar et al., 2005), and (Li, Zhou, et al., 2020)
		Farming system	(Rodríguez Sousa et al., 2020), (Tzouramani et al., 2020), (Troiano et al., 2019), (Talukder & Hipel, 2018), (Talukder et al., 2018), (Abdallah et al., 2018), (Tran et al., 2018), (Sajadian et al., 2017), (Renwick et al., 2019), (Mu et al., 2018), (Talukder, Blay-Palmer, et al., 2017), (Olveira et al., 2016), (Picazo-Tadeo et al., 2011), (Marta-Costa, 2010), (Parra-López et al., 2008), (Liu et al., 2007), (Bazzani et al., 2021)
		Cropping and farming systems	(Iocola et al., 2021)
		Agricultural system	(Maydana et al., 2020), (Srinivasa Rao et al., 2019), (Mwambo, Fürst, & Martius, 2021), (Talukder et al., 2016), (Veisi et al., 2016), (Damien Craheix et al., 2015), (Gerdessen & Pascucci, 2013), (Lara & Stancu-Minasian, 1999), (Yue & Guo, 2021), (Li, Fu, et al., 2020), (Li et al., 2019), (Kocjančič et al., 2018), and (Zhou, Y.W. and Fan, 2018)
Type of agriculture		Conventional+ Alternative agriculture	(Abdallah et al., 2018), (Bergez, 2013), (Sadok, Angevin, Bergez, Bockstaller, Colomb, Guichard, Reau, Messéan, et al., 2009), (Kocjančič et al., 2018), (Zhou, Y.W. and Fan, 2018), (Hawes et al., 2019), (Bazzani et al., 2021), . (Maydana et al., 2020), (Tzouramani et al., 2020), (Talukder & Hipel, 2018), (Talukder et al., 2018), (Mwambo, Fürst, Martius, et al., 2021), (Talukder, Blay-Palmer, et al., 2017), (Talukder et al., 2016), (Parra-López et al., 2008), (Troiano et al., 2019), (Srinivasa Rao et al., 2019), (Damien Craheix et al., 2015), and (Gerdessen & Pascucci, 2013)
		Conventional agriculture	(Viguier et al., 2021), (Tran et al., 2018), (Renwick et al., 2019), (Mu et al., 2018), (Pelzer et al., 2017), (Olveira et al., 2016), (Marta-Costa, 2010), (Liu et al., 2007), (Salazar et al., 2005), (Li, Zhou, et al., 2020), (Yue & Guo, 2021), (Li et al., 2019), (Li, Fu, et al., 2020)
		Organic agriculture	(Iocola et al., 2021), (Olguín et al., 2019) and (Sajadian et al., 2017)
		Non specified	(Mwambo, Fürst, & Martius, 2021), (Veisi et al., 2016), and (Lara & Stancu-Minasian, 1999)
		Integrated and Organic agriculture	(Rodríguez Sousa et al., 2020)
		Integrated agriculture	(Picazo-Tadeo et al., 2011)
		Conservation agriculture	(D. Craheix et al., 2016b)

Table 2: Analysis framework: structural dimensions and analytical categories

5. Discussion

The results show that does not exist a large number of MCDM/A approaches for assessing agricultural sustainability, corroborating the findings of Talukder and Hipel (2018) and Talukder (2016). Among MCDM/A methods, AHP is the most frequently applied method (12 occurrences). Within the group of non-compensatory methods, ELECTRE was applied 2 times and PROMETHEE once. The optimization techniques, considering a multicriteria perspective, have been employed 10 times. DEA, which is a multicriteria method based on linear programming, was used 5 times.

The choice of a specific MCDM/A method depends on a broad range of factors, such as the decision maker's preference structure, the type of problem, the availability of data, and how much desirable is the compensation among criteria. In the context of sustainability, it does not make sense that environmental or social aspects be compensated for by economical ones. In this sense, non-compensatory methods are more appropriate to be used in approaches for assessing sustainable agriculture. However, non-compensatory methods have been used 3 times only.

As for the data source, most approaches use a combination of primary and secondary data to assess the indicators. Secondary data (alone or in combination with other data sources) are used in 80% of the approaches. According to Dunn et al. (2015), this finding is explained by the fact that secondary data analysis typically requires less time and monetary resources, furthermore, secondary data sets often contain large sample sizes and longitudinal data which typically increases the generalizability of findings. Nevertheless, the use of primary data is extremely important in this area of knowledge that is considered already under development, because, as pointed out by Hox and Boeije (2004), on every occasion in which primary data are collected, new data are added to the existing store of social knowledge in a given area, contributing consequently with the development of the scientific field. Finally, some studies used the judgment of experts as a data source to compensate the scarcity of data or/and to the uncertainty which characterizes the problem addressed.

Concerning the sustainability dimensions, most of the reviewed studies (~68%) used approaches based on the classical TBL, corroborating the definition of agricultural sustainability provided by Ikerd (1993). But, in some studies, other dimensions appear in addition to the classic TBL, such as institutional (which includes governance and politics as subdimensions), technical (which deals with the help of technology in the dissemination of sustainability), regulations (which refers to the compliance whit rules and law that public institutions provide), knowledge (which refers to the ease of access to technical knowledge that business requires). Some studies proposed resources utilization and water efficiency as dimensions, where the first one refers to the quantity of non-renewable resources consumed by the agricultural system assessed, while the second one refers to the ability of the agricultural system to avoid overconsumption of water. We emphasize the existence of a conceptual mistake, since that it is widely accepted by the academic community that the environmental dimension encompasses a wide range of aspects, such as reduction of waste and pollution, limitation of non-renewable resources consumption, respect and preservation of biodiversity (Sachs, 2002).

Most of the approaches use a top-down methodological approach and perform an ex-post assessment. Nevertheless, the bottom-up approaches have recently gained more consideration into researchers' community as well as the ex-ante assessment. The bottom-up approaches, indeed, permit taking into consideration the point of view of stakeholders in the assessment process, while the ex-ante assessment performs an evaluation of agricultural systems nonexistent yet. The increasing adoption of the use of a bottom-up approach mixed with a top-down one, is due, seemingly, to the fact that a participatory approach may catch the multiple variations of agricultural sustainability along the geographical, political, ethical, and cultural boundaries (Funtowicz and Ravetz, 1993). Moreover, according to Craheix et al. (2015), a sustainability assessment model is more likely to be used if it is designed with a participatory approach. In addition, the use of an ex-ante evaluation offers the possibility to assess a large body of options *in silico*, and rapidly identify innovative, alternative agricultural systems without the need for in-field assessment, providing, consequently, great cost savings (Sadok et al., 2009).

Concerning the spatial applicability, the findings show that most of the researchers used approaches for assessing agricultural sustainability at the farming system level. In the second position there is the assessment at the regional level (agricultural system). The cause of this result lies, perhaps, in the fact that a farm is a very complex system and there is no one farm identical to another, therefore, achieving a shared approach is probably a utopian goal (Gaviglio et al., 2016).

Finally, it is worth mentioning that the main type of agriculture addressed is the conventional joint with the alternative ones. This outcome is probably due to the increasing need for assessing these agriculture types characterized by diametrically opposing goals, aiming to show the pros and cons of each of them.

Regarding the managerial implications of the study, MCDM/A methods have the potential to be useful in agricultural sustainability assessment, by supporting decision makers to make better decisions, for example: from the point of view of farm managers, selecting the most suitable agricultural practices and cropping patterns aiming at enhancing the sustainability performance of the farm; policymakers can select or design public policies aiming at helping farmers, and various stakeholders involved, to reach and maintain a sustainable agricultural system.

The study triggers another important managerial implication, which is the tendency of the farm managers in seeking cost-saving strategies, by developing frameworks that allow assessing a large body of cropping systems, farming systems, and agricultural practices in silico, and thus without the need for an in-field assessment (Sadok et al., 2009b). This innovative sustainability assessment is extremely advantageous considering that, because of the wide range of challenges that agricultural systems face, cropping systems, farming systems, and agricultural practices can vary in a very rapid manner.

As far theoretical implications are concerned, the study shows the increasing tendency in using participatory approach in designing multicriteria models to assess agricultural sustainability. However, participatory approach can be very complex in practice, requiring appropriate approaches for dealing with different perspectives and conflicts of interest. Meanwhile, the literature is still not clear about the degree of stakeholders' involvement during the decision process (Craheix et al., 2015).

6. Conclusions

In this work, 41 peer-reviewed journal papers dealing with the multi-criteria assessment of agricultural systems have been reviewed. The objective of the paper was to perform a literature review on the use of MCDM/A methods for assessing agricultural sustainability, focusing on verifying the distribution of papers according to year, journal, and countries; to identify the most productive authors in the area; to identify the most frequently used MCDM/A methods and their characteristics; to identify the type of system (spatial applicability) and the type of agriculture in which these methods are being performed; to identify the methodological approaches and assessment types; to identify the dimensions used in each method; and to present methodological and theoretical advances and emerging topics.

The results show that most of the reviewed studies (~85%) addresses approaches based on a single method, among which the AHP is the most frequently applied (~27%), while only 15% of the studies addresses approaches based on the integration of techniques. The integration of techniques is less used because it enhances the complexity of the approach which could require a high cognitive effort from the decision maker. Moreover, the results point out that the use of non-compensatory approaches is still incipient, as most approaches addressed (~93%) use a compensatory rationality. The TBL is used as dimensions of sustainability in most papers (~68%), although the use of other dimensions, such as governance, is slowly increasing. Even though most approaches (~71%) still adopt a top-down methodology, the results point out that the integration between top-down/bottom-up methodologies, which is widely acknowledged as the most suitable, have been quickly increasing. As for the type of assessment, the use of ex-ante evaluation is slowly growing, maybe because it allows preventive actions rather that corrective actions in the agricultural sustainability context.

The main contribution of this work lies in providing an in-depth overview of the MCDM/A methods applied in assessing agricultural sustainability, focusing not only on the cropping system level but on each spatial level of the assessment, showing the main theoretical and methodological advances as well as the emerging trends in this area of knowledge. Furthermore, the study contributes to future research, especially those that seek to develop new methodologies or adapt already existent ones for assessing agricultural sustainability.

This research is justified by scientific and social benefits. For the scientific community, this study can help to understand how the multi-criteria decision-making/aid area has evolved in assessing agricultural sustainability. And for society, it can help in the development of models that provide an intelligent and effective deployment of activities linked to the tripod of sustainability in agriculture systems.

The paper presents several limitations. Among others, the most important is the dimension of the sample, indeed only 41 papers were considered. This limitation arises from taking into consideration a database only; some relevant publications may have been overlooked because they are not available on Web of Science.

As a suggestion from future research, it is proposed to use a combination of databases to increase the number of papers in the sample, and the number of the structural dimensions and/or analytical categories to achieve a more thorough and in-depth understanding of the area of knowledge as well as its development.

Acknowledgement

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CHAPTER 3

SECOND PAPER

A FRAMEWORK TO DERIVE FAMILY FARMING SUSTAINABILITY INDICATORS AT A REGIONAL SCALE

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1. Introduction

According to the Food and Agriculture Organization of the United Nations (FAO) and the International Fund for Agricultural Development (IFAD), family farming constitutes the predominant form of agricultural production in both developed and developing countries, producing over 80% of the world's food in value terms (FAO & IFAD, 2019). Moreover, in developing countries, peasantry systems are the primary source of staple food, and it is estimated that 1.5 billion people earn a livelihood from such activities (López-Ridaura et al., 2005). The importance of family farming is still proven with its capacity to provide deep responses to emerging social, environmental, and economic challenges, as it can preserve biodiversity, resources, and landscape, generate jobs, and maintain community and cultural heritage.

Considering the importance of family farming in agricultural production and the environmental agenda of various countries worldwide, it is important to assess the sustainability of family farming practices, aiming to support decision-making processes, regarding different types of politics and strategies to promote the sustainable development of a region. However, translating the sustainability concept into operational definitions is not simple because it requires a set of appropriate multidimensional indicators that allow catching the needs of the broad range of stakeholders involved. Many scholars have dealt with the design of sets of indicators for gauging agricultural sustainability, and it was observed that the choice of an appropriate set of indicators is a crucial and complex problem. In fact, whenever too few

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indicators are selected, critical aspects may escape attention, and in contrast, if too many indicators are taken into consideration a series of problems can arise such as data collection, validation, as well as a general state of confusion in the decision-maker's mind. Furthermore, some indicators are appropriate for a region but for others are not: for instance, the indicators used to evaluate the sustainability of family farming in Europe, are different from those used in the dryland areas of the Brazilian semiarid region.

There is, in literature, a wide range of frameworks to derive indicators for assessing agricultural sustainability. These frameworks can be grouped into two broad classes: system-based frameworks, and content-based disciplinary frameworks. According to López-Ridaura et al. (2002), the system-based frameworks are the most proper to derive indicators because they use basic attributes of the system under study as a starting point to derive criteria and indicators. Basic attributes are those which haven't disciplinary biases, such as productivity, stability, equity, and durability, among others.

As for family farming sustainability assessment, there are a few system-based frameworks that can be used to derive indicators, among these, one of the most important is the MESMIS framework (Spanish acronym for the Indicator-Based Sustainability Assessment Framework program) (López-Ridaura et al., 2002; Astier et al., 2012). Although this framework has been largely used in a wide range of studies, it presents some limitations, such as: (1) it doesn't have a strong methodological approach for developing indicators based both on top-down (experts) and bottom-up (stakeholders) approaches (Talukder & Blay-Palmer, 2017), as only a bottom-up methodology is considered in the framework; (2) it uses only primary data (Talukder & Blay-Palmer, 2017); (3) the validation of indicators occurs only through the stakeholders' appraisal (Roy & Chan, 2012); and (4) it can be used in a very small spatial scale (production unit or community) (López-Ridaura et al., 2002), as a consequence its validity is flawed when a large territory is under study. Moreover, due to the strong participation of a large number of stakeholders, including laymen, at each stage of the framework, the procedure of deriving indicators through MESMIS can be heavy, as it is extremely difficult for the stakeholders to converge on a common vision in a short time.

To overcome the limitations of MESMIS and to ensure that the characteristics of each region are taken into consideration, this work proposes an approach to derive indicators for assessing the sustainability of family farms which can be applied on a regional scale. The approach is based on the MESMIS framework, with some adaptations, and it foresees the use of 4 phases. The first one provides a characterization of the system under study according to the guidelines provided by MESMIS. In phase 2, semi-structured interviews with farmers and relevant stakeholders are carried out and analyzed through the content analysis technique, aiming to set the critical points of the system under analysis. In phase 3, the critical points are converted into a set of potential indicators according to the MESMIS guidelines. Finally, in phase 4, these potential indicators are validated and converted into a set of definitive indicators by means of a modified Delphi method, which is carried out with the participation of a panel of experts.

2. Theoretical background

2.1. Related works

The theme of deriving sustainability indicators has been widely addressed in the literature (Fraser et al., 2006), meanwhile, few studies deal with framework to derive indicators in the context of family farming. Among these studies, some frameworks are content-based disciplinary, while others are system-based (Van Cauwenbergh et al., 2007). System-based frameworks provide indicators that are linked to basic attributes of the system under analysis, while content-based disciplinary approaches derive specific indicators related to the specific function of the system (Bossel, 2002). Put differently, basic attributes are general aspects that are not related to any specific discipline.

Furthermore, frameworks to derive sustainable indicators can follow two main methodological paradigms: top-down and bottom-up. In the top-down approach, indicators are selected directly by a set of experts, while the bottom-up approach foresees the use of stakeholders' participation. Nevertheless, according to Roy and Chan (2012), a suitable framework to derive indicators should be expert-led with the active participation of stakeholders, that is it must have a mixed top-down/bottom-up approach.

The most popular frameworks to derive indicators in family farming sustainability assessment are described as follows. SAFE (Sustainability Assessment of Farming and the Environment) is designed for three spatial levels: parcel, farm, and a higher spatial level (region or state). According to Van Cauwenbergh et al. (2007), it can be considered a content-based disciplinary framework and hierarchical, that is, composed of principles, criteria, indicators, and reference values in a structured way. At the first hierarchical level, principles are defined, which are general conditions to achieve sustainability. Successively, at the second level, principles are broken down into criteria that permit an easy linkage with the indicators at the third level. The SAFE framework adopts a top-down methodological paradigm and uses experts' opinions to select indicators, which, thereafter, are validated by means of expert appraisals. Primary and secondary data are also used to derive indicators, and the framework takes into consideration environmental, social and economic aspects of sustainability (Roy and Chan, 2012; Talukder and Blay-Palmer, 2017).

One of the most important frameworks to derive family farming sustainability indicators is the MESMIS framework (Spanish acronym for Indicator-based Framework for Assessing the Sustainability of Natural Resource Management Systems). It is a system-based framework projected for assessing smallholder agricultural farms in different agroecological regions (Speelman et al., 2007; López-Ridaura et al., 2002). MESMIS framework uses a bottom-up approach guaranteeing the participation of a wide range of stakeholders across every step of the process. The validation of indicators derived occurs by means of the stakeholders' opinion, while only primary data are taken into account to derive them. Indicators are derived starting from seven sustainability attributes and successively are distributed into three dimensions (economic, environmental, and social) (Talukder & Blay-Palmer, 2017).

Another important framework to derive family farming indicators is the Multiscale Methodological Framework (MMF) (López-Ridaura et al., 2005), which allows the assessment of peasant agriculture sustainability at different levels (farm, community, municipality, sub-region, region). The MMF has been developed using the MESMIS as a base, but, conversely, takes into consideration only 5 sustainability attributes (Productivity, Stability, Resilience, Reliability, and Adaptability). Like MESMIS, MMF is considered a system-based framework and uses a bottom-up methodological approach. Stakeholders' opinion is used both to select and validate indicators. Only primary data are employed to derive indicators, which are distributed into the three classical dimensions of sustainability.

The Sustainability Solution Space for Decision Making (SSP) (Wiek & Binder, 2005) is also a framework that can be used to derive sustainability indicators for family farming. SSP is considered a system-based framework and can be applied from farm to region spatial level. It adopts a mixed top-down and bottom-up approach using both stakeholders' opinions and experts' appraisals in the indicator selection and validation processes. Primary and secondary data are taken into account in deriving indicators, furthermore, environmental, social, and economic dimensions are considered in the framework.

The International Framework for Evaluating Sustainable Land Management (FESLM) is a system-based framework to derive indicators, which considers five basic attributes or pillars, that is productivity, security, protection, viability, and acceptability (Smith & McDonald, 1998). For each of these basic attributes, evaluation factors and diagnostic criteria are established, and, successively, indicators are derived. This framework is used at a small scale (field, crop, or farm) and uses a top-down methodological approach. Indicator selection occurs throughout experts' judgments and their validation is carried out by means of experts' appraisals. Primary and secondary data are considered in deriving indicators, which are distributed into the three pillars of sustainability.

The last framework considered in this overview is MOTIFS (Monitoring Tool for Integrated Farm Sustainability) (Meul et al., 2008). This framework is considered a system-based approach. It starts from principles that characterize sustainable family farming and, thereafter, translates them into concrete themes. For each theme, indicators are derived. Furthermore, MOTIFS is characterized by a top-down methodological paradigm, indicators are selected by means of experts' judgments and validated through experts' appraisals. Primary and secondary data are employed to derive indicators, and the three dimensions of sustainability are considered.

Table 1 summarizes the main characteristics of these frameworks.

FRAMEWORK	SPATIAL LEVEL	APPROACH	INDICATORS SELECTION METHOD	VALIDATION	DATA SOURCE FOR INDICATORS	FRAMEWORK TYPE
SAFE	Farm to Region	Top-down	Literature review, criteria, expert opinion	Expert appraisal	Primary and secondary data	CONTENT-BASED DISCIPLINARY
MESMIS	Farm to local community	Bottom-up	Stakeholders' opinion	Stakeholder opinion	Primary data	SYSTEM-BASED
MMF	Farm to Region	Bottom-up	Stakeholders' opinion	Stakeholder opinion	Primary data	SYSTEM-BASED
SSP	Field to region	Top-down, Bottom-up	Stakeholders' opinion or Expert appraisal	Stakeholders' opinion or Expert appraisal	Primary and secondary data	SYSTEM-BASED
FESLM	Field to farm	Top-down	Expert judgment	Expert appraisal	Primary and secondary data	SYSTEM-BASED
MOTIF	Field to farm	Top-down	Expert judgment	Expert appraisal	Primary and secondary data	SYSTEM-BASED

Table 1: Theoretical background outcomes. Source: The authors (2022)

All the frameworks use a hierarchical structure, that is, they start from a great goal and progressively break down just until obtaining indicators, and all consider the three pillars of sustainability.

As it can be seen, except SAFE all frameworks are system-based, thus, more suitable for deriving sustainability indicators (López-Ridaura et al., 2002). Among them, SSP seems the most complete, however, it allows the use of one between two different approaches to derive indicators: participatory approach, or expert approach. In the first one, stakeholders select indicators by means of a brainstorming process, and, successively, researchers revise the list of selected indicators. In the expert approach, experts are considered stakeholders, and they select indicators using a structured procedure. Once indicators are selected, researchers revise the set of indicators. Consequently, it can be stated that the participatory approach can be extremely heavy e difficult to converge into a solution, while the expert approach tends to overlook important issues related to stakeholders' opinions.

It would be interesting can dispose of a system-based framework that uses a mixed top-down/bottom-up approach, employs both stakeholders and experts in selecting indicators, relevant stakeholders and experts in validating indicators through a structured process, and takes into consideration primary and secondary data. Although all the analyzed frameworks can be considered powerful tools for deriving family farming sustainability indicators, we have selected the MESMIS framework as the base of our work because of its flexibility, and above all, because it is the only framework that has been developed specifically for the assessment of smallholder’s farms’ sustainability. In contrast, the other ones have been adapted for this task.

In the next section, we will present the fundamentals of MESMIS framework.

2.2. The MESMIS framework

The MESMIS is a framework developed by an interdisciplinary and multi-institutional team in Mexico which aims to operationalize the general principles of sustainability (López-Ridaura et al., 2002), giving rise to criteria, indicators, and agricultural practices. The MESMIS approach is based on the following four premises: (i) sustainability is defined by seven general attributes (or properties) of sustainable natural resources management systems (NRMS) that is Productivity, Stability, Reliability, Resilience, Adaptability, Equity, and Self-reliance; (ii) sustainability assessment is only valid for a specific management system in a given geographic location on a specific spatial and time scale; (iii) evaluation teams should include external and internal participants as the evaluation process is participatory; (iv) sustainability cannot be measured per se but through the comparison of two or more systems. This comparison can be made cross-sectionally (for instance, comparing an alternative with a reference system at the same time) or longitudinally (for instance, by analyzing the evolution of a system over time) (López-Ridaura et al., 2002).

As for the seven attributes of sustainable NRMS, Productivity relies on the capacity of the system to provide a level of goods or services. Stability refers to the ability to maintain its productive capacity constant in face of environmental changes. Resilience is related to the capability to recover after suffering severe or extreme disturbances such as pest damage, pandemics, drought, and natural calamities. Reliability refers to the ability to maintain the desired output level near equilibrium when facing normal disturbances in the environment. Adaptability is the capacity of NRMS to adapt himself to changes. Equity refers to the capacity to fairly distribute the benefits and the costs related to the management of the farming system. Finally, Self-reliance is the system's ability to regulate and control its interactions with the outside world.

The MESMIS framework foresees six steps, and it is conceived as a cyclic process (Figure 1).

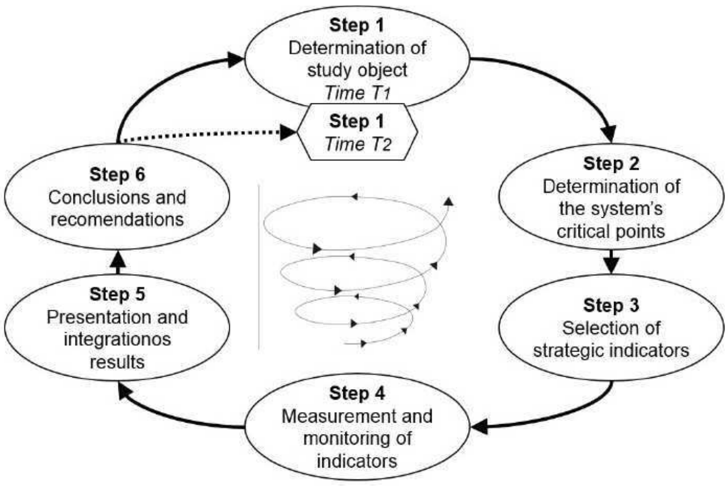

Figure 1: MESMIS framework evaluation cycle. Source: Adapted from López-Ridaura et al.(2002)

This cyclic process can be divided into two phases, a system analysis phase, and a system synthesis phase. In the system analysis phase, which comprises the first 3 steps of the cycle, sets of criteria and specific indicators are derived, while in the system synthesis phase the criteria and indicators are used to assess the sustainability of the agricultural system.

In the first step, the evaluation team characterizes the system under study as well as the socio-environmental context and scope (spatial or temporal) of the evaluation. An accurate description of the system will be undertaken that should include the components of the system, the input and output, the main management and productive activities, the main characteristics of the stakeholders, and the form of organization they have.

In the second step, critical features of the system concerning its sustainability are determined. These critical features reflect important factors that weaken or strengthen the sustainability of the system in relation to the proposed attributes.

Step 3 starts with defining a set of diagnostic criteria that arise from the critical points, helps begin grounding the general attributes of sustainability, and represents a level of analysis more detailed than attributes but more general than indicators. Once defined the diagnostic criteria, indicators may be identified and selected, for each critical point minimum of one indicator should be derived. The set of indicators selected should cover the seven attributes of NRMS.

Step 4 comprises measuring and monitoring the selected indicators. Monitoring the behavior of indicators over time is essential when evaluating sustainability, a concept that focuses on the behavior of a system over time.

In step 5, the results obtained by measuring and monitoring indicators are summarized and integrated. As a technique for integrating different indicators, MESMIS promotes the AMOEBA diagram. This diagram shows, in qualitative terms, whether the objective has been reached by comparing the actual value of each indicator with its ideal value (reference value).

Finally, step 6 recapitulates the results of the analysis and offers some recommendations to enhance the sustainability of the systems.

With the recommendations of this last step the first evaluation cycle is finished, and, at the same time, the first step of a new evaluation cycle begins (Speelman et al., 2007; Astier et al., 2012; López-Ridaura et al., 2002).

In most case studies, the MESMIS framework addressed three dimensions of sustainability, that is economic, environmental, and social. The social dimension incorporates also issues concerning the cultural and political dimensions. According to Speelman et al.(2007), the MESMIS framework is a dynamic framework that constantly evolves by virtue of the adoption of a strongly participatory approach in all their steps.

Even though it is mainly used as a tool to assess the sustainability of family farming at the local level, this operational framework also offers guidelines for the selection of indicators (Gharsallah et al., 2021), however only a few times it has been employed for this task.

3. Proposed framework

The proposed framework is divided into four phases (Figure 2): (i) phase 1 - characterization of the system under study, whose goal is to define and describe the system under study, that is identifying its boundaries, biophysical, socioeconomics, and technological components, as well as inputs, outputs, and social interactions; (ii) phase 2 - setting of the system's critical points, which is the core of the framework; (iii) phase 3 - proposition of a set of potential indicators; and (iv) phase 4 – modified Delphi session.

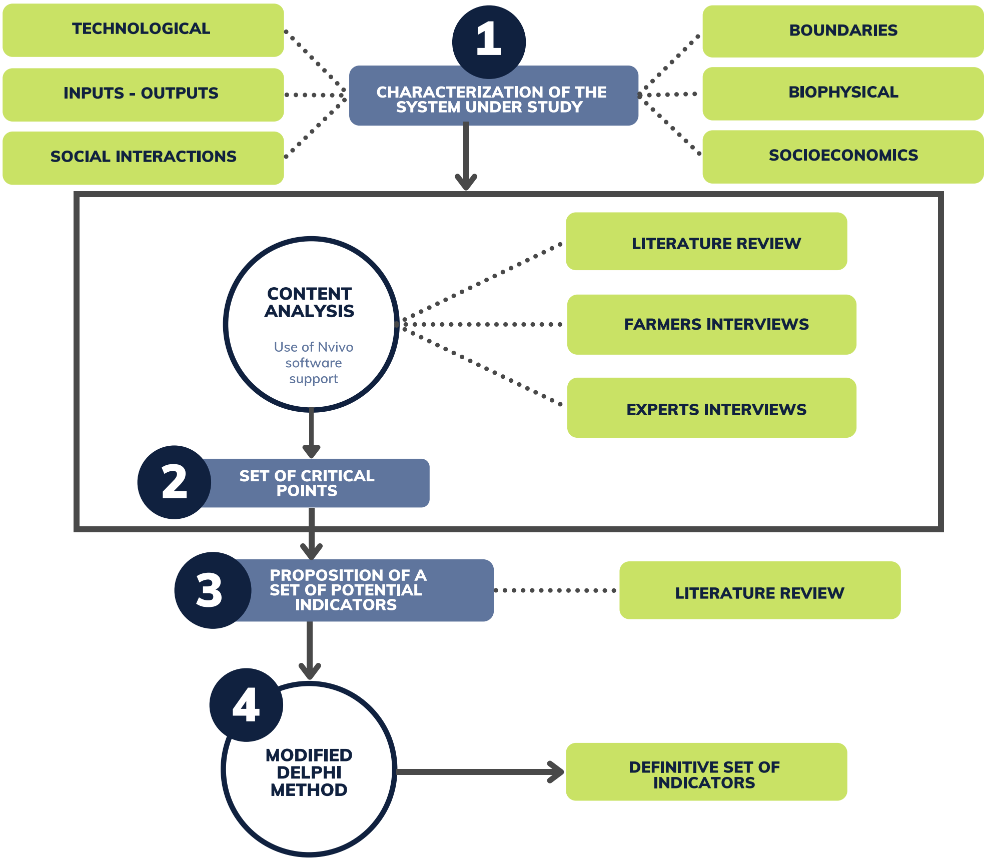

Figure 2: Framework of the proposed method. Source: The authors (2022)

3.1. Setting of the system's critical points

The second phase aims to reach a list of critical points of the system under analysis. The critical points are both negative and positive issues characterizing the system under study, and they constitute the source from which the indicators arise. To achieve the list of critical points, Moreira et al. (2019) recommended accessing multiple sources of data to develop a comprehensive understanding and improve the reliability of results through triangulation of pieces of evidence.

Therefore, at this phase, a threefold process is performed: (i) literature review, whose goal is to create the background necessary to formulate the questionnaire that will be used to conduct the semi-structured interviews; (ii) semi-structured interviews (farmers and experts) (Appendix II); and (iii) non-participant observation. During the non-participant observation, the researchers should stand apart from the individuals (farmers) being observed, interacting as minimally as possible with them, trying to catch information to confirm some pieces of evidence pointed out by the interviews (Barner-Barry, 1986).

Regarding the semi-structured interviews, the framework recommends performing interviews with two groups: a group of farmers and a group of experts. The first group is formed by family farm managers who are selected using the snowball sampling technique. The size of this group depends on the availability of respondents to participate in the survey, but, according to (Bowen, 2008), it is recommended to have at least a number of individuals correspondent to the theoretical saturation point; that is, a point at which all questions have been thoroughly explored in detail, and no new concepts or themes emerge in subsequent interviews (Saunders et al., 2018). As for the group of experts, it is recommended to select the experts representing the most important stakeholders at a regional level - that is federal universities, governmental institutions, private institutions, and research institutes. In this work, these stakeholders are named "relevant stakeholders" due to their importance and their wide knowledge of the system. The framework recommends selecting at least one expert for each relevant stakeholder.

After the data collection, the content analysis technique should be applied to identify the critical points that characterize the system. It is recommended to use the software Atlas.ti as a supportive tool, which provides reliability to the theoretical-empirical interpretations since it minimizes the bias of personal interpretations of the results (Moreira et al., 2019).

The content analysis should be performed following three steps: (i) pre-analysis; (ii) exploration of the material; and (iii) treatment of results, inference, and interpretation. Pre-analysis is characterized by the organization of the documents that must be analyzed. The first activity that must be undertaken is the "floating reading", which consists of establishing contact with the documents to be analyzed and knowing the text by allowing oneself to be invaded by impressions and guidelines. Afterward, the researchers select the "corpus" of the research, that is the set of documents considered for analytical procedures. The chosen documents should address the same theme and have been provided by means of identical techniques, in this case, semi-structured interviews. Finally, before the next step, the gathered material must be prepared, that is, recorded interviews are transcribed and recordings are retained. The exploration of the material consists essentially of encoding the "corpus". In this case, the encoding process must be undertaken using an inductive approach (Seuring & Müller, 2008), that is, the codes are developed directly from the answers obtained in the interviews. In this work, each code corresponds to a specific critical point.

3.2. Proposition of a set of potential indicators

The list of critical points is the input for the third phase. Firstly, they are distributed in the seven sustainability attributes according to the MESMIS guidelines López-Ridaura et al. (2002), then, they are converted into indicators. Each critical point should correspond to at least one indicator. The indicators should be chosen from the specialized literature (Cicciù et al., 2022), using the following selection criteria: scientific validity, measurability, data availability, relevance to the scope, and cost. The result of the third phase is a proposition of a set of potential indicators.

3.3. Modified Delphi session

The set of potential indicators is the input for the fourth phase whose goal is to determine the definitive set of indicators, by using a modified Delphi method (Turoff, M., & Linstone, 1975) (Figure 3). The modified Delphi session should be carried out through 3 rounds: 1st round - indicators set revision; 2nd round - indicators validation; 3rd round - seeking raters' consensus.

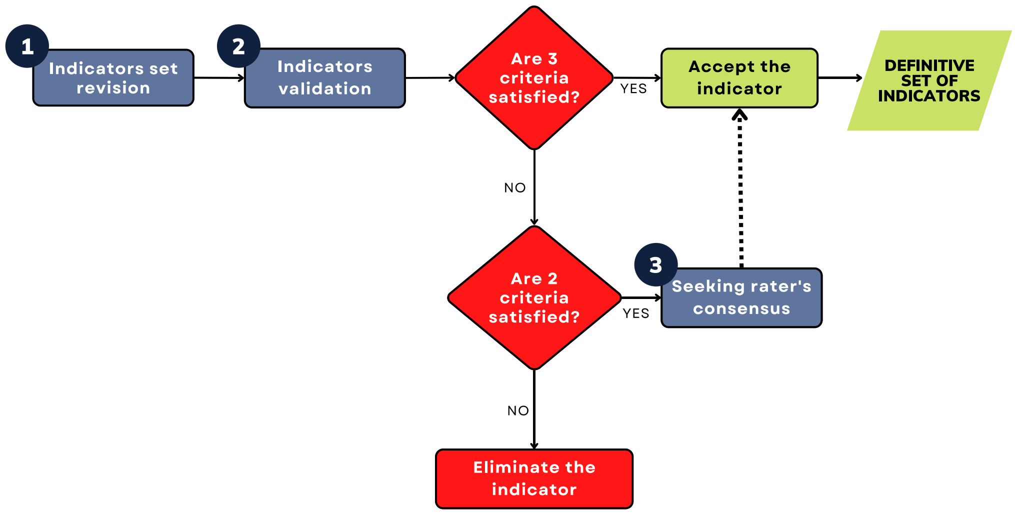

Figure 3: Rounds of the modified Delphi method. Source: The authors (2022)

Firstly, you should identify and select individuals who will compose the panel of experts. Ahmad and Wong (2019), recommend that the panel should have at least 7 or 8 individuals. In this study, it is suggested to select them according to the criteria pointed out by Roy & Chan (2012), that is, they must be local-specific, relevant to the discipline, and strongly experienced. Furthermore, in order to encompass most stakeholders involved, the panel of experts should be as heterogeneous as possible (Jiang et al., 2017). Once the panel is selected, a modified Delphi session should be performed.

In 1st round, various individuals online and face-to-face meetings are arranged with experts to discuss the proposed set of indicators, specifically, the relevance of the indicators obtained, their distribution in the different attributes, and the omission of some important indicators; notes must be taken and analyzed for revising the set of indicators.

In 2nd round, the link of an online questionnaire is sent by email to all members of the panel, by which they are asked to rate the level of importance of the indicators using a five-point Likert scale: (0) not important; (1) somewhat important; (2) relative important; (3) very important; and (4) extremely important. To assess consensus, three measures are used: (i) the percentage of experts responding to the category "very highly important"(Giannarou & Zervas, 2014); (ii) the Interquartile Range (IQR) below 2.0 (Von Der Gracht & Darkow, 2010); and (iii) the coefficient of variation between 0 and 0.5, that is $0 \leq CV \leq 0.5$ (English, J. M., & Kernan, 1976). The use of a combination of techniques for assessing the consensus level ensures the way of reaching consensus and provides a reliable manner to conclude on the experts' overall agreement upon the set of indicators (Giannarou & Zervas, 2014). If an indicator meets the three above criteria, it is included in the definitive set of indicators. If only two criteria are met, the indicator has reached a medium level of consensus, consequently, it will be accepted but should be analyzed in the 3rd round. Otherwise, the indicator should be eliminated.

Mean scores of the indicators are used to calculate the weights of the indicators, while mean scores of indicators weights are used to calculate the weight of each attribute. Still, the median is used to evaluate the importance of each indicator. Round 2 can be performed using the software SPSS as a supportive tool.

At least 2 experts (preferably the most experienced) are invited to participate in the 3rd round, whose goal is to seek the reasons that could have given rise to indicators with a medium level of consensus. To minimize potential biases and to limit potential group-thoughts, the experts should be blinded to each other during the rounds.

The next section presents a real application of the proposed method to derive a set of indicators for assessing the sustainability of family farming in the Brazilian semiarid region.

4. Application

4.1. Characterization of the system under study

The studied system is in the equatorial zone (1-21°S, 32-49°W) and covers an area of 1128697.4 km2 in which 27.8 million people live distributed into 1262 municipalities of

Northeast Brazil. These numbers make the Brazilian Semiarid Region (BSR) the most populated semiarid region in the world (Cunha et al., 2015). Most of this area is covered by mixed grasslands-croplands, other land covers are caatinga (closed and open shrublands), and savanna.

Although rich in natural resources, the semiarid area is characterized by the insufficiency and irregularity of rainfall, periodic occurrences of severe drought, high temperatures, and high evapotranspiration rates that converge in a strongly negative water balance. With average precipitation below 900 mm year $^{-1}$ and potential evaporation above 2200 mm year^{-1} (de Araújo et al., 2006), this negative water balance has become the main explanation for the regional crises, expressed in the low economic dynamics and in the extreme socioeconomic vulnerability. Currently, the BSR concentrates the largest share of the Brazilian rural population living in poverty and extreme poverty conditions.

Despite the recent process of economic modernization of agriculture in the BSR, a large part of the agricultural economy in this region is characterized by the family farming production model. In fact, according to the Brazilian Institute of Geography and Statistics - IBGE (2021), the last agricultural census held in 2017, pointed out the existence of 1.83 billion agricultural establishments in the BSR, corresponding to 36.2% of all Brazilian agricultural establishments. 78.8 % of these establishments are characterized as family farms, and they employ 3.65 million people which corresponds to 75.3% of all people working in rural areas.

In general, family farming in the BSR provides a wide range of crop and livestock activities. Regarding crop production, it is worthwhile to highlight the production of beans, rice, cassava, sugar cane, sweet potato, and pumpkin, in addition to a variety of horticultural products, all constituting fundamental components of the regional diet. In addition to food products, attention is drawn to the performance of family farming in extractive activities, with emphasis on derivatives of regional vegetation. As for livestock production, the agricultural census of 2017 highlights that family farming is responsible for 72% of the goat herd, 71% of the sheep herd, 76.1% of the swine herd, and 54.3% of the cattle herd. Still, according to IBGE (2021), family farming in the BSR is responsible for a production value of 1381916 R$ in 2017, which corresponds to 79.2% of the total production value of all agricultural activities in this region. These data point out the great capacity of resilience and the productive capacity of family farming in the BSR, even though it faces strong structural lacks and deep socio-economic problems.

Despite the challenges family farming in the BRS faces, according to IBGE (2021), its establishments have more preserved areas, adopt organic fertilizers more than chemical ones, and use polyculture and crop rotations. As for the use of chemical inputs, even though a part of family farming establishments uses them, this use is restricted mainly to medium and large establishments. In the last decade, Northeast Brazil has benefited from a wide range of initiatives of the federal government, which are generating numerous positive effects with the potential to transform the structure of the BSR and insert it into a virtuous cycle accumulation. However, the result of this initiative is still uncertain, especially in rural areas, where severe poverty makes it difficult to include a large part of people into the new wave of development and opportunities.

4.2. Setting of the system's critical points

Firstly, a literature review on family farming challenges in BSR has been carried out, aiming to identify the main topics to use as a guideline in the construction of a questionnaire survey that was thereafter applied. Secondly, we conducted 17 semi-structured interviews with a sample constituted of two groups of respondents. The first group of respondents encompasses 15 family farm managers spread over three different areas of the Paraiba state; however, as the saturation point was reached at the 10th interview, only 10 respondents have been taken into consideration. The second group consists of 7 experts who have been selected (Table 2). All the interviews have been undertaken in the period between January 22nd, 2022, and June 10th, 2022.

Age	Study Degree	Current Occupation	Relevant Stakeholders Represented
65-70	Ph. D. in Natural Resources Management	Federal Counselor and Senior Academic Researcher	Federal Council of Engineering and Agronomy and Federal University of Campina Grande
65-70	Bachelor in Agronomy	Regional Adviser	Research, Assistance, and Rural Extension Company
65-70	Bachelor in Agronomy	Rural Syndicate President	National Rural Learning Service
30-35	Master Science in Soil Science	Federal Researcher	National Institute of the Semiarid
30-35	Bachelor in Agricultural Engineering	Federal Agricultural Technician Advisor	Research, Assistance, and Rural Extension Company
40-45	Master Science in Administration	Senior bank manager	Northeast National Bank
40-45	Ph.D. in Agricultural and Veterinary Sciences	Federal Senior Researcher	Brazilian Agricultural Research Company

Table 2: Group of experts. Source: The authors (2022)

The analysis allowed the identification of 53 critical points. The most cited critical point was "Low propensity for innovation and technology" which points out the lack of propensity that the farmers have in taking training, and courses, as well as in using machinery or any form of technology. The second most cited critical point was "Low management ability" which indicates the lack of management practices that characterize in general each family in smallholder agriculture. The less cited critical points were: "High crop loss", which points out the loss of crops that in general characterizes the amount of crop lost in relation to the total crop planted, "Low productive process efficiency", which points out the profit margin for each unit of value sold, “Migration towards urban zone”, which indicates the number of family members migrating from rural to the urban area, "High rate of organic agriculture", which points out the rate of organic agriculture in the cultivated land, and “Poor quality of homes” that is related to the quality of houses in which the farmers live. The list of critical points obtained constitutes the input for the next phase of the model.

4.3. Proposition of a set of potential indicators

Once obtained the list of critical points, this step aims to provide a set of potential indicators. Firstly, the critical points have been distributed among the seven sustainability attributes (that is Productivity, Stability, Reliance, Reliability, Adaptability, Equity, and Self-Reliance) according to the MESMIS guideline. Then, each of them has been matched with one or more indicators that were derived from a literature review previously undertaken. Initially, 62 indicators have been derived, which were aggregated into 17 composite indicators. The list of potential indicators was delivered to a set of experts who will participate in the modified Delphi session.

4.4. Modified Delphi session

The panel of experts is composed of eight individuals that accepted to participate in the modified Delphi session.

4.4.1 1st round - indicators set revision

After various meetings, carried out both online with the google meet platform and face-to-face, 18 indicators have been added to the previous list, giving rise to a definitive list of 80 indicators, which have been definitively grouped into 21 composite indicators. This round has been undertaken in the period between June 15 th, 2022, and July 20 th, 2022.

All the outputs obtained in phases 2 and 3 of the model, including the 18 indicators that were added by the experts during the first round of the modified Delphi session, are presented in Appendix 1.

4.4.2 2nd round - indicators validation

This round has been undertaken in the period between July 21 th, 2022, and August 12 th, 2022. The link of an online questionnaire was sent to the experts to evaluate the level of importance of the 80 indicators. Results show that 88.75% of the indicators were rated very high on the importance scale (“Very important” to “Extremely important”), and the rest 11.25% were rated high (“Relatively important” to “Very important”). Regarding the attributes among which the indicators were clustered, the mean shows that they have approximately the same importance. The median points out that, except for adaptability, in all attributes, the indicators are considered very important to extremely important. Concerning adaptability, 10% of indicators have been considered relatively important.

As for the consensus levels (Table 3), the outcomes show that 78 indicators have IQR$\leq$ 2.0, and only I32 (Pesticide usage) and I33 (Fertilizer usage) have an IQR > 2.0, that is, achieved a low level of consensus, according to the second criterion. When it comes to CV, both indicators have 0$\leq$CV$\leq$0.5, matching, thus, the second criterion. However, when, finally, the first criterion is observed, the percentage of experts who responded that I32 and I33 was “very highly important” is 66.6%. In contrast, indicator I48 (Investment level), even though has reached a good value of IQR and CV (second and third criteria, respectively), only 44.4% of experts considered it as "very highly important".

Indicators I32, I33 and I48 have a 1.01 $\leq$ SD $\leq$1.49, this means that both have reached a reasonable level of consensus amongst the experts, then, they don't need to be rejected. However, the third round of discussion is necessary to evaluate the divergences among them regarding I32, I33 and I48.

COMPOSITE INDICATORS	INDICATORS	ID	Q3-Q1	% 3-4	CV
Productivity	Productive capacity	I1	1	88,8	0,212132
	Productive process efficiency	I2	1	88,8	0,204323
Financial	Profitability	I3	1	100	0,136364
	Economic efficiency	I4	1	100	0,148232
Quality of products	Certificated production	I5	2	66,6	0,298273
	Product labeling	I6	1	88,8	0,210914
Water availability	Water storage capacity (agricultural use)	I7	1	88,8	0,204323
	Water storage capacity (domestic use)	I8	1	100	0,136364
	Water supply sources (surface water + groundwater)	I9	1	100	0,153013
	Rainfall deviation	I10	2	66,6	0,298273
Water use	Water consumption rate	I11	1	88,8	0,212132
	Water use efficiency	I12	1	100	0,148232
	Family water footprint	I13	2	66,6	0,301601
Water quality	Water salinity in surface water	I14	2	66,6	0,301601
	Water salinity in groundwater	I15	1,5	66,6	0,259808
	Nitrates	I16	2	66,6	0,298273
	Nitrites	I17	2	66,6	0,298273
	Arsenic concentration	I18	2	66,6	0,301601
Soil quality	Organic material	I19	1	88,8	0,210914
	Carbon Nitrogen Ratio (C/N)	I20	2	55,5	0,338815
	Salinity	I21	2	66,6	0,298273
	Macronutrient N	I22	1,5	77,7	0,258621
	Macronutrient: P	I23	1,5	77,7	0,258621
	Macronutrients: K	I24	1,5	77,7	0,258621
	Soil erosion	I25	1	88,8	0,210914
	Slope	I26	2	66,6	0,364878
	Hydraulic conductivity	I27	2	55,5	0,403846
	Soil pH	I28	2	55,5	0,338815

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Agricultural Practices & Conservation	Tillage	I29	1	88,8	0,212132
	Crop rotation	I30	1	100	0,153013
	Cover crop	I31	1	100	0,148232
	Pesticide usage	I32	2,5	66,6	0,439372
	Fertilizer usage	I33	3	66,6	0,501996
	Organic fertilizers	I34	1	88,8	0,3
Diversity	Crop diversity	I35	1	88,8	0,212132
	Livestock activity	I36	1	77,7	0,235702
Protection	Forest area	I37	2	66,6	0,301601
	Organic area	I38	1,5	77,7	0,258621
	Pests and diseases management	I39	1	88,8	0,3
Resources availability	Labor availability	I40	1	100	0,148232
	Land use coefficient	I41	1,5	77,7	0,333333
	Crop loss	I42	1	88,8	0,206897
	Labor migration	I43	1	88,8	0,210914
	Young people working in agricultural activities	I44	1	100	0,136364
Added value to products	Added-value activities	I45	1	88,8	0,298273
	Brand	I46	2	66,6	0,364878
	Diversification	I47	1,5	66,6	0,349857
Entrepreneurial propensity	Investment Level	I48	1,5	44,4	0,396702
	Marketing strategies	I49	1	66,6	0,210914
Propensity for innovation	Training	I50	1	88,8	0,210914
	Machinery and equipment	I51	1,5	77,7	0,251272
	Research and experimentation	I52	1	88,8	0,212132
Technical knowledge	Knowledge and technical skills	I53	1	88,8	0,210914
	Specific equipment’s need	I54	1	77,7	0,248039
Opportunities creation	Women's involvement in decision-making about agricultural activities	I55	1	88,8	0,403978
	Education of farmers	I56	1	88,8	0,210914
	Access to sport, leisure, or culture	I57	1	88,8	0,210914
	Employment opportunities	I58	1	77,7	0,248039
Infrastructure	Road network	I59	1	88,8	0,212132
	Access to transportation and mobility	I60	1	100	0,15
	Settings where treatment is taken or public health	I61	0	100	0,085714
	Access to education services	I62	0,5	100	0,116724
	Housing quality	I63	1	100	0,153013
	Basic sanitation	I64	1	100	0,136364
	Wastewater treatment	I65	1	88,8	0,210914
	Communication (telephone/internet)	I66	1	88,8	0,212132
	Access to electronic media	I67	1,5	77,7	0,258621

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Associativism & Cooperation	Participation in consortia, associations or syndicates	I68	1	88,8	0,204323
	Activities managed jointly with other farmers	I69	2	66,6	0,298273
	Resources shared with other farmers (like seed banks)	I70	1,5	77,7	0,258621
Institutional support	Advisory contact per year	I71	1	100	0,136364
	Government support	I72	1	88,8	0,212132
	Subsidies, government program payments	I73	1	88,8	0,212132
	Rural crime rate	I74	1	88,8	0,204323
	Number of selling channels	I75	1	100	0,136364
Management ability	Waste reuse	I76	0,5	100	0,116724
	Farm management	I77	1	100	0,153013
Inputs dependence	Economic Independence	I78	1	100	0,153013
	Indebtedness	I79	1	100	0,212132
	Availability of seeds	I80	1,5	77,7	0,251272

Table 3: Consensus level on indicators. Source: Research data (2022)

4.4.3 3rd round - seeking rater's consensus

The interviews that have been carried out in this round allowed us to identify the source of divergence in the experts' opinions concerning indicators I32, I33, and I48. Some experts, named "conservatives", understand that "family farming" is a synonym for small agriculture and/or subsistence agriculture, whose greatest virtue lies in the fact that it doesn't use chemical fertilizer and doesn't need high investments; therefore, for them, indicators I32, I33 and I48 are not relevant. In contrast, other experts (progressives) understand that the use of investments and the controlled use of fertilizers can rise subsistence family farming towards business family farming with considerable positive consequences for the society as well as all the stakeholders involved, still avoiding environmental impacts. Another reason for the divergence in experts' opinions lies in the expert's experience, which can vary according to their own institutions.

At this step, the interviews with these experts were transcribed, and thematic analysis was applied to analyze the data.

5. Discussion

The proposed method was applied in the Brazilian Semiarid region in order to derive a list of indicators for assessing the sustainability of family farming. The content analysis, performed in the second step of the method, has been undertaken after 17 interviews with two groups of respondents (7 experts, and 10 farmers), and pointed out 53 critical points. The number of critical points found, highlights the extreme complexity of the system under study. In fact, according to Petersen and Silveira (2017), the BSR is embedded in the Northeast region, which is considered the macro-region that has the larger diversity of natural frameworks, being also the most divided from the political-administrative point of view. Still, according to the authors, the BSR is a complex reality both in terms of geophysicist aspects and regarding human occupation and exploration of its natural resources.

The critical points found have been clustered into 7 attributes of sustainability according to the MESMIS framework, in order to cover all facets of the sustainability concept. Specifically, 4 critical points have been placed into "Productivity", and 21 critical points (~39.6%) have been placed into the dimension named “Stability, Reliance, and Reliability”, which constitutes the main dimension. These three attributes have been grouped together because of their similarity according to the suggestions of Ripoll-Bosch et al. (2012) and López-Ridaura et al. (2002). In fact, all three attributes are related to the capacity of the system to face disturbances. The attribute “Adaptability” encompasses 4 critical points also, while both “Equity” and “Self-Reliance” include 12 critical points (~22.6%). Each critical point has been matched with one or more indicators, and these have been grouped into 21 composite indicators.

As far as the dimensions of sustainability are concerned, the set of indicators is well distributed among the dimensions: economic (18 indicators), environmental (36), and social (26). As for data type (qualitative, or quantitative), 46 indicators are quantitative, while 34 indicators are qualitative; according to (Talukder & Blay-Palmer, 2017) an assessment framework that can handle both qualitative and quantitative information is appropriate for sustainability assessment. Regarding the data sources, that is, the way to obtain the information that feeds the indicators, only an indicator is fed by secondary data, and the rest are fed by primary data. This result corroborates the finding of Dantsis et al. (2010), according to which agricultural sustainability indicators should be developed based on both primary and secondary data sources.

Two indicators “Fertilizer usage” and “Investment level” have achieved a medium level of consensus because they match only two criteria simultaneously, which required a round 3 of discussion, showing that the group has two different ways of interpreting the term "family farming": conservative and progressist. The conservative perspective emphasizes the importance of avoiding large inputs’ use and investments corroborating the findings of

Chayanov (1974), according to whom in the family farming production system, capitalist calculation of profit is inexistent.

The progressive perspective emphasizes the importance of the use of investments and the controlled use of fertilizers in family farming, corroborating the findings of Abramovay (2012) that established the term peasantry farming to differ from family farming. According to the author, a peasant is a familiar producer intimately integrated with agriculture but who doesn't realize any investment aiming at obtaining profit; in contrast, a family farmer sees agriculture as commerce and understands the land not as a lifestyle, but as capital and merchandise to use to get profit.

Methodologically, the proposed framework appears extremely useful in achieving the study's aims. The use of the MESMIS framework as a guideline has provided ease in deriving indicators, and the use of the software ATLAS.ti and SPSS has provided more reliability and robustness to the approach, as well as the triangulation of the three techniques used to calculate the consensus level.

6. Conclusions

The main objective of this research was to propose a novel approach to derive indicators for assessing family farming on a regional scale. The method proposed is mainly based on the experiences gained in the MESMIS framework, moreover, it uses some adaptations to overcome the limitations of MESMIS, involving stakeholders and experts in setting critical points of the system, involving experts in setting indicators, using both primary and secondary data, and using a modified Delphi method to validate indicators. The method was applied at a regional scale, in attempting to derive indicators to assess the sustainability of family farming in the Brazilian Semiarid Region (BSR).

After the description of the system under analysis, through the content analysis technique, a list of 53 critical points was obtained, characterizing family farming in the BSR. These critical points were distributed into the 7 attributes of sustainability using the guideline of the MESMIS framework. Critical points have been used to derive a list of 80 indicators and 21 composite indicators. The indicators have been validated through a modified Delphi method. The modified Delphi method pointed out that 88.75% of the indicators derived, were rated very high on the importance scale ("Very important" to "Extremely important"), and the rest 11.25% were rated high ("Relatively important" to "Very important"). Moreover, a high level of agreement in the expert's opinion on the importance of 97.5% of indicators indicates the high reliability of the set.

The study has practice and methodological implications. From a practical point of view, the study offers a robust framework that can provide reliable indicators, which likely reflect in-depth every system under analysis. From a methodological point of view, the study allows an advance in the knowledge of frameworks to derive indicators above all in the MESMIS methodology, allowing the overcoming of its limitations by means of the introduction of content analysis and the use of a modified Delphi method, which take into consideration farmers, experts, and relevant stakeholders. This solution allows a mixed top-down and bottom-up approach, the validation of indicators through experts' and stakeholders' appraisal, and the application of the framework at a regional scale. Moreover, in the framework, a new modified Delphi method is proposed combining three different techniques, which increase the robustness and reliability of results.

The framework can be used to provide indicators to employ in a multi-criteria decision-making/aid model, which can be used by different stakeholders who have an interest in assessing and monitoring the sustainability of family farming at a regional scale.

The research presents some limitations, the most important is the number of farmers interviewed, in fact, despite it was justified by the theoretical saturation, from a statistical point of view this sample continues too small for a region the size of Brazilian Semiarid; moreover, it was built considering farmers of the Paraiba state only. Second, round three of the Delphi method was used only to explain the reason for the divergence and not to improve the consensus level.

For future research, the use of successive rounds is suggested, as far as the consensus level reaches 100%. Moreover, the sample of farmers interviewed can be improved by means of a proportional stratification sampling that could encompass farmers from each state belonging to the Semiarid Region.

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CHAPTER 4

THIRD PAPER

MODEL FOR EVALUATING FAMILY FARMING SUSTAINABILITY BASED ON A NON-COMPENSATORY AGGREGATION OPERATOR

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ABSTRACT: Even though the existence of a broad range of holistic methods for assessing family farming sustainability, the employment of multi-criteria methods in this task is increasing in the last three decades and seems still underexplored. The use of these methods is strongly justified by the conflicting nature of the social, environmental, and economic dimensions of sustainability, further than they can handle some scientific issues such as sensitivity analysis, incommensurability, and the aggregation of indicators in a single index, which allow a less cognitive effort of the decision maker. Nevertheless, due to the complexity of the problem addressed, the number of variables considered can be very high, and, consequently, measuring them in a quantitative manner can be extremely costly and time-consuming, rather than not practical. For this, an evaluation of family farming sustainability based on ordinal information is needed, and, furthermore, due to the nature of the problem addressed, a non-compensatory method is more suitable. To our knowledge, no studies exist in the literature using ordinal methods for assessing the sustainability of family farming, and, in addition, the use of non-compensatory multi-criteria methods is still scarce. By virtue of this, in this study we propose an evaluation of family farming sustainability by the use of the De Borda method, which rather than an ordinal method is also considered a non-compensatory method. Results show that the method offers reliable results and presents strong robustness, in addition, the study has managerial, social, and academic implications.

Keywords: Family farming, Sustainability, Multi-criteria methods, Ordinal information

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1. Introduction

Since 1960, agricultural systems have been adopting intensive practices based on mechanization, monoculture, and high levels of inputs such as energy, pesticides, and fertilizer (Rana & Paul, 2017) to comply with the world's population increasing - it is expected to reach 9.8 billion in 2050 and 11.2 billion in 2100 (United Nations, 2019).

In this context, family farming has a key role, because, according to FAO and IFAD (2019), it constitutes the predominant form of agricultural production in both developed and developing countries, producing over 80% of the world's food in value terms (FAO; IFAD, 2019). There are various definitions of family farming; in this study, we have adopted the definition by FAO and IFAD (2019): family farming is a means of organizing agricultural, forestry, fisheries, pastoral, and aquaculture production that is managed and operated by a family and is predominantly reliant on the family labor of both women and men. The family and the farm are linked, co-evolve, and combine economic, environmental, socio, and cultural functions.

However, food security does not depend only on the production capacity of a system in the current moment, but also on how sustainable this production is in the future. In fact, the modern agrarian model, notoriously known as the "Green Revolution" has generated a rapid increase in agricultural outputs, but, on the other hand, it has given rise to serious socio-environmental problems that can put at risk future generations.

Considering the importance of family farming and the need for sustainable agricultural systems, assessing the sustainability of family farming practices is a key issue that allows for identifying the status of family farming as it is, and as should be. Based on this, policymakers, governmental institutions, farm managers, and simple farmers can implement actions aiming at making family farming more sustainable. Given this, efforts have been applied to investigate to what extent family farming can be considered sustainable; that is, can family farming truly produce enough foods for all, guarantying high quality, and simultaneously be environmentally sound, resource-conserving, economically viable, and socially acceptable?

There are lots of holistic methods which have been used over the years to assess the sustainability of family farming, among the most important IDEA (*Indicateurs de Durabilité des Exploitations Agricoles*), RISE (Response Inducing Sustainability Evaluation), SAFE (Sustainability Assessment of Farming and the Environment), SEAMLESS (System for Environmental and Agricultural Modelling Linking European Science and Society), MOTIFS (Monitoring Tool for Integrated Farm Sustainability), MESMIS (*Marco para la Evaluación de Sistemas de Manejo de recursos naturales mediante Indicadores de Sustentabilidad*).

In the last decade, however, the use of Multi-Criteria Decision Making/Aid methods (MCDM/A) in assessing agricultural sustainability, is been increasing in a rapid manner (Cicciù et al., 2022). The increased use of these methods is justified by virtue of the conflicting nature of the issues encompassed into social, environmental, and economic dimensions of sustainability. Further, Talukder et al. (2018) and Talukder and Blay-Palmer (2017), argue that MCDM/A methods are more suitable, in comparison to other holistic methods, for assessing agricultural sustainability, since they can handle some scientific issues such as sensitivity analysis, incommensurability, and, above all, aggregation of indicators into a single index. The use of a single index is extremely useful because the cognitive effort required to evaluate and interpret these indicators separately is very high and time-consuming.

As for indicators, the number of variables can still be very high, because various aspects should be taken into consideration to evaluate all dimensions of sustainability. Ideally, these variables should be measured considering their respective natural scale, which requires the involvement of specialists from different areas to provide reliable assessments, based on historical data, measurement of parameters, estimates, etc. Therefore, the process is highly costly and time-consuming and from a practical point of view, it does not work. Therefore, we propose an evaluation based on ordinal information; instead of quantifying the performance of each alternative (family farming) in each criterion, the individual (decision-maker) will be asked to provide only the ordering of alternatives from the best to the worst in each indicator. Note that this makes the evaluation process cognitively easier, avoiding the need of experts for providing the assessments; also, it makes the model useful to be applied in real-life cases.

When the evaluation of alternatives within each criterion is carried out based on an ordinal scale, ordinal methods, such as Borda Method, can offer good results. Ordinal methods have a very close relationship with methods that use the outranking approach, and for this reason are considered non-compensatory (Almeida, 2013; da Rocha et al., 2016). No studies have been found in the literature using ordinal methods for assessing the sustainability of family farming (Cicciù et al., 2022) and the use of non-compensatory methods is very scarce, pointing out an evident conceptual error in the sustainability assessment sphere, where it doesn't make sense to adopt compensatory rationality.

Considering the above-mentioned, this work presents a model for evaluating family farming sustainability, considering a set of indicators that are defined through a participative system-based framework, based on the MESMIS methodology. The list of indicators provided by the MESMIS-based approach is validated by a panel of experts through a modified Delphi method and then they are aggregated into composite indicators aiming to reduce the number of variables. The modified Delphi method is also employed to assign the weights of indicators, considering the agricultural system under study. Finally, a non-compensatory method is used to aggregate the information reducing the effect of compensation among dimensions that happens when any additive model-based operator is used.

2. Theoretical background

MCDM/A is considered a branch of the Operational Research area that deals with multi-criteria decision problems (Schramm et al., 2020). A multi-criteria decision problem consists of a situation in which there are at least two different alternatives to be selected, and this choice is led by the desire to satisfy multiple goals, which, in most cases, are conflicting (Almeida, 2013). Schramm et al. (2020) add that multi-criteria methods are a set of quantitative techniques that can recommend the best compromise solution, from a set of alternatives to a Decision Maker (DM) based on his/her preferences, in a situation in which no optimal solution exists.

According to Talukder and Hipel (2018), MCDM/A methods can be successfully applied in assessing the sustainability of complex agricultural systems, because of their integration ability, transparency, robust analysis, and stakeholder opinion consideration.

According to Talukder and Hipel (2018), there are around 120 methods that have been developed to assess the agricultural sustainability of different types of agricultural systems; meanwhile, the use of MCDM/A methods in this sphere is still underexplored, especially in the context of family farming (Cicciù et al., 2022).

Very few studies have been undertaken using MCDM/A methods as a tool for sustainability assessment in the context of family farming, Dos Reis et al. (2014) have employed a basic multi-criteria method that uses a simple deterministic additive model as an aggregation process, aiming at selecting a suitable tractor for smallholder farmers. Data Envelopment Analysis (DEA) was applied, instead, in the studies of Mutyasira et al. (2018) and Godoy-Durán et al. (2017): the first one aims to create an index that permits the assessment of the relative sustainability of smallholder farms in a given region, while the second one analyzes eco-efficiency at the micro-level, focusing on small-scale family farms as the principal decision-making unit of horticulture in southeast Spain. Alary et al. (2020) proposed an assessment of the sustainability of family farming systems using a combination of two approaches, multiple-factor analysis, and multi-criteria assessment; in this case, an easy multi-criteria method using a simple deterministic additive model as an aggregation process was still employed.

All the methods above mentioned, use compensatory rationality, that is they permit compensation among attributes, as a loss in an indicator can be compensated with a gain in another. Considering the non-compensatory nature of our problem, a new model is needed, which can also catch the different perspectives of actors involved in the assessment process by means of a mixed top-down/bottom-up approach in the phase of problem structuring.

3. The proposed model

The proposed model is divided into four modules (Figure 1): (i) framework for the establishment of indicators; (ii) weighting of indicators, in which a modified Delphi method is employed; (iii) Borda method scoring; and (iv) sensitivity analysis and recommendation. In the following sub-topics, each step of the proposed model will be described.

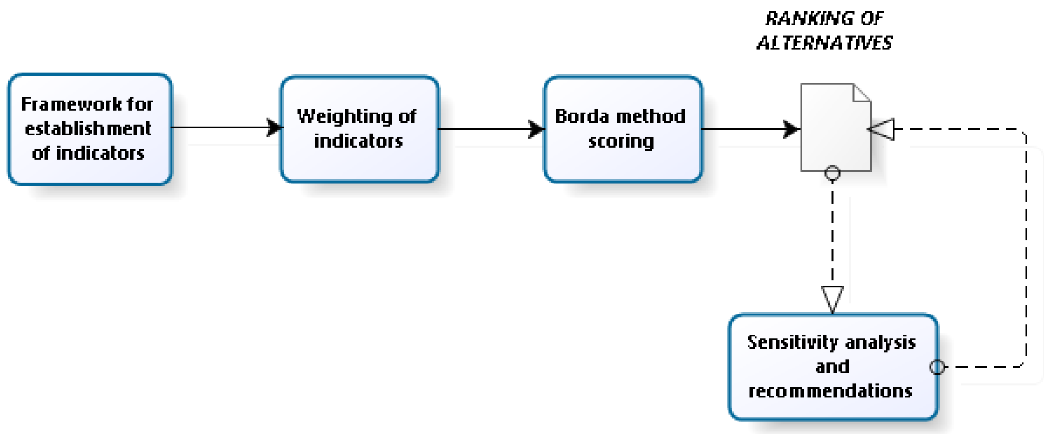

Figure 1: Proposed model

3.1. Framework for the establishment of indicators

The framework for the establishment of indicators is divided into four phases (Figure 2): (i) phase 1 - characterization of the system under study; (ii) phase 2 - setting of the system's critical points; (iii) phase 3 - proposition of a set of potential indicators; and (iv) phase 4 – modified Delphi session.

The goal of phase 1 is to identify boundaries, biophysical, socioeconomics, and technological components, as well as inputs, outputs, and social interactions. In phase 2, semi-structured interviews with farmers and experts are undertaken, and in the sequence a content analysis is carried out to identify the critical points that characterize the system under analysis. Once the critical points are identified, during phase 3, they are distributed into seven sustainability attributes according to the MESMIS guidelines; (López-Ridaura et al., 2005). Then, they are converted into indicators. Each critical point should match at least one indicator. The framework suggests selecting the indicators from the specialized literature, using the following criteria selection: scientific validity, measurability, data availability, relevance to the scope, and cost. Phase 3 provides a set of potential indicators. In phase 4, a modified Delphi method is carried out to determine the definitive set of indicators. Once the definitive list of indicators is obtained, they should be grouped into composite indicators.

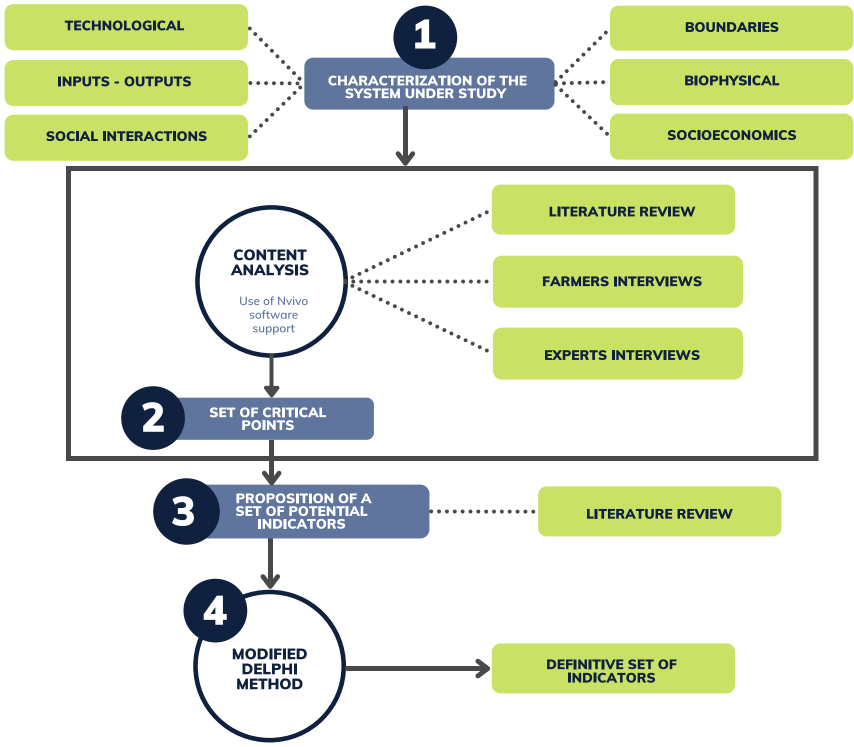

Figure 2: Framework to derive criteria

3.2. Weighting of indicators

Once indicators have been grouped into composite indicators (from this point on, composite indicators will be referred to as criteria to avoid mistakes with the term indicator), the weighting phase begins, whose aim is to allocate the weights to indicators and criteria.

In this case, using the outcomes of the modified Delphi method of the previous phase, mean scores of indicators are employed for calculating the weights of indicators. An indicator weight is calculated as the ratio of its mean score to the sum of the mean scores of all indicators in a given dimension. Let us denote by D the number of dimensions considered in the study and by n the number of criteria used to classify indicators, so that $j \in \{1, 2, \cdots, n\}$. Let be $d \in \{1, 2, \cdots, D\}$ a generic dimension, then p_d denotes the number of indicators assigned to the dimension d. Equivalently, $\forall\, j \in \{1, 2, \cdots, n\}$, p_j denotes the number of indicators assigned to the generic criterion *j*. We denote by I_{jk}^{d} $(k = 1, 2, \cdots\cdots, t)$ the value of indicator *k* for criterion *j* and dimension *d*. Then, the weight of the generic indicator *k* is obtained as follows:

$$w_k = \frac{M\left(I_{jk}^{d}\right)}{\sum_{k=1}^{p_d} M\left(I_{jk}^{d}\right)} \quad \forall\, j\ 1, 2, \cdots n \ \ and\ \forall\ d = 1, 2, \cdots, D$$

where $M\left(I_{jk}^{d}\right)$ is the mean score of indicator *k* belonging to the criterion *j* and dimension *d*.

The weight of a criterion is the ratio of the sum of the mean scores of all indicators in that criterion to the sum of the mean scores of all indicators in that sustainability dimension (Ahmad & Wong, 2019):

$$w_j = \frac{\sum_{k=1}^{p_j} M\left(I_{jk}^{d}\right)}{\sum_{k=1}^{p_d} M\left(I_{jk}^{d}\right)} \quad \forall\, j\ 1, 2, \cdots n \ \ and\ \forall\ d = 1, 2, \cdots, D$$

Finally, the criteria weights obtained must be normalized by dividing the weight of each criterion by the sum of all criteria weights.

$$\widehat{w_j} = \frac{w_j}{\sum_{j=1}^{n} w_j}$$

3.3. Borda Method

Firstly, the performance of each family framing unit A_i $(i = 1, 2, \cdots, m)$ in each criterion C_j $(j = 1, 2, \cdots, n)$ is evaluated, based on the Borda method scoring. For this, the decision-maker should order the alternatives from the best to the worst in each criterion. Secondly, for each criterion C_j, each alternative A_i will receive a ranking score that varies according to its linguistic evaluation in each criterion, that is $r_j(A_i)\ \forall\ i, j$. If *m* is the number of alternatives, the best performance in the criterion *j* gets *m* score; 2nd best performance in criterion C_j gets *(m-1)* score; thus, the worst alternative, which had the m^{th} best performance, gets *1* as a score (da Rocha et al., 2016).

It may occur a tie in the performance of some alternatives in the same criterion *j*, in this case, these alternatives receive the same ranking score, and the following procedure should be adopted. Suppose a problem with 5 alternatives (A_1, A_2, A_3, A_4, A_5), and the following situation happens. In criterion C_1, A_1 is the best evaluated, and A_2 is the second best; the other alternatives are tied. In this case, A_1 receives 5 points as a ranking score, A_2 receives 4 points, and the other alternatives receive the average score referring to the last three positions, that is, $\frac{(3+2+1)}{3}$.

Once the ranking score of each alternative in each criterion is determined, it is possible to build the decision matrix which assumes the following shape (Table 1):

	C_1	C_2	⋯	C_n
A_1	$r_1(A_1)$	$r_2(A_1)$	⋯	$r_n(A_1)$
A_2	$r_1(A_2)$	$r_2(A_2)$	⋯	$r_n(A_2)$
⋮	⋮	⋮	⋮	⋮
A_m	$r_1(A_m)$	$r_2(A_m)$	⋯	$r_n(A_m)$

Table 1: Decision matrix

Once the decision matrix is obtained the evaluation in each criterion should be aggregated to determine the sustainability of each unit. The aggregation should be carried out by means of a sum (compounded by criteria weights) of the scores of each alternative in each criterion, obtaining, thus, a global order number $b(A_i)$ for each alternative A_i as follow:

$$b(A_i) = \sum_{j=1}^{n} r_j(A_i) * w_j \qquad \forall\, i = 1,2,\cdots,m$$

The higher $b(A_i)$, the more sustainable the alternative A_i is in comparison to the remaining alternatives of the set A.

3.4. Sensitivity analysis and recommendation

The number of criteria is very high due to the complexity of the addressed problem and the importance of these criteria depends on the context in which family farms are embedded. This makes the process of assigning weighs to the criteria very difficult to the decision makers and consequently with a high level of imprecision. To deal with this, we recommend a sensitivity analysis over the weights to verify the effect of this in the values $b(A_i)$. We recommend a range of weight deviations is applied to the weights of the most important criteria, which are altered by a small increment throughout this range. All other criteria weights are proportionately adjusted to satisfy the condition $\sum_{j=1}^{n} \widehat{w_j} = 1$.

4. Application of the proposed model

4.1. Sampling

The proposed model was applied to 3 different smallholder family farming communities located in Paraiba state (Brazil), respectively in Lagoa Nova, Lagoa Seca, and Barra de Santa Rosa, in the period between December 27, 2022, and January 10, 2023. A sample of 10 smallholder family farmers has been employed, using snowball, purposive, and convenient non-probabilistic sampling technique (Teddlie & Yu, 2007).

The decision-maker considered is a regional senior manager of an important governmental institution who acts in support of family farming communities. He has been selected based on his broad knowledge of family farming issues, moreover, he represents an important stakeholder related to family farming in the analyzed region.

4.2. Framework for the establishment of indicators

The set of indicators used in the proposed model is presented in Table 2. Indicators are grouped into criteria, and, in turn, these ones are grouped into sustainability attributes, which have the same function of dimensions. These criteria have general validity for all types of family farms distributed in the Brazilian semiarid region.

ATTRIBUTES	CRITERIA	INDICATORS	DESCRIPTION
PRODUCTIVITY	Productivity	Productive capacity	Total production in the farm
		Productive process efficiency	Total output of crops, livestock, and other outputs divided by the input costs linked to the agricultural activities
	Financial	Profitability	Semi-net margin
		Economic efficiency	Rate of operational costs turned into profit
	Quality of products	Certified production	Certifications obtained
		Product labeling	Product labels obtained
STABILITY, RELIANCE, RELIABILITY	Water availability	Water storage capacity (agricultural use)	Capacity to store water (agricultural use)
		Water storage capacity (domestic use)	Capacity to store water (domestic use use)
		Water supply sources (surface water + groundwater)	Quantity of water supplied by sources
		Rainfall deviation	How much precipitation is received for a specified area
	Water use	Water consumption rate	Quantity of water consumed for ha
		Water use efficiency	Kg of crop produced with a m3 of water
		Family water footprint	The extent of water uses in relation to consumption
	Water quality	Water salinity in surface water	Quantity of salts dissolved in the surface water
		Water salinity in groundwater	Quantity of salt dissolved in groundwater
		Nitrates	Number of nitrates in the water
		Nitrites	Number of nitrites in the water
		Arsenic concentration	Parts of arsenic per million of water parts

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STABILITY, RELIANCE, RELIABILITY	Soil quality	Organic material	Amount of organic material present in the soil
		Carbon Nitrogen Ratio (C/N)	Ratio of the mass of carbon to the mass of nitrogen in the soil
		Salinity	Quantity of salts present in the soil
		Macronutrient N	N rate in the soil
		Macronutrient: P	P rate in the soil
		Macronutrients: K	K rate in the soil
		Soil erosion	Potential risk of soil erosion
		Slope	Slope degree
		Hydraulic conductivity	Ease with which water moves under the soil
		Soil pH	pH of the soil
	Agricultural Practices & Conservation	Tillage	Level of tillage practices in the farm
		Crop rotation	Number of crop rotations per year
		Cover crop	Points out if the cover crop is done or not
		Pesticide usage	Quantity of pesticide used per ha
		Fertilizer usage	Quantity of fertilizer used per ha
		Organic fertilizers	Quantity of organic fertilizer used per m2
	Diversity	Crop diversity	Nº of different crops in the land
		Livestock activity	Level of livestock activity in the farm
	Protection	Forest area	Number of hectares of forest area in relation to the total area available
		Organic area	% Of organic culture in the cultivated land
		Pests and diseases management	Level of diseases management in the farm
	Resources availability	Labor availability	Number of fulltime family labor
		Land use coefficient	Amount of cultivated area in relation to total area available
		Crop loss	Amount of crop lost in relation to total crop
		Labor migration	Nº of family members migrating from rural to urban area
		Young people working in agricultural activities	Amount of young people working in the family business
ADAPTABILITY	Added value to products	Added-value activities	Product transformation facilities in a farm
		Brand	Points out if some family products have their own brand trademark
		Diversification	Points out if there is some diversification activity
	Entrepreneurial propensity	Investment Level	Capital invested in agriculture by the family
		Marketing strategies	Propensity to develop a marketing strategy to create value-added
	Propensity for innovation	Training	Level of training and courses taken from farmers
		Machinery and equipment	Level of machines and equipment employed
		Research and experimentation	Level of research and experimentation did in the farm area
	Technical knowledge	Knowledge and technical skills	Level of business and technical knowledge possessed by the family
		Specific equipment needs	Point out if the need for specific equipment as PE exists

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EQUITY	Opportunities creation	Women's involvement in decision-making about agricultural activities	% Of women involved in decision making
		Education of farmers	Level of family education
		Leisure time	Time for sport, family, or culture
		Employment opportunities	Nº of employed persons (direct and indirect) per year
	Infrastructure	Road network	Quantity and quality of road network
		Access to transportation and mobility	Quantity and quality of transportation
		Settings where treatment is taken or public health	Access and quality of health services
		Access to education and extension	Level of access to governmental education and extension services
		Quality of housing	Quality of houses in which the farmers live
		Basic sanitation	Points out if the sewage is treated correctly or put out outside
		Wastewater treatment	Points out if the wastewater is treated correctly or put outside
		Communication (telephone/internet)	Level of access to the internet and telephone
		Access to electronic media	Level of access to electronic media
SELF-RELIANCE	Associativism & Cooperation	Participation in consortia, associations, or syndicates	Level of family participation in associations
		Activities managed jointly with other farmers	Nº of activities managed jointly
		Resources shared with other farmers (like seed banks)	Nº of resources shared
	Institutional support	Advisory contacts per year	Number of times an agricultural technician was contacted in a year
		Government support	Level of governmental support
		Subsidies, government program payments	Subsidies in R$ received from various entities
		Rural crime rate	Level of public safety perceived
		Number of selling channels	Nº of channels to sell products
	Management ability	Waste reuse	Level of waste management in the farm
		Farm management	Level of management practices used in the farm
	Inputs dependence	Economic Independence	Independence from direct subsidies
		Indebtedness	% Of NM obtained with debts
		Availability of seeds	Level of availability of the seeds

Table 2: Indicators and criteria used in the proposed model

With regard to the seven attributes, Productivity is related to the capacity of the family farm to produce products or services; Stability, Reliance, and Reliability are related to the capacity of the farm to recover after any stress; Adaptability is related to the capacity of adaptation of the family farm to a new balance position; Equity reflects the capacity of the farm to create equal opportunities in the society; and finally Self-reliance is related to the dependence from external outputs and capacity to manage themselves (López-Ridaura et al., 2002).

4.3. Weighting of indicators

The collection of value judgments with regard to the level of importance of indicators was performed with a group of eight experts who agreed to participate. To this aim, a five-point Likert scale has been employed, that is: (0) not important; (1) somewhat important; (2) relative important; (3) very important; and (4) extremely important. Successively, mean scores of indicators have been employed to obtain the weights according to sub-topic 3.2. Results are presented in Table 3.

	CRITERIA	WEIGHTS
C1	Productivity	0,0667
C2	Financial	0,0699
C3	Quality of products	0,0634
C4	Water availability	0,0222
C5	Water use	0,0163
C6	Water quality	0,0258
C7	Soil quality	0,0511
C8	Agricultural Practices & Conservation	0,0312
C9	Diversity	0,0102
C10	Protection	0,0158
C11	Resources availability	0,0273
C12	Added value to products	0,0554
C13	Entrepreneurial propensity	0,0379
C14	Propensity for innovation	0,0625
C15	Technical knowledge	0,0442
C16	Opportunities creation	0,0606
C17	Infrastructure	0,1394
C18	Associativism & Cooperation	0,0444
C19	Institutional support	0,0788
C20	Management ability	0,0324
C21	Inputs dependence	0,0444

Table 3: Criteria weights

Once the criteria weights were obtained, the performance of the family farming units in each criterion should be evaluated based on the De Borda method scoring.

4.4. Borda Method

Initially, the alternatives are evaluated for each criterion, according to a complete pre-order preference that is provided by the decision maker. In our case the decision maker has opted for the following evaluation (Table 4).

CRITERIA	COMPLETE PRE-ORDER
C1	(*F3, F10*) **P** *F7* **P** *F8* **P** (*F1, F9*) **P** *F6* **P** *F2* **P** *F5* **P** *F4*
C2	(*F3, F10*) **P** *F7* **P** *F1* **P** *F6* **P** *F2* **P** (*F5, F9*) **P** *F8* **P** *F4*
C3	*F10* **P** *F3* **P** *F8* **P** *F1* **P** *F2* **P** (*F4, F5, F6, F7, F9*)
C4	(*F3, F10)* **P** *F7* **P** (*F1, F6*) **P** *F2* **P** *F5* **P** *F4* **P** (*F8, F9*)
C5	(*F8, F10*) **P** *F4* **P** *F1* **P** (*F2, F3*) **P** *F5* **P** *F6* **P** *F9* **P** *F7*
C6	(*F3, F10*) **P** *F1* **P** *F2* **P** *F7* **P** *F5* **P** *F6* **P** *F4* **P** (*F8, F9*)
C7	*F3* **P** (*F1, F10*) **P** (*F6, F7*) **P** *F5* **P** (*F2, F4*) **P** (*F8, F9*)
C8	(*F8, F10*) **P** *F6* **P** (*F1, F5*) **P** (*F2, F4*) **P** *F3* **P** (*F7, F9*)
C9	(*F8, F10*) **P** *F2* **P** *F3* **P** *F1* **P** (*F4, F5*) **P** *F6* **P** (*F7, F9*)
C10	*F10* **P** *F8* **P** *F3* **P** *F6* **P** *F1* **P** *F5* **P** *F4* **P** *F7* **P** (*F2, F9*)
C11	(*F3, F10*) **P** *F8* **P** *F1* **P** *F4* **P** *F2* **P** (*F5, F6*) **P** (*F7, F9*)
C12	*F10* **P** *F3* **P** *F1* **P** *F2* **P** *F8* **P** (*F4, F5, F6, F7, F9*)
C13	*F10* **P** *F3* **P** *F8* **P** *F2* **P** *F1* **P** *F5* **P** (*F4, F6, F7, F9*)
C14	*F10* **P** *F8* **P** *F3* **P** *F1* **P** *F2* **P** *F7* **P** *F5* **P** (*F4, F6, F9*)
C15	*F10* **P** *F8* **P** *F3* **P** *F1* **P** *F9* **P** *F2* **P** *F5* **P** (*F4, F6, F7*)
C16	*(F3, F10)* **P** *F1* **P** *F4* **P** *(F5, F6)* **P** *F2* **P** *F7* **P** (*F8, F9*)
C17	*F1* **P** (*F3, F10*) **P** (*F2, F7*) **P** *F6* **P** *F5* **P** (*F4, F8, F9*)
C18	*F10* **P** *F8* **P** *F1* **P** *F4* **P** *F5* **P** *F3* **P** *F2* **P** (*F6, F7, F9*)
C19	*F10* **P** *F3* **P** *F7* **P** *F5* **P** (*F2, F4, F9*) **P** *F1* **P** *F6* **P** *F8*
C20	*(F3, F10)* **P** *F1* **P** *F8* **P** *F2* **P** *(F4, F5, F6, F7, F9)*
C21	*(F3, F10)* **P** *F7* **P** *F2* **P** *(F5, F6)* **P** *(F1, F4)* **P** *F9* **P** *F8*

Table 4: Complete pre-order preference. F = Family farming unit; P = preferred to.

At this point, the De Borda scoring was applied, and the values were aggregated into a global parameter that was used to rank the alternatives. Considering the criteria weights (Table 3), the global order number for each alternative, as well as the final ranking is presented in Table 5.

RANKING	ALTERNATIVE	$b(A_i)$
1st	F10	8.894
2nd	F3	8.139
3rd	F1	6.268
4th	F2	4.642
5th	F7	4.555
6th	F8	4.378
7th	F5	4.218
8th	F6	3.964
9th	F4	3.564
10th	F9	2.423

Table 5: Final ranking of alternatives

According to the De Borda method, therefore, the alternative FARM 10 is ranked in 1st place with 8.894 points, the alternative FARM 3 comes in 2nd place with 8.139 points, and the alternative FARM 1 occupies the 3rd position with 6.268 points. The last place is occupied by FARM 9 which got 2.423 points only.

4.5. Sensitivity analysis and recommendations

In this paper, a ±10% weight range with a 1% increment was applied to the 3 most important criteria (Financial, Infrastructure, and Institutional Support) giving rise to 60 simulation runs. Results underline that, as for criterion C17 (Infrastructures), no changes occur in the alternatives' ranking.

Considering, instead, criterion C19 (Institutional Support), it can be stated that for variations of its weight above 7%, alternatives FARM 2 and FARM 7 occupy the same position in the final ranking (that is position 4), while no change occurs in the other alternatives' positions.

Finally, when it comes to criterion C2 (Financial), the outcomes highlight that the final ranking changes for any positive weight variations, causing that alternatives FARM 2 and FARM 7 to occupy the same position (that is position 4), while no change occurs concerning the other alternatives' positions.

In conclusion, in light of the results pointed out by the sensitivity analysis, it can be affirmed that, when criteria C2 and C19 are taken into consideration, FARM 2 and FARM 7 are slightly sensible to positive weights' variations, while the final ranking of alternatives maintains its stability with regard the criterion C17. By virtue of these findings, it can be stated that the final result offered by the De Borda method has satisfactory robustness and stability.

5. Discussion

In light of the findings, it can be stated that there is a great divergence between the farms located in the first three positions and the other farms. This result is due to the fact that farms from the third position onwards did not truly achieve sustainability, manifesting major problems in all aspects of sustainability attributes. More likely, it is possible that these results reflect the enormous difficulty of most smallholder family farmers to switch from a subsistence unsustainable agriculture to a more market-oriented and sustainable agriculture.

Findings pointed out by our model, reflect in-depth what was observed during the field observation of our research, in which we were able to verify that the majority of family farming units are affected by a wide range of problems that inhibit their potential sustainability performance. Among them, as far as we know, the lack of entrepreneurial propensity, propensity for innovation, management ability, and ability to add value to products – which are directly related to the educational level of farmers – are the main shortcomings that prevent family farming, in Brazilian semiarid region, from can move from an unsustainable livelihood to a more sustainable one.

As a consequence of this, most family farming units, in this Brazilian region, live in poor condition which trigs an unsustainable performance.

Within the analyzed sample, farms 3 and 10, are the only ones that – notwithstanding having several problems across all sustainability attributes – present a high propensity for innovation, a high entrepreneurial mindset, a high management ability, and a high ability to add value to the products. Farm 1, instead, which occupies the third position in the ranking, doesn't present high levels of ability to add value to products, but it has a great propensity for innovation as well as a moderate entrepreneurial mindset and management ability.

The proposed model adopts a mixed top-down/bottom-up approach with the intention to allow a holistic view of the complex problem faced, thus corroborating the findings of Dijk et al. (2017), according to which to catch all the possible facets of a pluralistic context, such as the sustainability assessment, the involvement of stakeholders is necessary. In addition, the integration of the two above-mentioned approaches has been used, also, aiming at reducing the inevitable tension between expert knowledge and stakeholders' preferences in a collaborative way, thus making the sustainability assessment model more likely to be used, corroborating the findings of Craheix et al. (2015). In our knowledge, in fact, if policymakers and managers want to facilitate change in farming practices then it is essential that they understand what is important to those who have to make the change, in line with the findings of Dooley et al. (2009).

The outcomes underline that the use of the modified Delphi procedure allows a balanced criteria weight distribution. This occurs by virtue of a stakeholder's engagement process, which, according to Henke et al. (2020), provides a shared point of view through interactions between experts that represent also stakeholders interested or involved in the project. Moreover, this approach has proved to be extremely useful, since the evaluation of the agricultural production units in relation to the indicators is made by an individual (or group of individuals) who has knowledge of the reality of the region, but who is not a specialist in the areas related to the aspects evaluated in the model. In light of these issues, the use of the modified Delphi method gave more reliability to the criteria weight distribution.

6. Conclusions

This works proposes an integrated multi-criteria model for evaluating family farming sustainability. The model comprises four modules. The first one aims to apply a framework for establishing composite indicators that will be used in the model. In the second module, a modified Delphi procedure is applied to determine the weights of composite indicators. The third module aims at assessing the sustainability performance of different family farming units, using the Borda method scoring. Finally, a sensitivity analysis is carried out to verify the robustness and stability of outcomes.

The proposed model is very useful in cases like this, that are characterized by a broad range of indicators because of the complex nature of the problem addressed. Normally, in these cases, indicators should be measured taking into account their natural scale, involving specialist from several areas, thus spending lot of time and money and being not practical.

The advantage of our model lies in avoiding the performance assessment of alternatives in each criterion through a quantitative evaluation of indicators, by means of an evaluation based on ordinal information which allows the decision-maker to order the alternatives from the best to the worst in each criterion.

By virtue of this, the cognitive effort made by the decision-maker becomes easier and the employment of experts is not necessary.

Another important advantage of the proposed method lies in its non-compensatory feature, which doesn't permit a bad performance in a criterion to be compensated by a better performance in another one. This makes our model more effective, and their results more reliable, considering the non-compensatory nature of the problem addressed.

The model was applied to 10 family farming units spread over three different rural zones of Paraiba state, which is embedded in the Brazilian semiarid region, and, therefore, faithfully reproduces its critical features.

Results show that the proposed method can be used as an effective tool for assessing family farming sustainability on a large spatial scale (from community to region) allowing a robust and stable ranking of the alternatives and, also, identifying the way by which it is possible to achieve better performance.

The study provides managerial, social, as well as theoretical contributions. From a managerial point of view, the proposed method can be used by a broad range of users, from farmers to governmental institutions. For farm managers, it can be used as a guidance to evaluate the sustainability performance of the family farm and points out how to increase this performance. As for governmental institutions, the proposed method could be useful to identify suitable public policies aiming at improving the sustainable performance of family farming in different regions, considering the particularities of each. From a social point of view, it can improve the livelihood of smallholder farmers in a given region helping them at achieving better living conditions for themselves and the society as a whole. Finally, the study provides a theoretical advance in the area of multi-criteria decision-making aid method, by proposing an integrated model with the De Borda method as a non-compensatory aggregation operator, which, to our knowledge is a novelty in assessing family farming sustainability.

As for limitations of the study, it can be stated that the first limitation lies in its application in a region only, while the second, and most important limitations, is the lack of impartiality of the decision analyst employed.

As for recommendations for future research, therefore, it is recommended to apply the model on a larger spatial scale, as well as to employ a more impartial decision analyst.

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Final remarks

This thesis proposes a multi-criteria model aiming at assessing the sustainability of family farming. For this, three papers were developed. The first paper performs a literature review on the use of MCDM/A methods for assessing agricultural sustainability, considering the last two decades (1999 – 2021) as a timespan. Hence, it was possible to verify an increase in the number of publications, particularly since 2016. Most of these papers were developed in China and in France and published in the journal Agricultural Systems.

According to the sample taken into consideration, the results highlight also that doesn't exist a wide range of methods for assessing agricultural sustainability, and, moreover, most of them use a compensatory approach. Indeed, the content analysis points out that the most used multi-criteria method is the AHP which was used 11 times, followed by the decision-rules methods. The outranking methods, instead, were used only 3 times. In 68% of the papers the classical Triple Bottom Line was used as dimensions, and in 41% of the papers the spatial applicability was the farming system.

By virtue of these findings, it is possible to remark that the use of multi-criteria methods in assessing agricultural sustainability is still underexplored and can be improved.

In the second paper a framework to derive family farming indicators having regional validity has been proposed for assessing sustainability of family farming. The framework uses a bottom-up mixed with a top-down approach, in which both experts and stakeholders are involved. Data were gathered through documents consulting, workshops, semi-structured interviews with experts and stakeholders, and field observations. Successively they were analyzed using content analysis. Finally, a modified Delphi method has been employed to validate indicators derived. The framework has been used for deriving family farming sustainability indicators in the Brazilian Semiarid Region and, successively, as input for a multi-criteria model that will be developed and implemented in the third paper.

In the third paper, a non-compensatory MCDM/A model was developed and implemented for assessing and managing the sustainability performance related to smallholder farming systems in the Brazilian Semiarid Region. The model has been applied to 10 family farming production units spread in three different zones of Paraiba state. Results show that the proposed model can be used as an effective tool for assessing family farming sustainability on a large spatial scale (from community to region) allowing a robust and stable ranking of the alternatives and, also, identifying the way by which it is possible to achieve better sustainable performance.

This thesis brings academic, managerial, and social contributions. In the academic context, the study contributes to an advance in knowledge concerning the use of MCDM/A method for the sustainability assessment of family farming, as it proposes an integrated model with the De Borda method as non-compensatory aggregation operator, which, to our knowledge, is a novelty.

From a managerial point of view, the study can offer a tool to support decision making process for a broad range of users, from family farm managers to policymakers, whose objective is to improve the sustainability performance of family farming.

From a social perspective it contributes to improve the livelihood of family farmers, as well as the living conditions of the community as a whole.

The study presents some limitations. The main limitation is the farmers' sample size used in the framework to derive indicators. Another important limitation lies in the proposed model, which presents a limited spatial application, as well as a lack of impartiality of the employed analyst.

As recommendation for future research, we suggest using a more comprehensive farmers' sample size in the proposed framework, by the employment of a proportional stratification sampling technique. We suggest also to employ the model in another social and geopolitical context, as well as using a more impartial decision analyst.

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Appendices

Appendix I: Outputs obtained in phases 2 and 3 of the model

ATTRIBUTES	CRITICAL POINTS	INDICATOR	COMPOSITE INDICATOR	DESCRIPTION	FORMULA	UNIT	DATA TYPE	SUSTAINABILITY PILLAR	DATA SOURCE	REFERENCES
PRODUCTIVITY	Low Productive Capacity	Productive capacity	Productivity	Total production in the farm		ton/ha	QT	ECONOMIC	QS	(Parra-López et al., 2008)
	Low productive process efficiency	Productive process efficiency		Total output of crops, livestock, and other outputs divided by the input costs linked to the agricultural activities	Total output revenues/ total cost of inputs	%	QT	ECONOMIC	QS	(Tzouramani et al., 2020)
	Low Profitability	Profitability	Financial	Semi-net margin	SNM=GP - OC	R$/ha	QT	ECONOMIC	QS	(Sadok et al., 2009a)
		Economic efficiency		Rate of operational costs turned into profit	(SNM/OC) *100	%	QT	ECONOMIC	QS	(D. Craheix et al., 2016a)
	High quality of products	Certified production	Quality of products	Certifications obtained		binary yes/no response	QL	ECONOMIC	QS	(Veisi et al., 2016)
		Product labeling		Product labels obtained		binary yes/no response	QL	ECONOMIC	QS	(Veisi et al., 2016)

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STABILITY, RELIANCE, RELIABILITY	Low Water availability	Water storage capacity (agricultural use)	Water availability	Capacity to store water (agricultural use)			QT	ENVIRONMENTAL	QS	(Tran et al., 2018)
		Water storage capacity (domestic use)		Capacity to store water (domestic use use)			QT	ENVIRONMENTAL	QS	(Tran et al., 2018)
		Water supply sources (surface water + groundwater)		Quantity of water supplied by sources			QL	ENVIRONMENTAL	QS	(Sajadian et al., 2017)
	Rainfall inefficiency	Rainfall deviation		How much precipitation is received for a specified area			QT	ENVIRONMENTAL	SD	(Srinivasa Rao et al., 2019)
	Low efficiency in water use	Water consumption rate	Water use	Quantity of water consumed for ha			QT	ENVIRONMENTAL	QS	(Sajadian et al., 2017)
		Water use efficiency		Kg of crop produced with a m3 of water	WUE= Crop yield /water used to produce the yield		QT	ENVIRONMENTAL	QS	(Howell, 2001)
		Family water footprint		The extent of water uses in relation to consumption			QT	ENVIRONMENTAL	QS	(Galli et al., 2012)
	Low Water quality	Water salinity in surface water	Water quality	Quantity of salts dissolved in the surface water			QT	ENVIRONMENTAL	LA	(Talukder, Blay-Palmer, et al., 2017)
		Water salinity in groundwater		Quantity of salt dissolved in groundwater			QT	ENVIRONMENTAL	LA	(Talukder, Blay-Palmer, et al., 2017)
		Nitrates		Number of nitrates in the water			QT	ENVIRONMENTAL	LA	(Almeida et al., 2007)
		Nitrites		Number of nitrites in the water			QT	ENVIRONMENTAL	LA	(Almeida et al., 2007)
		Arsenic concentration		Parts of arsenic per million of water parts			QT	ENVIRONMENTAL	LA	(Talukder, Blay-Palmer, et al., 2017)

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STABILITY, RELIANCE, RELIABILITY	High Soil quality	Organic material	Soil quality	Amount of organic material present in the soil		mg/dm3	QT	ENVIRONMENTAL	LA	(Talukder, Blay-Palmer, et al., 2017)
		Carbon Nitrogen Ratio (C/N)		Ratio of the mass of carbon to the mass of nitrogen in the soil		Number	QT	ENVIRONMENTAL	LA	(Migliorini et al., 2018)
		Salinity		Quantity of salts present in the soil		dS/m	QT	ENVIRONMENTAL	LA	(Talukder, Blay-Palmer, et al., 2017)
		Macronutrient N		N rate in the soil		Cmolc/dm3	QT	ENVIRONMENTAL	LA	(Talukder, Blay-Palmer, et al., 2017)
		Macronutrient: P		P rate in the soil		Cmolc/dm3	QT	ENVIRONMENTAL	LA	(Talukder, Blay-Palmer, et al., 2017)
		Macronutrients: K		K rate in the soil		Cmolc/dm3	QT	ENVIRONMENTAL	LA	(Talukder, Blay-Palmer, et al., 2017)
		Soil erosion		Potential risk of soil erosion		Mg /ha*yr	QT	ENVIRONMENTAL	LA	(Wang et al., 2006)
		Slope		Slope degree		Verbal scale 1=very low; 5=very high	QT	ENVIRONMENTAL	QS	(Iocola et al., 2021)
		Hydraulic conductivity		Ease with which water moves under the soil		cm/h	QT	ENVIRONMENTAL	LA	(Wang et al., 1985)
		Soil pH		pH of the soil		Number ranging from 0 to 14	QT	ENVIRONMENTAL	LA	(Talukder, Blay-Palmer, et al., 2017)

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STABILITY, RELIANCE, RELIABILITY	Low tillage	Tillage	Agricultural Practices & Conservation	Level of tillage practices in the farm		Verbal scale 1=very low; 5=very high	QL	ENVIRONMENTAL	QS	(Sajadian et al., 2017)
	High crop rotation	Crop rotation		Number of crop rotations per year		Number	QT	ENVIRONMENTAL	QS	(Talukder, Blay-Palmer, et al., 2017)
	High cover crop	Cover crop		Points out if cover crop is done or not		binary yes/no response	QL	ENVIRONMENTAL	QS	(Rodríguez Sousa et al., 2020)
	Low use of pesticides	Pesticide usage		Quantity of pesticide used per ha		Kg/ha	QT	ENVIRONMENTAL	QS	(Tzouramani et al., 2020)
	Low use of fertilizer	Fertilizer usage		Quantity of fertilizer used per ha		Kg/ha	QT	ENVIRONMENTAL	QS	(Srinivasa Rao et al., 2019)
	High organic fertilization of the soil	Organic fertilizers		Quantity of organic fertilizer used per m2		kg/m2	QT	ENVIRONMENTAL	QS	(Troiano et al., 2019)
	High Crop diversification	Crop diversity	Diversity	Nº of different crops in the land		Number	QT	ENVIRONMENTAL	QS	(Sadok et al., 2009a)
	Integration crop-livestock	Livestock activity		Level of livestock activity in the farm		Verbal scale 1=very low; 5=very high	QL	ECONOMIC	QS	(Srinivasa Rao et al., 2019)

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STABILITY, RELIANCE, RELIABILITY	High forest preservation	Forest area	Protection	Number of hectares of forest area in relation to the total area available	(Number of hectares of preserved area/ total area available) *100	%	QT	ENVIRONMENTAL	QS	(Iocola et al., 2021)
	High rate of organic agriculture	Organic area		% of organic culture in the cultivated land	Number of hectares of organic agriculture / cultivated area in the farm	%	QT	ENVIRONMENTAL	QS	(Troiano et al., 2019)
	Lack of pests and diseases management	Pests and diseases management		Level of diseases management in the farm		Verbal scale 1=very bad; 5= very good	QL	ENVIRONMENTAL	QS	(Sajadian et al., 2017)
	Low labor availability	Labor availability	Resources availability	Number of fulltime family labor		Number	QT	SOCIAL	QS	(Mazvimavi and Twomlow, 2009)
	Low Land availability	Land use coefficient		Amount of cultivated area in relation to total area available	[cultivated area/ (total area- preserved area)]*100	%	QT	ENVIRONMENTAL	QS	(Srinivasa Rao et al., 2019)
	High crop loss	Crop loss		Amount of crop lost in relation to total crop	(Harvested area/ planted area) *100	%	QT	ENVIRONMENTAL	QS	(Walker, 1983)
	Migration toward the urban zone	Labor migration		Nº of family members migrating from rural to urban area		Number	QT	SOCIAL	QS	(Spangenberg, 2002)
	Exodus of younger	Young people working in agricultural activities		Amount of young people working in the family business	Farmers <35 years/ farmers> 55years	Ratio	QL	SOCIAL	QS	(Gerdessen and Pascucci, 2013)

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ADAPTABILITY	Lack of entrepreneurial mindset	Added-value activities	Added value to products	Product transformation facilities in a farm		binary yes/no response	QL	ECONOMIC	QS	(Lecegui et al., 2022)
		Brand		Points out if some family products have their own brand trademark		binary yes/no response	QL	ECONOMIC	QS	(Chen et al., 2022)
		Diversification		Points out if there are some diversification activity		binary yes/no response	QL	ECONOMIC	QS	(Lebacq et al., 2013)
		Investment level	Entrepreneurial propensity	Capital invested in agriculture by the family		R$/m2	QT	ECONOMIC	QS	(Gerdessen & Pascucci, 2013)
		Marketing strategies		Propensity to develop marketing strategy to create value added		Verbal scale 1=very low; 5= very high	QL	ECONOMIC	QS	(Pelzer et al., 2012)
	Low propensity for innovation and technology	Training	Propensity for innovation	Level of training and courses taken from farmers		Verbal scale 1=very bad; 5= very good	QL	SOCIAL	QS	(Iocola et al., 2021)
		Machinery and equipment		Level of machines and equipment employed		Verbal scale 1=very bad; 5= very good	QL	SOCIAL	QS	(Iocola et al., 2021)
		Research and experimentation		Level of research and experimentation done in the farm area		Verbal scale 1=very bad; 5= very good	QL	SOCIAL	FO	(Iocola et al., 2021)
	Lack of knowledge and appropriate management technologies	Knowledge and technical skills	Technical knowledge	Level of business and technical knowledge possessed by the family		Verbal scale 1=very low; 5= very high	QL	SOCIAL	QS	(Viguier et al., 2021)
	Low use of protective equipment	Specific equipment's need		Point out if the need for a specific equipment as PE exists		binary yes/no response	QL	SOCIAL	QS	(D. Craheix et al., 2016)

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EQUITY	Low participation of women in management	Women's involvement in decision-making about agricultural activities	Opportunities creation	% Of women involved in decision making	Nº of women involved in decision-making/ Nº of family members	Rate	QT	SOCIAL	QS	(Talukder & Hipel, 2018)
	Low Education	Education of farmers		Level of family education	ΣLi/N (Li = Education level of a single member; N= number of members)	Verbal scale 1= primary school; 5= post-Graduate	QL	SOCIAL	QS	(Talukder et al., 2018)
	Low leisure availability	Leisure time		Time for sport, family, or culture		Verbal scale 1=very bad; 5= very good	QL	SOCIAL	QS	(Ripoll-Bosch et al., 2012)
	Job generation	Employment opportunities		Nº of employed persons (direct and indirect) per year		Number	QT	SOCIAL	QS	(Tran et al., 2018)
	Low Roads availability and status	Road network	Infrastructure	Quantity and quality of road network		Verbal scale 1=very bad; 5= very good	QL	SOCIAL	FO	(Talukder, Hipel, et al., 2017)
	Lack of transportation infrastructures	Access to transportation and mobility		Quantity and quality of transportation		Verbal scale 1=very bad; 5= very good	QL	SOCIAL	QS	(Larrauri et al., 2016)
	Intermediate level of access to health services	Settings where treatment is taken or public health		Access and quality of health services		Verbal scale 1=very bad; 5= very good	QL	SOCIAL	QS	(Talukder, Hipel, et al., 2017)
	Level of access to educational services	Access to education and extension		Level of access to governmental education and extension services		Verbal scale 1=very bad; 5= very good	QL	SOCIAL	QS	(Veisi et al., 2016)
	Poor quality of homes	Quality of housing		Quality of houses in which the farmers live		Verbal scale 1=very bad; 5= very good	QL	SOCIAL	QS	(Havanon et al. 1992)
	Low level sanitation	Basic sanitation		Points out if the sewage is treated correctly or put out outside		binary yes/no response	QL	ENVIRONMENTAL	QS	(Wohlenberg et al., 2020)
		Wastewater treatment		Points out if the wastewater is treated correctly or put outside		binary yes/no response	QL	ENVIRONMENTAL	QS	(Wohlenberg et al., 2020)
	Low access to internet	Communication (telephone/internet)		Level of access to internet		Verbal scale 1=very bad; 5= very good	QL	SOCIAL	QS	(Miraílh & Albano, 2021)
	Low access to electronic media	Access to electronic media		Level of access to electronic media		Verbal scale 1=very bad; 5= very good	QL	SOCIAL	QS	(Talukder, Hipel, et al., 2017)

Continue to the next page

SELF-RELIANCE	Lack of associative propension	Participation in consortia, associations or syndicates	Associativism & Cooperation	Level of family participation in associations		Verbal scale 1=very bad; 5= very good	QL	SOCIAL	QS	(Iocola et al., 2021)
	Lack of cooperation	Activities managed jointly with other farmers		Nº of activities managed jointly		Number	QT	SOCIAL	QS	(Iocola et al., 2021)
		Resources shared with other farmers (like seed banks)		Nº of resources shared		Number	QT	SOCIAL	QS	(Iocola et al., 2021)
	Low acceptance of technical support	Advisory contact per year	Institutional support	Number of times an agricultural technician was contacted in a year		Number	QL	SOCIAL	QS	(Tzouramani et al., 2020)
	High Presence of Public policies	Government support		Level of governmental support		Verbal scale 1=very low; 5= very high	QL	ECONOMIC	QS	(Olguín et al., 2019)
	Access to credit	Subsidies, government program payments		Subsidies in R$ received from various entities		R$/m2	QT	ECONOMIC	QS	(Troiano et al., 2019)
	Lack of public safety	Rural crime rate		Level of public safety perceived		Verbal scale 1=very low; 5= very high	QL	SOCIAL	QS	(Rephann, 1999)
	Few Marketing channels	Number of selling channels		Nº of channels to sell products		Number	QT	ECONOMIC	QS	(Iocola et al., 2021)
	Low waste management	Waste reuse	Management ability	Level of waste management in the farm		Verbal scale 1=very low; 5= very high	QL	SOCIAL	QS	(Haffar & Searcy, 2018)
	Low management ability	Farm management		Level of management practices used in the farm		Verbal scale 1=very low; 5= very high	QL	SOCIAL	QS	(Talukder & Hipel, 2018)
	Low Economic Independence	Economic Independence	Inputs dependence	Independence from direct subsidies	EI=(1-DS/NM) *100	Rate	QT	ECONOMIC	QS	(Sadok et al., 2009a)
	High indebtedness rate	Indebtedness		% Of NM obtained with debts	(FC/ NM) *100	Rate	QT	ECONOMIC	QS	(Ripoll-Bosch et al., 2012)
	High availability of seeds	Availability of seeds		Level of availability of the seeds		Verbal scale 1=very low; 5=very high	QL	ECONOMIC	QS	(Talukder & Hipel, 2018)

Appendix II: Questionnaire

QUESTIONNAIRE

Questionnaire Nº : **Date :**

GPS information:

Part 1: General information

a. Code:
b. Age:
c. Village: City or County: State:
d. Sex: Female () Male ()
e. Marital status: Unmarried () Married () Widow(er) () Other ()
f. Educational level of the respondent:

Educational Level	Please tick
Illiterate	
Incomplete primary schools	
Complete primary schools	
Incomplete secondary schools	
Complete secondary schools	
Incomplete higher education	
Complete higher education	
Incomplete Postgraduate	
Complete Postgraduate	

g. Number of family members: 3
h. Structure of the family: Joint Family () Single family ( )
i. Age of children:

Children No. and sex	1		2		3		4		5		6		7		8		9		10		>10	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
Age (years)																						

Note: M= male; F= female; NB= Newborn

j. Educational status of children:

Children Nº and sex			EDUCATIONAL LEVEL								
Nº	M	F	Illiterate	Incomplete primary schools	Complete primary schools	Incomplete secondary schools	Complete secondary schools	Incomplete higher education	Complete higher education	Incomplete Postgraduate	Complete Postgraduate

Note: M= male; F= female

k. Occupation:

Family member	Occupation
Household head	
Wife	
1st child	
2nd child	
3rd child	
4th child	
5th child	
6th child	
7th child	
Others	

l. Sources of drinking, household use and irrigation water:

	Uses		
Name of the sources	Household	Drinking	Irrigation
Deep tube well			
Tube Well			
River			
Lake			
Barrier			
Rainwater			
Cistern			
Other			

m. Land area of homestead (in m^2):

n. Area of agriculture land (in ha):

o. Total family income (R$/year):

Part 2: Information about crop production (PRODUCTIVITY)

Total amount of crop production in 2021:

Type of agriculture (irrigated or rainfed)	Land area (ha)	Crop type name	Total amount	Market value
Additional information:				

2.2 Cost of seeds in 2021:

Name of the seeds	Total amount of seeds (Tons/year)	Total cost (R$/year)
Additional information		

2.3 Cost of fertilizer in 2021:

Name of the fertilizer		Total amount (kg)	Total cost (R$/year)
Commercial	Chemical		
Additional information:			

2.4 Cost of pesticides in 2021:

Name of the pesticide		Total amount (kg/liters)	Total cost (R$/year)
Commercial	Chemical		
Additional information:			

2.5 Cost of irrigation in 2021: m^3

Source of irrigation	Total amount (m^3/day)	Total cost (R$/year)
Additional information:		

2.6 Cost of labor in 2021:

Name of the crop	Total working days	Nº of employees	Total cost (R$/day)
Additional information:			

2.7 Cost of electricity or fuel used in 2021:

Coost of electricity (R$/month)	Cost of fuel (R$/month)	Total cost (R$/month)
Additional information:		

2.8 Cost of agriculture equipment in 2021:

Name of the equipment	Total cost (R$/month)
Additional information:	

Part 3: Information about livestock production (PRODUCTIVITY)

3.1 Total amount of poultry production in 2021:

Poultry	Total Number	Market value
Hen for meat		
Hen for egg		
Additional Information:		

3.2 Total amount of cattle production in 2021:

		Total amount		Market value	
Type of cattle	Total number	Milk (Liter/month)	Meat	Milk (R$/month)	Meat (R$/month)
Cow					
Goat					
Ram					
Buffalo					
Pig					
Sheep					
Additional information:					

3.3 Cost related to cattle cultivation in 2021:

Items		Total cost (R$/month)
Chemical use		
Commercial name	Product name	
Medicine		
Security		
Feed		
Labor		
Total (R$/month)		
Additional information:		

3.4 Cost related to poultry cultivation in 2021:

Items		Total cost (R$/month)
Chemical use		
Commercial name	Product name	
Medicine		
Security		
Feed		
Labor		
Total cost (R$/month)		

Part 4: Information about agricultural and conservation practices

4.1 Do you produce your own seeds? If yes, where do you produce them? If no, where do you buy your seeds from?

4.2 What cropping pattern do you use?

4.3 What type of machine do you use? How often?

4.4 What type of fertilizers do you use? Organic only? Conventional only? Both?

4.5 What type of irrigation do you use? Precision irrigation? Conventional irrigation? No one?

4.6 How do you preserve your seeds?

4.7 How do you preserve your products?

4.8 Do you have any agricultural loans? What purpose for?

4.9 What safety measures do you maintain or take in using fertilizers and pesticides? Do you use IEP?

4.10 Do you recycle waste?

4.11 Do you adopt some environmental conservation practices on the property? If yes which ones?

Part 5: Information about commercialization

5.1 Where do you sell your products? Is there a market for your products?

Nº	Name of the product	Sale place
1		
2		
3		
Additional information:		

5.2 Are there any institutions helping the commercialization of your products?

5.3 Do you use marketing for your products?

5.4 Did you get any quality label for your products?

5.5 How do you communicate to your costumers the quality of your products?

5.6 Do you have any micro credit? If yes, where did you get that credit from? What is the purpose of taking the credit?

5.7 Do you use any government program? If yes, which ones?

Part 6: Information about stability, reliability, resilience of the system

6.1 Do you usually face any pests in your agricultural activity? If yes, which ones and how often?

6.2 Do you have a control of diseases and pests?

6.3 What about water availability, water quality, energy availability, and soil quality?

6.4 Where does most household waste go?

6.5 Do you have any form of planning? If yes, which ones?

6.6 What do you do to lead with drought and lack of water?

6.7 Evaluate the water availability into your land.

6.8 Do you have a control form of production costs?

6.9 Do you perform a formal planning of production activities?

6.10 Evaluate the level of involvement of young people in working in the farm.

6.11 Do you make green manure?

6.12 Do you have any form of debt?

6.13 Do you have other jobs besides farm activities? If yes, which ones?

Part 7: Information about adaptability

7.1 Do you take some courses? If yes, which ones?

7.2 Do you take any training for your activity? If yes, which ones?

7.3 Do you receive technical assistance?

7.4 How do you consider the quality of suggestions of the technical assistance?

7.5 What do you think about the use of technology in family farming?

7.6 Do you use any technology in your activities? If yes, which one?

7.7 What do you do to adapt your business to market turbulence (volatility)?

Part 8: Information about equity of the system

8.1 What roles do women play in family farming activity?

8.2 How many hours do the women work inside and outside of the home?

8.3 Have the women their own salary?

8.4 Do children have access to school?

8.5 Has the system any access to shared resources?

8.6 Are there any forms of recreation? If yes, which ones?

8.7 Where do you go for health care?

8.8 How is the access to internet and electronic media?

8.9 How is the status of the access roads?

8.10 Are there any sanitation services? If yes, which ones?

Part 9: Information about self-reliance of the system

9.1 Are there any form of associations? If yes, which ones?

9.2 Do you take any kind of government support for agricultural activities? If yes, what types and from which agencies?

9.4 How do you rate your trust with the associations?

9.5 How do you rate the level of organization of Associations?

Part 10: Strengths and weaknesses of the system

10.1 How can your business be improved?

10.2 What type of help do you need for enhancing your agricultural performance?

10.3 Speak about some advantages your product or activity can offer to society

Appendix III: Publication proof of the 1st paper

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