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# Multicriteria, multi-phases, multi-decision makers aid for sustainable innovative strategies selection: Case of the olive supply chain

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# Abstract

Making decisions in the agriculture sector is a complex and challenging process, especially when aiming for sustainability. Decision-makers (DMs) face multiple contradictions, particularly when trying to reduce environmental and social impacts without decreasing economic profits. Therefore, the objective of this thesis is to support a group of DMs in choosing the most sustainable agricultural practices, extraction method and waste recovery management method so that the entire product life cycle becomes circular and sustainable. To achieve this goal, we propose a new multi-criteria framework to help DMs rank the different life cycle scenarios. The main contributions of this thesis are as following: first, to build sustainable scenarios under the circular economy (CE) thinking, the Structured Analysis and Design Technique (SADT) have been integrated to close and valorize the waste loops for each scenario. Then, the 2-Tuple model was used to deal with uncertainty in expert knowledge application. Afterward, a synthetic dynamic weight algorithm was used to aggregate the DMs opinions. Next, the VIKOR method was extended with the 2-Tuple model to rank the sustainability of each scenario. To illustrate the applicability of the proposed approach, a case study of olive oil life cycle in Sfax-Tunisia was conducted. Also, we perform a sensitivity analysis to reveal the effect of the subjective parameter variations on the initially obtained ranking. Finally, the obtained results prove that the proposed method is more accurate and effective for the agricultural sustainability problem. Furthermore, the integration of TRIZ methodology with Multicriteria Decision Analysis (MCDA) and life cycle sustainability assessment (LCSA) methods presents an innovative approach to enhance decision-making processes. The study showcases the successful application of this approach in improving the sustainability and environmental friendliness of the olive oil industry. By combining TRIZ with MCDA and LCSA methods, decision-makers can effectively address complex decision-making challenges. Overall, this research highlights the importance of sustainability, circular economy principles and informed decision-making in the olive oil supply chain. By considering environmental, economic and social factors, stakeholders can make informed decisions that promote long-term sustainability and resilience in agriculture. The research findings contribute valuable insights and methodologies that can be applied to other industries and sectors, fostering a more sustainable and environmentally conscious future.

**keywords**: Sustainability, Multi-criteria, Multi-phases, Multi-decision-makers, decision analysis, Agriculture, Similarity aggregation method, Circular economy, Contradiction identification, Contradiction solving.

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# Contents

# List of Figures

# List of Tables

# General Introduction

The global food system is challenging a sustainability crisis as it struggles to face the mounting demand for food while minimizing negative impacts on the environment, society and the economy. The Agricultural supply chain is no exception, facing several challenges related to sustainability, such as environmental degradation, economic instability and social inequality. The new concept of circular economy, which highlights the reduction, reuse and recycling of resources, has developed as a promising approach to address sustainability problems in the food system.

## Objectives and research questions

The agricultural life cycle analysis is a complex process that involves several phases, each with its own decision makers and production methods. The decisions made during each phase have significant impacts on the environment, economy and society, leading to conflicting and difficult choices for decision makers (DMs). As such, the primary objective of this thesis is to provide guidance to DMs on selecting the most sustainable agricultural practices, extraction methods and waste recovery management techniques to create a circular and sustainable product life cycle.

To achieve this goal, it is important to understand the different phases of the agricultural life cycle, including cultivation, harvesting, processing, packaging, transportation, distribution, consumption and disposal. Each of these phases has unique environmental, economic and social impacts and requires different production methods and decision makers.

One of the key challenges facing DMs is balancing the need for increased agricultural production with the need to protect the environment and support sustainable development. To address this challenge, it is important to prioritize sustainable agricultural practices, such as crop rotation, integrated pest management and conservation tillage, which can help to reduce environmental impacts and enhance ecosystem services.

Additionally, it is important to consider the extraction methods used during the harvesting phase, such as manual labor, mechanization, or animal power. Each method has different impacts on the environment, economy and society and must be carefully evaluated to determine the most sustainable option.

Finally, the waste recovery management phase is critical for creating a circular and sustainable product life cycle. DMs must consider options for reducing waste generation, reusing materials, recycling and composting to minimize environmental impacts and support sustainable development.

In conclusion, the analysis of the agricultural life cycle is a complex process that requires careful consideration of the environmental, economic and social impacts of each phase. By prioritizing sustainable agricultural practices, evaluating extraction methods, and implementing effective waste recovery management strategies, DMs can create a circular and sustainable product life cycle that benefits the environment, economy and society.

## Thesis contributions

The aim of this thesis is to help decision-makers by proposing new framework in order to choose the most sustainable agricultural practice, extraction method and waste management strategy so that all stages of the olive oil production process are circular and sustainable. By applying circular economy principles, different scenarios for the olive oil transformation chain's life cycle can be identified. Subsequently, by implementing Life Cycle Environmental Assessment, Life Cycle Cost Analysis and Social Life Cycle Assessment, it is possible to evaluate the sustainability of the life cycle relative to each scenario related to olive oil transformation chain processes. Then, it is possible to compare the different scenarios to assist stakeholders in making decisions about their strategic choices based on a multicriteria decision-making framework.

In terms of theoretical aspects, a literature review was conducted to identify the most relevant works that would best address the research problem and the research context. These works are mainly focused on a bibliometric literature review related to the primary basic concepts of the subject, namely:

- In the first place, the olive oil production process, the identification of different loops in the olive transformation chain and the identification of different scenarios for the return/valorization of unintended products (alternatives).
- Secondly, the identification of multicriteria methods and criteria related to the case study. In this part, a systematic literature review was conducted with 133 articles. This

type of analysis aims to verify if the scientific literature provides sufficiently strong evidence to answer a research question accurately.

- Positioning the research problem with the literature review to highlight the thesis's contributions.

Regarding the practical part, a conceptual model linking the practical framework of the olive chain and the general theoretical framework was constructed. After conducting semi-structured interviews with experts in the field, it was found that there are different important phases in the life cycle of all agricultural products (agricultural phase, production phase, waste management phase and transport). In fact, all these phases contribute to and characterize the entire life cycle of any product (olives, grapes, etc.). Each phase has its own decision-makers and each decision-maker has his or her own specific method among several methods to produce agricultural products. Each method has a specific impact on the environment, economy and society. Therefore, decision-makers are always faced with conflicting and difficult choices.

We are thus faced with several problems:

- **Multi-phase problem:** Because we have different phases in any life cycle of any agricultural product.
- **Multicriteria problem:** Different, contradictory and unexpected criteria must be studied.
- **Decision-makers' group problem:** Decision-makers come from different phases of the agricultural product life cycle.
- **Circular and sustainable problem**: The current trend is to protect the environment for future generations.

To achieve our objective, a new multicriteria framework has been proposed to assist decision-makers in comparing and ranking different alternatives.

Therefore, an innovative multicriteria approach based on the 2-Tuple model combined with the VIKOR method has been developed to overcome the limitations of traditional multicriteria methods and improve the efficiency of evaluating the sustainability of olive oil. The main contributions of the proposed new method are summarized as follows:

(1) Uncertainty in the evaluation process, particularly randomness and fuzziness, can be comprehensively considered by the 2-Tuple model, which reduces the influence of uncertainty on evaluation results.

(2) An improved synthetic dynamic weighting algorithm, which considers the level of confidence of domain experts' opinions, is proposed to better manage the multiplicity and uncertainty of expert knowledge information.

(3) An integrated weighting method is used to calculate the subjective and objective weights of criteria, by assigning more reasonable weights to these factors for a comprehensive evaluation.

(4) The VIKOR method is combined with the 2-Tuple model to calculate the sustainability of each scenario of the olive oil chain, which offers a compromise solution under multicriteria conditions.

Therefore, in order to demonstrate the practicality of the newly proposed approach, a case study on the life cycle of olive oil in Sfax-Tunisia was carried out. Furthermore, a sensitivity analysis was conducted to investigate the impact of variations in subjective parameters on the initial ranking obtained. The results obtained from this study provide strong evidence that the proposed method is both accurate and effective in addressing issues related to agricultural sustainability. By implementing this approach, decision-makers and stakeholders can make informed decisions that are grounded in objective data, leading to more sustainable outcomes in the agricultural sector.

Finally, by using the TRIZ method to resolve any contradictions that may exist in the best scenario proposed by VIKOR, our goal is to propose an innovative scenario. This new method not only considers the various uncertainties and complexities involved in the evaluation process, but also provides a more reasonable and comprehensive evaluation of the sustainability of agriculture supply life cycle.

## Thesis structure

The thesis is structured into five chapters, each builds on the previous one to provide a comprehensive analysis of sustainability issues in the context of the olive oil supply chain. The following diagram presents the overall structure of this thesis:

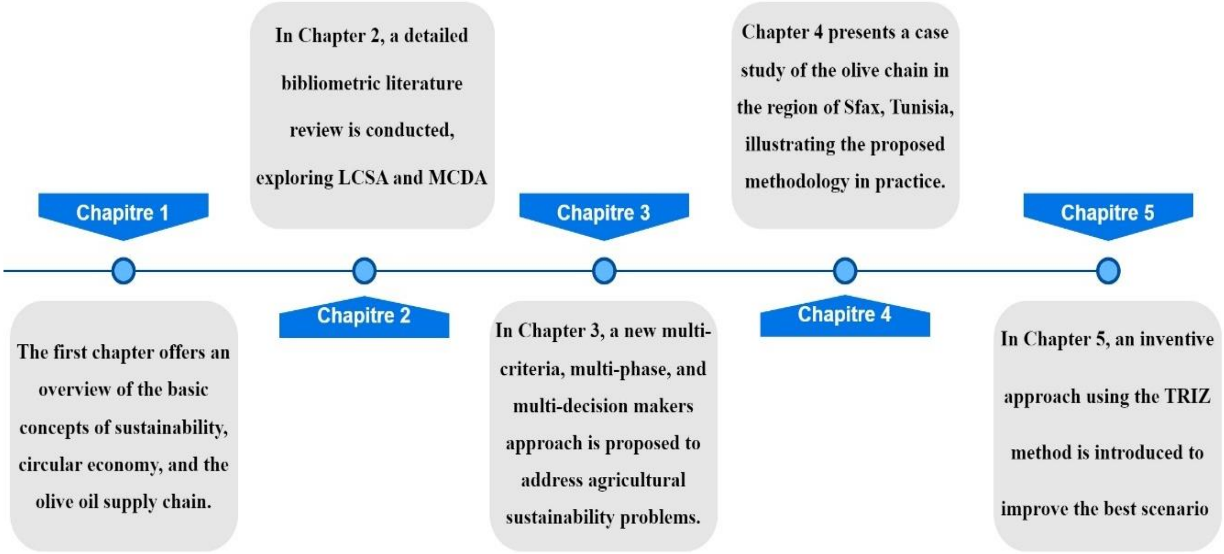


Figure I : Manuscript structure

The first chapter offers an overview of the basic concepts of sustainability, circular economy, and the olive oil supply chain and sets the stage for the subsequent chapters. In Chapter 2, a detailed bibliometric literature review is conducted, exploring life cycle sustainability assessment and multicriteria decision analysis methods. The review methodology and findings are presented, followed by interpretations of the results. In Chapter 3, a, new multi-criteria, multi-phase and multi-decision makers, approach is proposed to address agricultural sustainability problems. This chapter provides a preliminary discussion and proposed methodology. Chapter 4 presents a case study of the olive chain in the region of Sfax, Tunisia, illustrating the proposed methodology in practice. The case study includes an application of the methodology and a validation and discussion of the findings. Chapter 5 combine an innovative TRIZ-based approach method to enhance the best scenario identified through the multi-criteria decision method. This chapter provides an introduction to the TRIZ method and discusses its application to optimize the problem, ultimately proposing a more sustainable and inventive solution. The process involves combining the multi-criteria decision framework with TRIZ to improve the overall sustainability.

Overall, the thesis aims to provide a comprehensive analysis of sustainability issues in the olive oil supply chain, using a multi-criteria and multi-phase approach that incorporates circular economy principles.

# Chapter I: Sustainability, Circular Economy and Olive Oil Chain: Basic Concepts

## I.1. Introduction

This chapter introduces the basic concepts of sustainability and sets the stage for the observed research presented in the following chapters. We begin by defining the concept of sustainability then we discuss the idea of the Sustainable Supply Shain (SSC) and its key components. The next step, we introduce the concept of Circular Economy (CE) and its potential to address sustainability challenges in the agriculture industry. We discuss the principles of CE, including designing out waste and pollution, keeping products and materials in use and regenerating natural systems. We also explore the idea of a new SSC under the framework of the CE, which promotes a more efficient, resilient and environmentally-friendly supply chain. Next, we focus on the olive oil supply chain and its unique sustainability challenges. We discuss the different stages of the olive oil supply chain, from cultivation to consumption and review the main sustainability issues associated with each stage.

Overall, this chapter provides a broad overview of the basic concepts related to sustainability, CE and the olive oil supply chain and establishes the context and motivation for the research presented in the rest of the thesis.

## I.2. Sustainability aspects

Sustainability refers to the ability to maintain or improve the health and well-being of the planet and its inhabitants, both now and in the future. It involves balancing economic, social and environmental factors (See Figure 1) to ensure that resources are used in a responsible and ethical manner (Riesgo & Gallego-Ayala, 2015). Sustainability is often associated with the concept of sustainable development, which seeks to meet the needs of the present generation without compromising the ability of future generations to meet their own needs (Dolores Mainar-Toledo et al., 2023).

In practical terms, sustainability involves reducing waste and pollution, conserving natural resources, promoting renewable energy and sustainable agriculture and ensuring social and economic equity. It is a broad concept that encompasses many different areas of human activity, including business, government and individual behavior (Gómez-Limón et al., 2020).

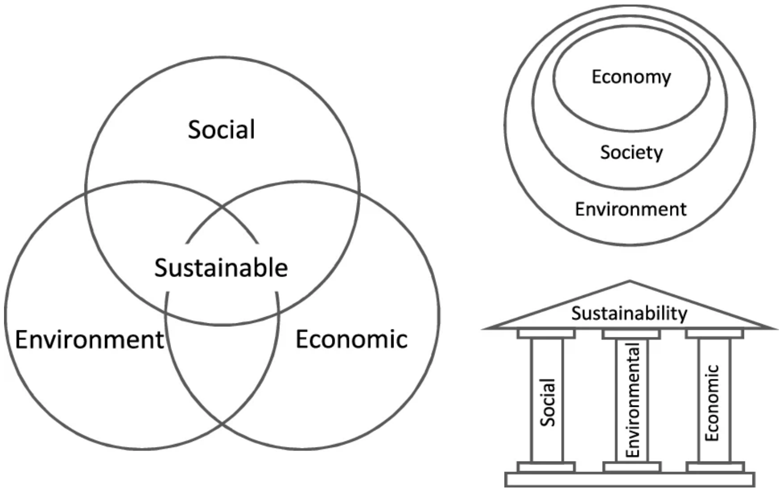


Figure 1: The three pillars of sustainability (Ben Purvis et al., 2019)

This concept has been defined and explored extensively in the scientific literature, across a range of disciplines including ecology, economics, sociology and engineering (Ben Purvis et al., 2019).

- From an ecological perspective, sustainability refers to the ability of natural systems to maintain themselves over time. This involves preserving biodiversity, ecosystem services and the resilience of ecosystems to withstand disturbances such as climate change and human activities.
- In economics, sustainability is often framed in terms of the triple bottom line, which considers the economic, social and environmental impacts of business practices. This approach recognizes that sustainable development requires balancing the needs of stakeholders, including shareholders, employees, customers and the environment.
- Sociologists have explored the social dimensions of sustainability, including issues related to social equity, community development and cultural diversity. They recognize that sustainable development must be inclusive and address the needs of marginalized and disadvantaged communities.
- In engineering, sustainability is often considered in the context of resource management and the development of sustainable technologies. This involves optimizing the use of resources, reducing waste and pollution and promoting the use of renewable energy sources.

Overall, sustainability is a complex and multifaceted concept that requires the integration of multiple perspectives and disciplines. It involves balancing economic, social and environmental considerations to promote a more equitable and sustainable future for all.

### I.2.1. **Environmental aspects**

Taking care of the environment means making sure that the natural world around us stays healthy and continues to provide us with the resources we need to survive. We need to use these resources wisely so that they don't run out and we need to reduce the harm we do to the planet so that it can continue to support us for generations to come (Gómez-Limón et al., 2020).

Some of the most important natural resources we depend on are water, air, animals and plants. But unfortunately, these resources are at risk of being depleted or polluted, which could threaten our survival (Ben Purvis et al., 2019). Climate change is also affecting the planet, causing more floods, heatwaves and other extreme weather events that can harm people and animals and even cause entire communities to be displaced. The loss of animal and plant species, known as biodiversity loss, is also a growing concern as it can lead to ecological imbalances and even more risks to human survival (Ren et al., 2019).

To help protect the environment, we need to using less water or electricity, driving less or using public transportation. It might also mean supporting policies that protect natural resources.

### I.2.2. **Economic aspects**

The idea of sustainable production and consumption involves creating a balance between economic growth, environmental protection, and social well-being. This approach is based on the belief that economic development should not come at the expense of the environment or people's quality of life. Instead, it aims to promote economic growth that is sustainable in the long-term and that benefits everyone in society, including future generations (Ren et al., 2019).

One way to achieve sustainable production and consumption is to use prices that reflect the true cost of a product or service. This means considering not only the direct costs of production, but also the environmental and social costs that are often hidden or ignored. For example, the cost of extracting raw materials can include damage to the environment, pollution of waterways and harm to the health of local communities. The cost of manufacturing a product can include emissions of greenhouse gases that contribute to climate change. The cost of using a product can include waste disposal, energy consumption and other environmental impacts. By including these costs in the price of a product or service, we can encourage more sustainable production and consumption practices (Ben Purvis et al., 2019).

Another way to promote sustainable production and consumption is to encourage innovative and ethical business practices. This can involve creating new products and services that are environmentally friendly, such as renewable energy technologies, biodegradable packaging and sustainable agriculture practices (De Luca et al., 2018a). It can also involve promoting fair trade and ethical business practices that benefit workers and communities, such as paying fair wages, providing safe working conditions and supporting local economies. Governments can also play a role by creating policies and regulations that encourage sustainable economic growth, such as incentives for renewable energy, taxes on pollution and support for public transportation. Overall, sustainable production and consumption is a key part of creating a more sustainable future for everyone.

### I.2.3. **Social aspects**

The social dimension of sustainable development focuses on meeting human needs and promoting social equity in terms of health, housing, education, consumption and other essential elements that contribute to social well-being (Zepharovich et al., 2021). Ensuring social well-being is critical, as it enables households to access basic needs, such as food, shelter and healthcare. However, it is important to note that environmental pollution is a significant cause of many public health issues, including respiratory problems, infectious diseases and cancer (Ren et al., 2019).

To address these issues, it is necessary to identify the different key social challenges, such as exclusion and discrimination, ensuring good working conditions and promoting solidarity by reducing inequalities. Some scholars even include a fourth dimension of sustainable development, the societal aspect (D'Adamo et al., 2019). This aspect focuses on the quality of social interactions between actors in society and includes social links of all kinds that allow for reciprocity, partnership, solidarity, social cohesion and trust (Foolmaun & Ramjeeawon, 2013).

The social dimension of sustainable development is concerned with the relationships between individuals and the wider society. At its core, social development is about improving human welfare by addressing social and economic inequalities, building human capital and promoting social inclusion. The concept of social sustainability is closely linked to social development and requires a multidimensional approach that considers the economic, social and environmental dimensions of sustainability.

Sustainable performance refers to the combination of economic, social and environmental performance, which should be evaluated in a holistic manner to ensure long-term success and a positive impact on society as a whole (D'Adamo et al., 2019). Therefore, the social dimension of sustainable development is crucial for achieving sustainable development goals and creating a more just and equitable society (Ferrão et al., 2014).

## I.3. Circular Economy (CE)

Over the last decade, the consequences of the continued depletion of natural resources on the environment, economy and society have highlighted the need for humanity, business and governments to change the management of their relationship with the environment. However, various companies were immersed in a traditional linear economic system which is based on consumption, production and disposal (Geng et al., 2010, Keskes, Zouari, Lehyani, et al., 2022). This approach presents a "linear model" which leads to the waste of resources in the environment and which is considered by consensus as obsolete. In fact, this phenomenon takes on considerable importance because it has negative effects on scarce natural resources. In terms of volume, 65 billion tons of raw materials were injected into the economy in 2010 and reached 82 billion tons in 2020 (Ncube et al., 2022). The emergence of the new CE model has attracted remarkable amount of attention around the world. In this regard, (Keskes, Zouari, Lehyani, et al., 2022) considered CE as an efficient solution to the problem of global population growth and increasing pollution in general. However, CE is one of the concepts derived from sustainable development which is based on the production of eco-designed, easily repairable, totally or partially reusable and recyclable products to reduce manufacturing impact on the environment (Zouari, 2019). For Prieto-Sandoval et al., 2018) the CE is "an economic system that represents a change of paradigm in the way that human society is interrelated with nature and aims to prevent the depletion of resources, close energy and materials loops and facilitate sustainable development". Consequently, CE proposes to close the loop through the recovery of raw materials. According to (Patwa et al., 2021), the importance of innovation for recovery and materials enrichment used manifests either by environment or by industrial processing instead of removing or wasting them. Yet, waste can be valorized by two ways: biological or technical resource that can then be reoriented and returned to the biosphere or the industrial process (Ellen Macarthur Foundation, 2013), Figure 2.

For the first time, the term "Circular Economy" was used in a formal context in an economic model presented by the environmental economists (Segerson et al., 1991). These researchers have explained the transition from the traditional linear economic system to the circular economic system as a result of thermodynamics law.

Additionally, described CE as a cycle of extraction, resource management, distribution, use and recovery of goods and materials. Indeed, (Alhawari et al., 2021) consider it as where resources become products and emphasize recycling. The CE is a practical approach to achieving sustainability by rethinking how we produce, consume and dispose of goods and services. This concept is based on the principles of resource efficiency, waste reduction and closed-loop systems (Keskes, Zouari, Lehyani, et al., 2022). By promoting circular business models such as rental, resale and repair, the CE can help to minimize the environmental impact of economic activity while also promoting economic growth and social development (Illankoon et al., 2023).

For (Ellen Macarthur Foundation, 2013), CE is "an industrial system that is restorative or regenerative by intention and design. It replaces the end-of-life concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse and return to the biosphere and aims for the elimination of waste through the superior design of materials, products, systems and business models". It is noticed that the most of definitions focalizes on raw materials use and the 3-R method (Zouari, 2019).

According to (Prieto-Sandoval et al., 2018) CE is "a system of production and exchanges that take into account, from their conception, the durability and recycling of the products or their components in order to make of them either reusable objects or new raw materials, which is aimed at improving the efficiency of the use of resources". This definition elucidates the principles of the production of eco-designed (minimum use of raw materials), easily repairable, fully or partially reusable (products and its components reuse for long time) and recyclable (most of product materials are recycled or recyclable). This means that products are designed in a method that makes it possible to reintroduce them in production cycles as soon as they become used items or waste (Zouari, 2019). The overall objective is to minimize the consumption and waste of raw materials, natural resources and non-renewable energies in the production of new items. These approaches are commonly referred to as the effective management of resources.

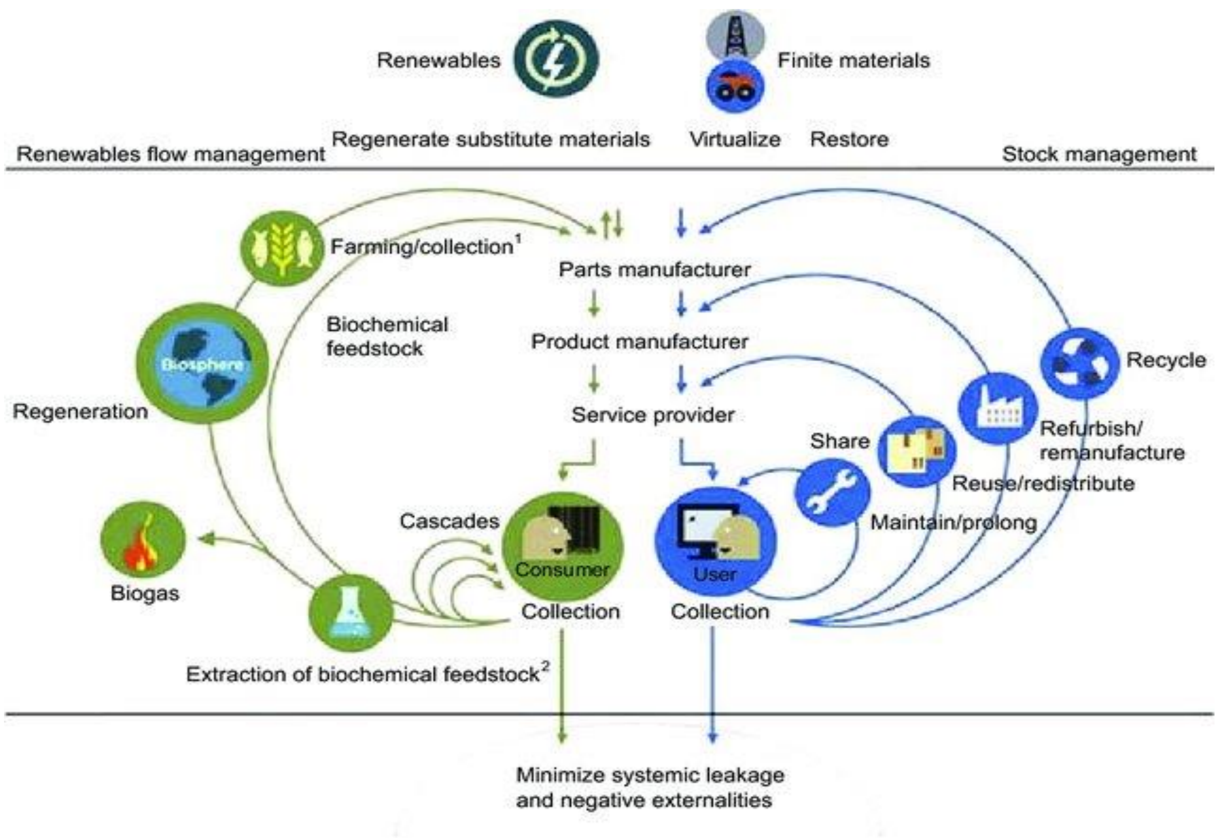


*Figure 2: CE foundation proposed by MacArthur (2015)*

## I.4. The Sustainable Supply Chain (SSC)

SSC refers to the management of environmental, social and economic impacts throughout the life cycle of goods and services, from raw material extraction to disposal(Jellali et al., 2021). The goal of a SSC is to minimize negative environmental and social impacts while maximizing economic benefits for all stakeholders involved. SSC practices include responsible sourcing, energy efficiency, waste reduction, water conservation, ethical labor practices and community engagement.

Responsible sourcing involves selecting suppliers that adhere to environmental and social standards, such as using eco-friendly materials, reducing greenhouse gas emissions and respecting human rights. This helps to reduce the environmental and social impacts associated with the extraction and production of raw materials (Pereira et al., 2019). Energy efficiency measures include reducing energy consumption in manufacturing processes and transportation, as well as using renewable energy sources like solar and wind power. This helps to reduce greenhouse gas emissions and mitigate climate change (Keskes, Zouari, Lehyani, et al., 2022).

Waste reduction involves minimizing waste generation throughout the supply chain, such as through product design that reduces packaging and using reusable or recyclable materials. This reduces the environmental impact of waste disposal and conserves resources (Oldfield et al., 2018). Water conservation involves reducing water use in manufacturing processes, as well as implementing water recycling and reuse systems. This helps to conserve scarce water resources and reduce the environmental impact of water use (García-Cascales et al., 2021).

Ethical labor practices involve ensuring that workers in the supply chain are treated fairly, with respect for their human rights, such as fair wages, safe working conditions and the right to organize. This helps to promote social sustainability and reduce the negative impacts of exploitative labor practices. Community engagement involves working with local communities to understand and address their needs and concerns and to create mutually beneficial relationships. This helps to promote social sustainability and build trust and partnerships between supply chain actors and local communities (Vidergar et al., 2021).

In conclusion, SSC is essential for promoting environmental, social and economic sustainability in today's globalized economy. By adopting sustainable practices, companies can reduce their environmental and social impacts, while also improving their economic performance and creating value for all stakeholders. However, achieving SSC requires collaboration and partnership among all actors in the supply chain, as well as a commitment to continuous improvement and transparency.

## I.5. SSC model based on the principles of CE

The CE concept involves rethinking the entire value chain, from raw materials and product design to end-of-life disposal. By adopting CE principles throughout the value chain, we can create a more sustainable and resilient economy in any supply chain (Vidergar et al., 2021) :

In the context of product design, circular principles require that products are designed with the end-of-life in mind. This means that products should be designed to be easily disassembled and recycled and to use less materials in their production (Egea & Pérez y Pérez, 2016). This approach can help to reduce waste, conserve natural resources and promote resource efficiency.

In the context of production, circular principles require that businesses adopt closed-loop systems, where waste is minimized and resources are used efficiently (Maesano et al., 2021). For example, businesses can implement strategies to reduce waste and improve efficiency in their production processes. They can also implement circular business models such as rental, resale and repair, which can extend the life of products and reduce waste by the industrial symbiosis.

In the context of consumption, circular principles require that individuals and businesses make choices that promote resource efficiency and waste reduction (Rajaeifar et al., 2016). This can involve practices such as reusing and repairing products, recycling, and composting. By adopting circular consumption practices, we can minimize waste and conserve natural resources.

In the framework of agriculture, circular principles require that we adopt practices that promote soil health, biodiversity and regenerative agriculture. This means that we must prioritize practices such as crop rotation, cover cropping and conservation tillage to promote healthy soils and reduce the use of synthetic fertilizers and pesticides. Additionally, circular agriculture practices promote the use of renewable energy sources and the adoption of closed-loop systems, such as nutrient cycling and waste reduction. This agriculture can also promote economic growth and social development by creating new opportunities for farmers and rural communities. By adopting circular practices such as regenerative agriculture and agroforestry, farmers can improve soil health, reduce costs and increase yields. Additionally, those practices can create new markets for organic and sustainably produced food, promoting economic growth and social development in rural communities (Keskes, Zouari, Houssin, et al., 2022).

In the context of disposal, circular principles require that waste is treated as a resource and kept in the economy for as long as possible. This means that waste should be sorted and recycled wherever possible and that landfill should be minimized. By keeping waste in the life cycle, we can minimize the environmental impact of waste disposal and promote resource efficiency (Valenti et al., 2020).

In conclusion, the new concept of circularity is a critical tool for achieving sustainability in practice. By adopting CE principles throughout the value chain, we can create a more sustainable and resilient economy that balances economic growth, environmental protection, and social development. This concept provides a framework for designing out waste and pollution, keeping products and materials in use, and regenerating natural systems. By transitioning towards a new thinking way, we can work towards a more sustainable future where resources are used efficiently, waste is minimized, and economic growth is decoupled from environmental degradation.

## I.6. Olive oil supply chain

The process of olive oil production encompasses a series of interrelated stages, all of which are geared towards establishing a sustainable and efficient life cycle. Figure 3 provides an overview of these distinct phases, and in the subsequent section, each phase will be thoroughly described. These include the Agriculture phase (I.6.1), the Extraction phase (I.6.2), the Packaging phase (I.6.3), and the Waste management phase (I.6.4).

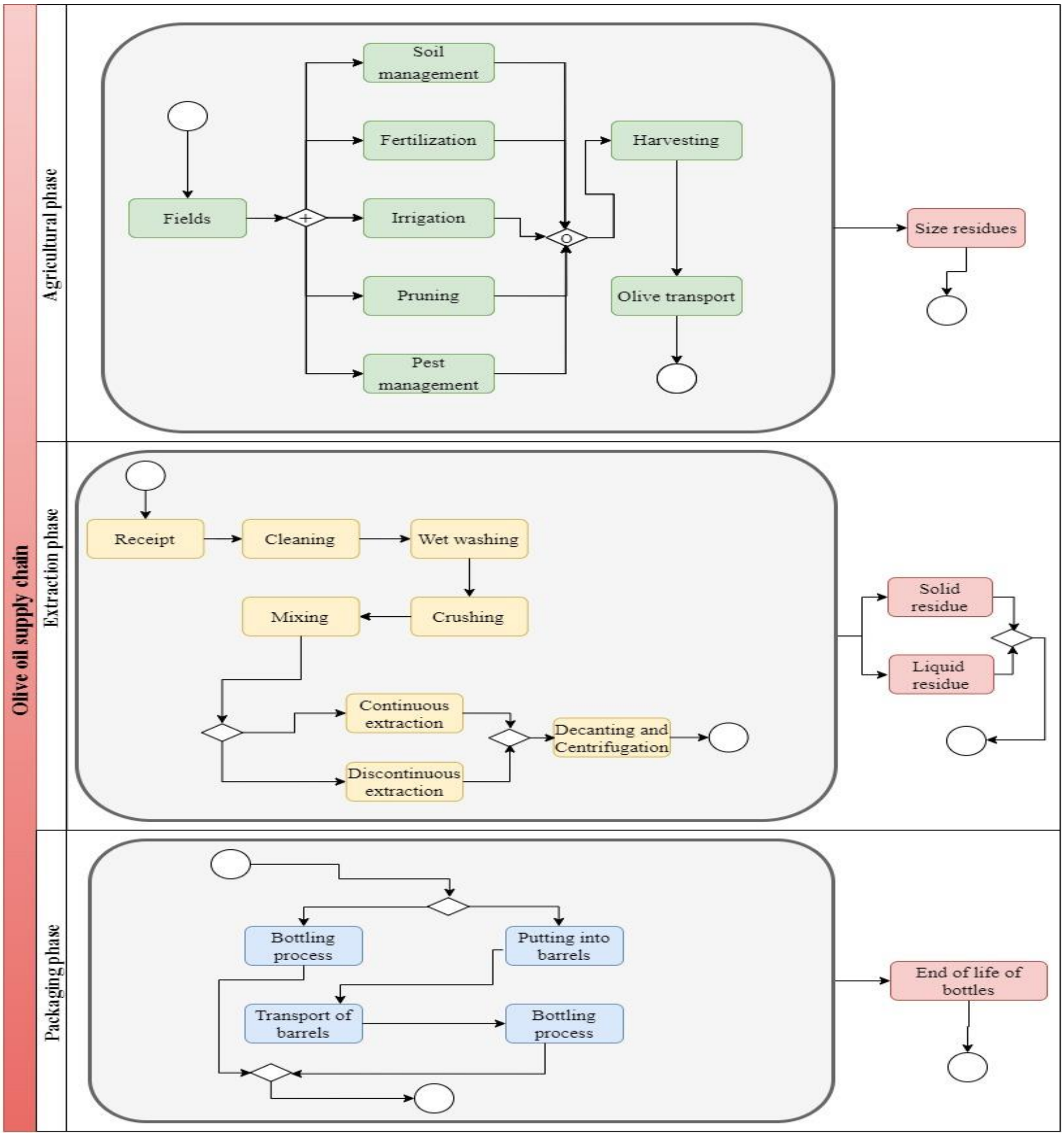


*Figure 3: Olive oil supply chain*

### *I.6.1.**Agriculture phase***

The agricultural phase of the olive oil life cycle is critical for ensuring the quality and quantity of the olives that will be used for oil production (Duman et al., 2020). This phase includes careful site selection based on factors such as soil type, topography, and climate, as well as planting, pruning, fertilization, and pest management activities. Pruning and training the olive trees is important to ensure optimal fruit production and quality, as well as to promote the longevity and health of the trees. Effective pest management strategies such as integrated pest management are important for reducing the use of pesticides and minimizing environmental impacts (Salomone & Ioppolo, 2012a). At the end of the agricultural phase, olives are harvested either by hand or mechanically. The agricultural phase comprises the primary practices that farmers employ (Salomone & Ioppolo, 2012a), including:

*Site selection and preparation*: This stage involves selecting an appropriate site for olive cultivation based on factors such as soil type, topography, and climate. The site is then prepared through activities such as clearing vegetation, plowing, and leveling.

*Planting:* Olive trees are typically propagated through cuttings or grafting and planted in the prepared site. The trees are spaced apart to allow for optimal growth and yield.

*Pruning and training:* Olive trees require regular pruning and training to maintain their shape, promote healthy growth, and optimize fruit production. This involves removing dead or diseased branches, shaping the canopy, and maintaining a balanced structure.

*Fertilization and irrigation:* Olive trees require proper fertilization and irrigation to ensure healthy growth and optimal fruit production. This involves applying appropriate fertilizers and providing regular irrigation based on soil moisture levels.

*Pest and disease management:* Olive trees are susceptible to a variety of pests and diseases that can impact fruit quality and yield. Integrated pest management strategies that rely on biological, cultural, and chemical control methods are used to manage these threats.

*Harvesting:* Olives are typically harvested by hand or through mechanical means. The timing of the harvest is critical to ensure optimal fruit quality and oil yield.

*Processing:* After harvesting, olives are typically washed and sorted before being pressed to extract the oil. The oil is then filtered and bottled for distribution and sale.

*Post-harvest management:* After processing, olive growers must manage the waste generated from the production process, such as olive pits and pomace. These waste products can be used for energy production, composting, or other purposes.

Overall, the life cycle of olive growing involves a series of interconnected stages that require careful management to ensure optimal growth, fruit production, and sustainability.

### *I.6.2.**Extraction phase***

During the extraction phase, the olives are transported to the processing facility where the oil is extracted. There are several different extraction methods available, ranging from traditional stone milling to modern continuous processing techniques. The choice of method can impact the quality and quantity of the oil produced, as well as the amount of waste generated. The waste products generated during extraction include olive pomace and wastewater. These waste products must be managed carefully to minimize environmental impacts and promote sustainability (Duman et al., 2020). There are several different methods used for the extraction of olive oil, including traditional and modern techniques (Duman et al., 2020). The most common methods summarized in figure 4.

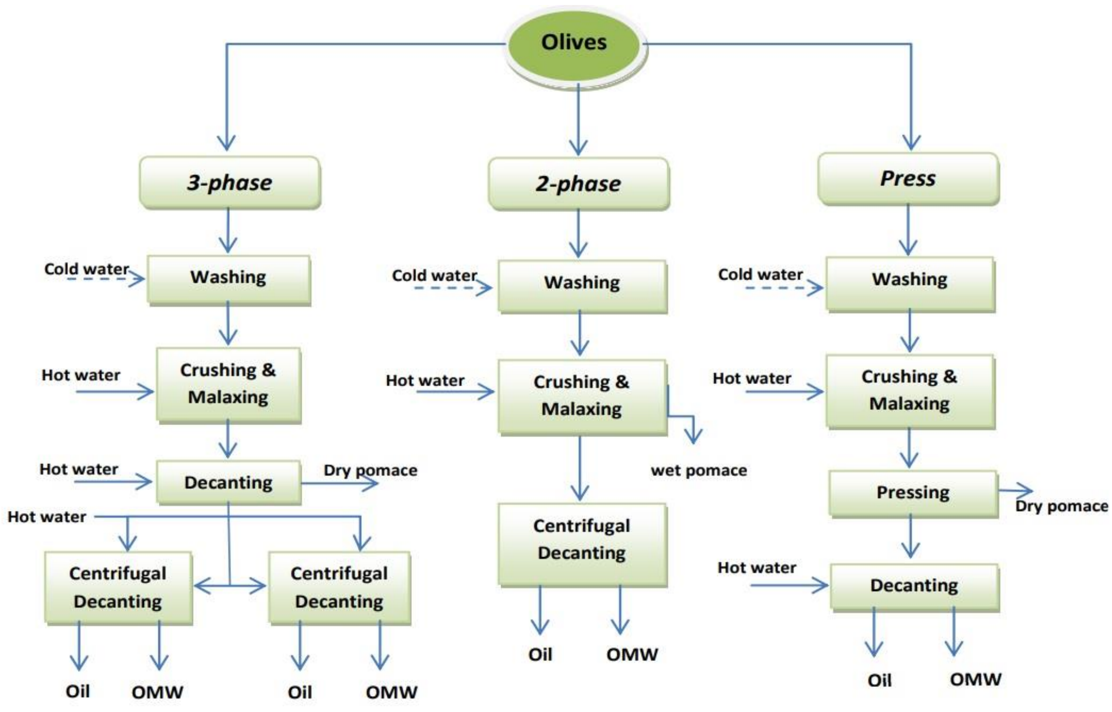


*Figure 4: The different olive oil extraction* (Ouazzane et al., 2017)

*<u>Traditional Pressing</u>*: This method involves crushing the olives using stone mills or presses to extract the oil. The resulting paste is then pressed to separate the oil from the solids.

*<u>Two-Phase Decanter</u>*: This method involves using a decanter to separate the oil and water from the crushed olives. The resulting paste is first mixed and then separated by the centrifugal force of the decanter into two parts: a wet solid residue and a liquid mixture of oil and water.

*Three-Phase Decanter*: This method is similar to the two-phase method, but includes an additional step to extract the pomace or waste material from the olives. The resulting three products are oil, water, and pomace.

Overall, the choice of method for extracting olive oil depends on factors such as the quality of the olives, the desired yield, and the available equipment and resources. It is important to note that traditional is often preferred by consumers for their perceived quality and health benefits, while modern methods such as solvent extraction are generally used for larger scale production of lower quality of olive oil. All the advantage and disadvantages of each technology summarized in table 1.

*Table 1: Advantages and disadvantages of each extraction technology*

| Technology | | Description | Advantages | Disadvantages |
|---|---|---|---|---|
| **Discontinue** | Pressing | Method of pressing the paste using hydraulic presses | -Good brand image towards the customer.<br>-Better oil quality.<br>-Does not require adding large amounts of water. | -Takes a lot of time.<br>-Requires oil/water separation. |
| **Continu** | Two-Phase Decanter | The decanter separates the oil and mixes the pomace and vegetation water into a single, paste called wet pomace. | -Olive oil directly separated from wet pomace | -Precise adjustments needed.<br>-Expensive technology. |
| | Three-Phase Decanter | Separation of oil through centrifugation using a horizontal centrifuge called a "decanter", which operates continuously. | -Fast.<br>-Good productivity.<br>-Easy to clean. | -Requires significant amounts of water.<br>-Expensive technology. |

### *I.6.3.**Packaging phase***

The packaging process for olive oil typically involves several steps:

*Bottling:* The olive oil is poured into glass or plastic bottles of various sizes, depending on the intended use.

*Labeling:* The bottles are labeled with information such as the product name, ingredients, nutritional information, and expiration date.

*Sealing:* The bottles are sealed with a cap or cork to prevent the olive oil from leaking or becoming contaminated.

*Quality control:* A sample of the olive oil is taken from each batch and tested for quality and purity. This includes testing for acidity, peroxide value, and other indicators of freshness and quality.

*Packaging:* The bottles are then packaged in cardboard boxes or other protective packaging for shipping and storage.

*Distribution:* The packaged bottles of olive oil are shipped to retailers or directly to consumers.

It's worth noting that some producers may also use alternative packaging methods, such as tin cans or bag-in-box packaging, which may involve slightly different packaging processes.

#### *I.6.4.* ***Waste management phase***

The waste management phase includes strategies such as composting, energy recovery, and wastewater treatment. Olive pomace can be composted to produce organic fertilizer or used for energy production, while wastewater can be treated and recycled for irrigation or other purposes. Effective waste management is essential for reducing pollution, conserving resources, and promoting a CE. By managing waste products effectively, olive oil producers can contribute to a sustainable and efficient life cycle that supports environmental and economic sustainability (Uceda-Rodríguez et al., 2020). Numerous studies have been conducted on olive oil waste using various methods, mostly in Mediterranean countries (Benavente et al., 2017; Duman et al., 2020; Landi et al., 2019; Rivela et al., 2006). These studies have examined the entire supply chain of the olive oil industry, including its farming, production, distribution, and by-products (Cappelletti et al., 2017; Kizos & Vakoufaris, 2011; Salomone & Ioppolo, 2012a). As a result, several observations have been made about the process.

Each phase of the olive oil life cycle generates a significant quantity of waste. During the agricultural phase, waste such as pruning wood, leaves, and olive twigs are produced. In the production phase, solid and liquid residues are the main types of waste generated. Finally, the packaging phase generates various materials, including glass, polypropylene, polyethylene terephthalate, and metal.

It's worth noting that these waste materials can have different environmental impacts, depending on the disposal method used. For example, improper disposal of plastic packaging materials can lead to negative impacts on marine life, while the burning of olive wood waste can contribute to air pollution. However, there are different methods for managing and reducing these waste streams, such as composting, recycling, and using them as biomass for energy production, which can mitigate their environmental impacts, (See Figure 5).

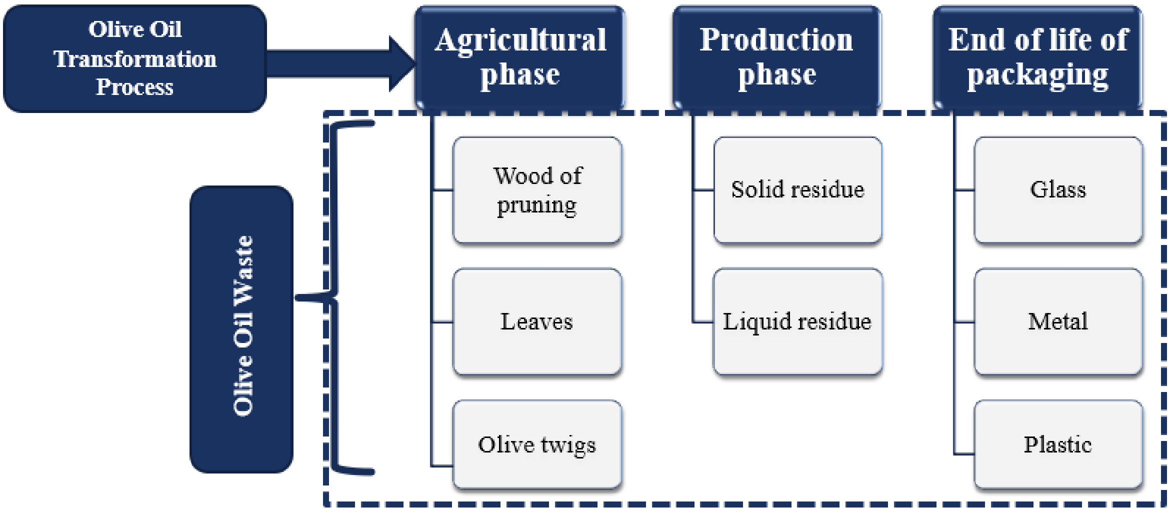


*Figure 5: Olive oil waste generated from each phase* (Keskes, Zouari, Houssin, et al., 2022)

### I.6.4.1. *Agricultural waste*

During the agricultural phase of olive oil production, various residues are generated, including pruning wood, leaves, and olive branches from harvesting processes. The quantity of these residues varies based on several factors, such as the age of the tree, as reported by(Nefzaoui, 1991). Recent research by (Bernardi et al., 2021) attempted to calculate the amounts of twigs and leaves harvested from olive trees in several Spanish environments. They found that the harvests of leaves and branches can range from 18 to 30 kg, but can reach up to 45 kg for olive trees in favorable growing conditions. The weighted average per tree is estimated to be around 22 kg of twigs, according to (Parellada Vilella & Gómez Cabrera, 1982), which is generally in agreement with the findings of Nefzaoui (1991). Table 2 provides information on the quantity of wood waste, including leaves and branches residues, from the agricultural phase in different pruning types (mild or severe). According to the principles of the circular economy, these high quantities of wood waste can be valorized and reintegrated into the environment (Keskes, Zouari, Lehyani, et al., 2022). There are various methods for managing and reducing these waste streams, such as composting, using them for energy production, or transforming them into new products, such as furniture or other useful items.

*Table 2: Pruning residues from the agriculture phase*

| Age of the tree | Pruning type | Total quantity of wood kg/tree | % Of leaves and branches | quantity of leaves and branches kg/tree |
|---|---|---|---|---|
| Young | Mild<br>Severe | -<br>30 | -<br>60 | -<br>18 |
| Adult | Mild<br>Severe | 50<br>100 | 50<br>30 | 25<br>30 |
| Old | Mild<br>Severe | -<br>100 | -<br>12 | -<br>12 |

- ***Valorisation scenarios for the agricultural waste:***

There is a scarcity of life cycle analyses that specifically focus on the waste of the agriculture phase. In our search, we were unable to find any such studies. As a result, we have considered articles that deal with waste management similar to this phase. For example, we have looked at the work of (Diaz et al., 2018 and Ten Hoeve et al., 2019), who both investigate various types of agricultural waste, including leaves, branches, and wood (municipal garden waste), and evaluate different scenarios for waste management, such as composting, incineration, recycling, and combustion. These studies aim to identify the environmental impacts associated with the different waste recovery scenarios in the agriculture phase.

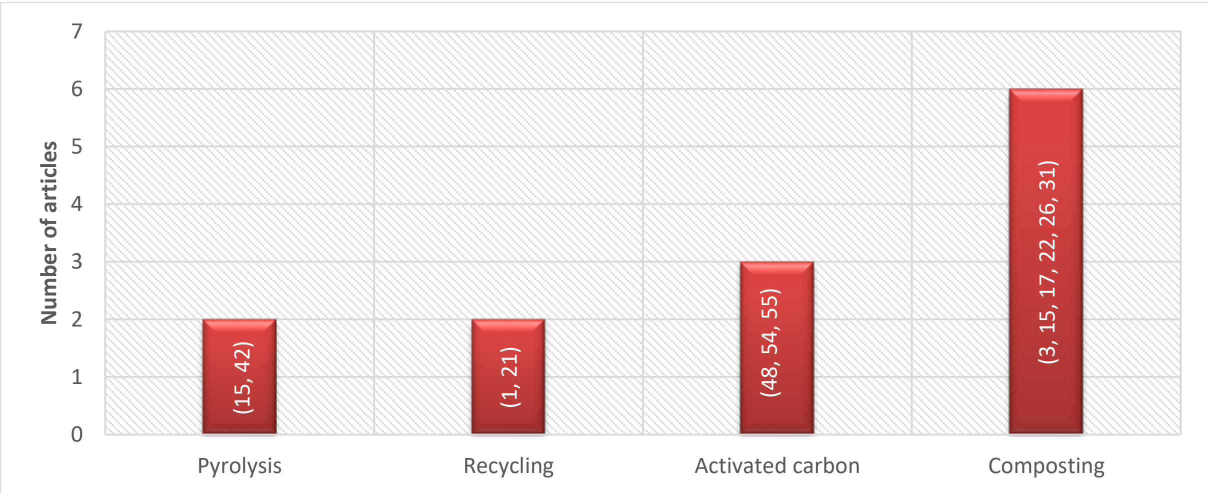


*Figure 6: Scenarios used to valorize olive oil wastes in agricultural phase*

Figure 6 depicts the key methods utilized to valorise olive oil wastes during the agricultural phase. Based on the literature reviewed, it is noteworthy that composting was the most frequently cited technique, being mentioned in 6 of the articles analysed. Recycling and pyrolysis were each cited twice. (All the numbers presented in Figure 6 correspond to the codes assigned to each article in Appendix A).

#### I.6.4.2. *Production waste*

After the extraction of olive oil, a significant amount of waste was detected. There is:

- Solid residue or Olive Pomace (OP): made up of the pulp, stone and husk of the olive.
- Wet pomace: residue with a pasty consistency at humidity greater than 60%. This residue if using a two-phase extraction system.
- Liquid residue or Oil Mill Wastewater (OMW): made up of the vegetation water of the olive, often mixed with water that is added during the operation. These vegetable waters have a high, but variable, polluting power.

• Vegetable and earthy remains from washing the olive that has just been harvested.

These residues are considered as olive waste and are very difficult to treat given their quantities and are an important environmental problem. An average-sized mill receives 10-20 ton of olives per day and produces 0.5 and 1.5 m3 of wastewater per one ton of olives (Banias et al., 2017).The oil only representing on average 20% of the mass of an olive, the remaining 80% constitute waste. Therefore 100 kg of olive gives an average of 20 kg of oil whatever the extraction method. The amount of residue differs depending on the extraction method, (Duman et al., 2020). Table 3 summarized the different extraction method and their waste quantities.

*Table 3: Quantity of waste generated from the different extraction technology*

| Extraction method | Quantity of OP | Quantity OMW | Quantity of olive oil |
|---|---|---|---|
| **Pressing** | 40 kg | 40 kg | 20 Kg |
| **Two-Phase Decanter** | 70 kg | 10 kg | |
| **Three-Phase Decanter** | 55 kg | 100 kg | |

The 2-phase system generates less wastewater than the 3-phase system, primarily from wash water. This innovative technology is referred to as “green” by many decision makers due to the reduced water and energy requirements and its comparatively reduced pollution load. The 2-phase system has been supported by national policies in Spain aimed at minimizing the high costs of wastewater treatment and disposal. This system has received public funding for its implementation (Orive et al., 2021). Other olive oil producing countries like Tunisia are also slowly implementing this kind of technology. It is suggested that the 2-phase technology saves 80% of water and up to 20% of energy. It requires up to 25% less investment costs compared to the 3-phase system. This technology creates mixed solid-liquid waste (Banias et al., 2017).

The 3-phase system generates approximately three times more volumes of oil mill wastewater than the Press system. While 0.4-0.6 $m^3$ of wastewater is produced per ton of product in the Press system, the production of wastewater reaches up to 1.0-1.2 $m^3$ in the 3-phase system. However, the press system results in wastewater which is more concentrated in pollutants compared to the 3-phase system (Banias et al., 2017).

- ***Valorisation scenarios for the production waste***

The literature contains several studies on the production phase of olive oil, mainly conducted in Mediterranean countries, where different methods were used for the life cycle assessment (LCA) of olive oil production (Banias et al., 2017; Cusenza et al., 2021; El Hanandeh & Gharaibeh, 2016). Additionally, many studies have examined the environmental impacts associated with the management and use of waste from olive oil production processes (Duman et al., 2020; Parascanu et al., 2018). Figure 7 presents the main techniques used for the valorization of olive oil wastes in the production phase, (All numbers in the figure representing the article codes in Appendix A).

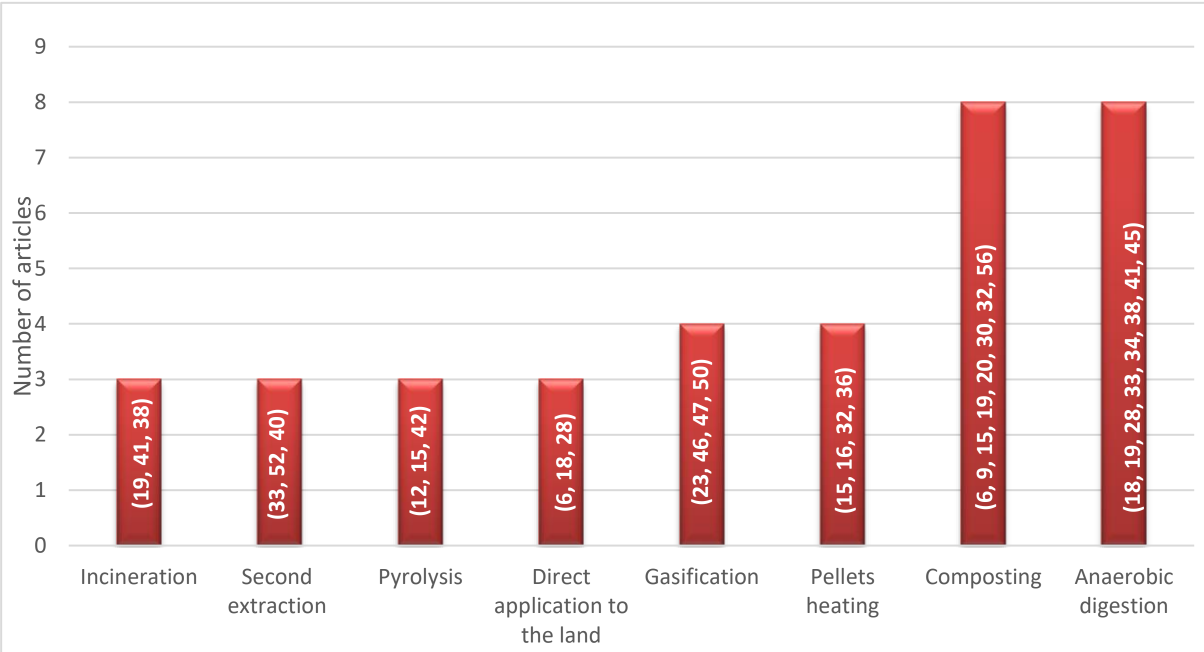


*Figure 7: Scenarios used to valorise olive oil wastes in production phase*

According to the articles studied, anaerobic digestion and composting were the most commonly used techniques to valorise waste from olive oil production. Studies by Cossu et al. (2013), El Hanandeh (2015), and Salomone & Ioppolo (2012) showed that composting had significant environmental benefits, while Benavente et al. (2017) found that alternatives using hydrothermal carbonization (HTC) were more environmentally beneficial than composting.

However, a study by Duman et al. (2020) found that composting had a high impact score due to the raw materials used and hazardous chemicals emitted during the process.

In Italy, a comparative LCA study by Batuecas et al. (2019) and Valenti et al. (2020) evaluated two waste management scenarios for olive oil production: anaerobic digestion and disposal on soil. The study found that disposing of waste on the ground resulted in worse environmental performance for all impact categories. Anaerobic digestion was found to have a lower environmental impact compared to soil disposal. Dumping waste olives on the ground can alter the chemical properties of the soil and contaminate aquifers, resulting in more serious impacts on climate change, such as acidification, terrestrial eutrophication, depletion of water resources, and cumulative energy demand.

A study carried out in Cyprus evaluated the environmental impact of the granulation of olive waste through a full LCA. The study developed a new parametric mathematical model and implemented non-linear programming to determine optimal locations for management facilities that required the lowest energy for transportation purposes. The study concluded that the location of biomass management centres and the use of renewable energy technologies for energy production significantly affect the environmental impact of biomass use.

#### I.6.4.3. *The end of life of the packaging materials*

Packaging plays a crucial role in the olive oil supply chain, as the choice of packaging material can impact economic, social, and environmental factors. Recent studies, such as Aryan et al. (2019), have emphasized the importance of making sustainable packaging decisions to minimize environmental impacts. The main types of packaging waste generated from olive oil include glass, stainless steel, polypropylene (PE), polyethylene terephthalates (PET), and tinplate. Considering the average annual worldwide consumption of olive oil during the 2007/2008-2012/2013 period, which was 2,862,800 tons, and assuming that only 1-liter bottles are used, it can be estimated that more than 2,860,000,000 bottles are used annually.

- ***Valorisation scenarios for the Packaging waste***

Packaging and containers are directed to different end-of-life depending on consumer behaviour and the waste treatment channels. Among these channels, recycling, landfill or incineration were distinguished. The main objective of LCA is to evaluate the environmental impacts associated with an activity or the life cycle of a specific product. Also, it has been applied to evaluate the environmental performance related to waste management scenarios. In this part, packaging waste management system has been studied for evaluating environmental impacts, considering packaging phase scenarios. According to the diagnosis of studied articles, we have distinguished 3 possible types of waste such as PET, Aluminium and Glass. Figure 8 shows the most used techniques to valorise olive oil packaging wastes; Landfilling, Incineration, Recycling and Reuse (The numbers in the figures are the code of articles in Appendix A).

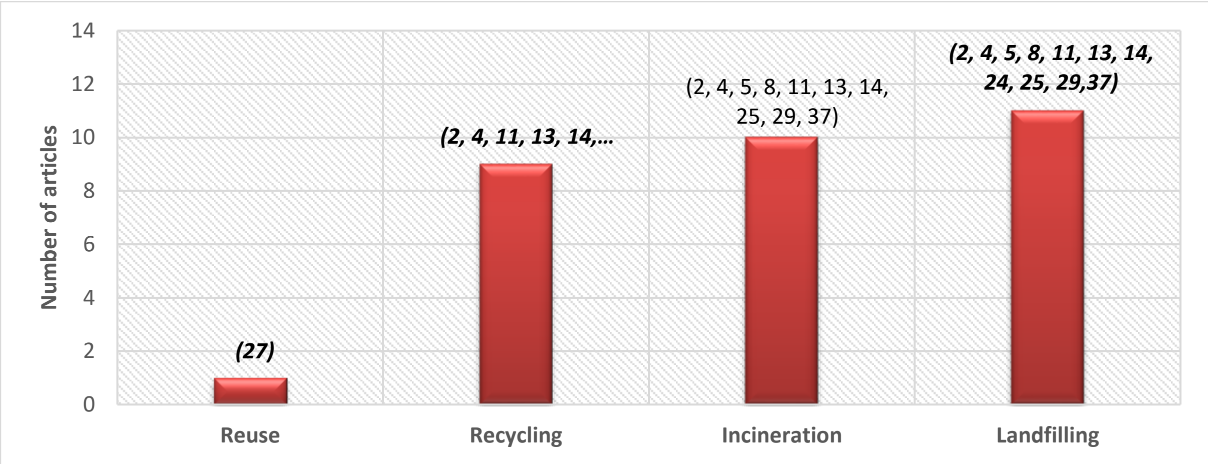


*Figure 8: Scenarios used to valorise olive oil packaging wastes*

The literature review revealed that authors generally prefer recycling PET bottles as the technique with the least environmental impact in most categories, except for abiotic depletion and acidification (Aryan et al., 2019). Ferreira et al. (2014) compared the environmental performance of three recovery scenarios (landfilling, recycling, and incineration) for various wastes, including plastic, aluminum, and glass. Their results showed that recycling is more environmentally friendly than the other scenarios. However, Foolmaun and Ramjeeawon (2012) found that incineration with energy recovery has the least environmental impact. They did not consider recycling since it is not carried out in their country, Mauritius. Sawatani and Hanaki (2002) compared incineration with energy recovery, landfilling, and recycling of PET bottles and found that incineration is better than materials recycling for reducing solid waste. However, Mendes et al. (2004) argued that the best waste management option for a given system depends on the specificity of local conditions.

For glass bottles, the valorization scenarios are recycling and reuse. Landi et al. (2019) compared these two scenarios and found that reuse is very promising to reduce environmental problems related to glass bottles. Reuse resulted in negative environmental impacts in all categories (except fossil depletion), indicating potential environmental benefits. This is because reuse allows for the recovery of the entire bottle and avoids the use of new glass. Sawatani and Hanaki (2002) found that $CO_2$ emissions from a single-use glass bottle are much higher than multi-use bottles, suggesting that glass bottles should be used repeatedly to reduce emissions and be more durable. Foolmaun and Ramjeeawon (2013) found that mechanical glass recycling has the best environmental performance and is a best practice in waste management, as it leads to savings in raw materials. However, each material requires a specific recycling scenario, and each scenario has environmental, economic, and social impacts. Landi et al. (2019) proposed reuse as a scenario to avoid large quantities of consumed electricity and heat necessary for different phases, particularly glass melting and the bottling process, leading to significant environmental savings in all impact categories.

So, olive oil is a staple ingredient in many households around the world, and it's important to choose the most sustainable packaging options to reduce the environmental impact. When it comes to sustainability, glass bottles are one of the best choices for packaging olive oil. Unlike plastic bottles, glass bottles are 100% recyclable and reusable. They can be recycled endlessly without losing their quality or purity. Moreover, glass does not contain any harmful chemicals that can leach into the oil, making it a safer option for both the consumer and the environment. Another advantage of using glass bottles for olive oil packaging is that they help to protect the quality of the oil. Olive oil is sensitive to light, oxygen, and other external factors that can degrade its quality and flavour. Glass bottles prevent any light or oxygen from coming into contact with the oil, thus preserving its freshness and taste. Furthermore, glass is a non-porous material that does not absorb any flavours, which can affect the quality of the oil. This ensures that the oil retains its unique flavour profile, which is essential for its culinary and nutritional benefits.

In conclusion, using glass bottles is the most sustainable and beneficial packaging option for olive oil, that’s why many authors prefer it. By choosing this type of packaging not only reduce the environmental impact but also protect the quality and flavour of the oil.

## I.7. Conclusion

In conclusion, this chapter has emphasized the importance of sustainability and circular economy principles in the olive oil supply chain. We have explored the various aspects of sustainability and discussed the need for a sustainable supply chain to ensure long-term viability and minimize the environmental impact. Additionally, we have looked into the specifics of the olive oil supply chain, including the agricultural practices phase, extraction systems and packaging phase, as well as the waste valorization scenarios (See Figure 9). So, a circular economy approach in the domain of the olive oil supply chain can lead to a more sustainable and resilient system for all stakeholders involved.

In conclusion, chapter 1 establishes a strong foundation for the rest of the thesis, laying out the fundamental concepts and principles necessary for a deeper exploration of sustainable and circular practices in the olive oil supply chain. The insights and proposals presented in this chapter will guide the subsequent chapters and provide a valuable contribution to the existing literature on sustainability and CE.

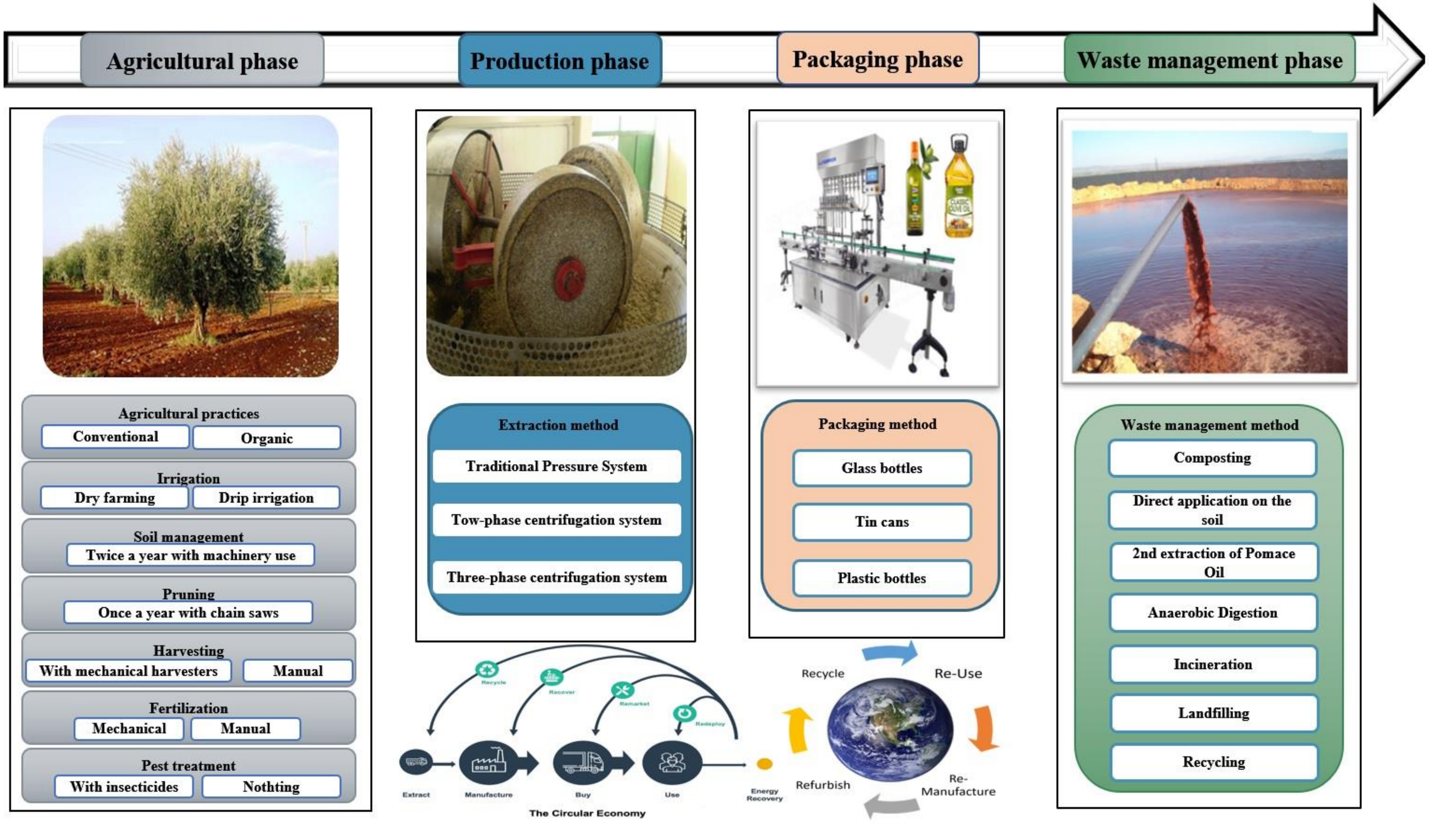


*Figure 9: Summarizing the main outputs from chapter*

# Chapter II: A Bibliometric Literature Review

## II.1. Introduction

This chapter presents a literature review of Life Cycle Sustainability Assessment (LCSA) and Multicriteria Decision Analysis (MCDA) frameworks related to the agriculture issue. The goal of this chapter is to explore how LCSA and MCDA methods can be combined to address sustainability issues in agriculture, and to review the different approaches, criteria, and tools used in the literature to achieve this goal.

The chapter is structured as follows. First, we provide an overview of the LCSA and MCDA frameworks and their relevance to agriculture. We then discuss the research method of the literature review, including the search strategy used to identify relevant articles and sources.

The third part of the chapter presents the findings from the literature review, focusing on the different criteria used in the literature related to sustainability problems in agriculture. We also review the different alternative, weighting, ranking, and sensitivity and robustness tools used in the literature to assess sustainability in agriculture. These findings help us to position our work in relation to other research in the literature, and to identify gaps and opportunities for further research.

Overall, this chapter provides a comprehensive review of the literature related to LCSA and MCDA frameworks for sustainability assessment in agriculture, and lays the groundwork for the future research presented in the following chapters.

## II.2. Exploring life cycle sustainability assessment and multicriteria decision analysis methods

### II.2.1. Life cycle sustainability assessment

Life Cycle Sustainability Assessment (LCSA) is a comprehensive approach to assess the sustainability of a product, process, or system across its life cycle. It integrates three dimensions of sustainability: environmental, economic, and social. Life cycle assessment (LCA), life cycle costing (LCC), and social life cycle assessment (S-LCA) it's called the three pillars of LCSA, (See Figure 10).

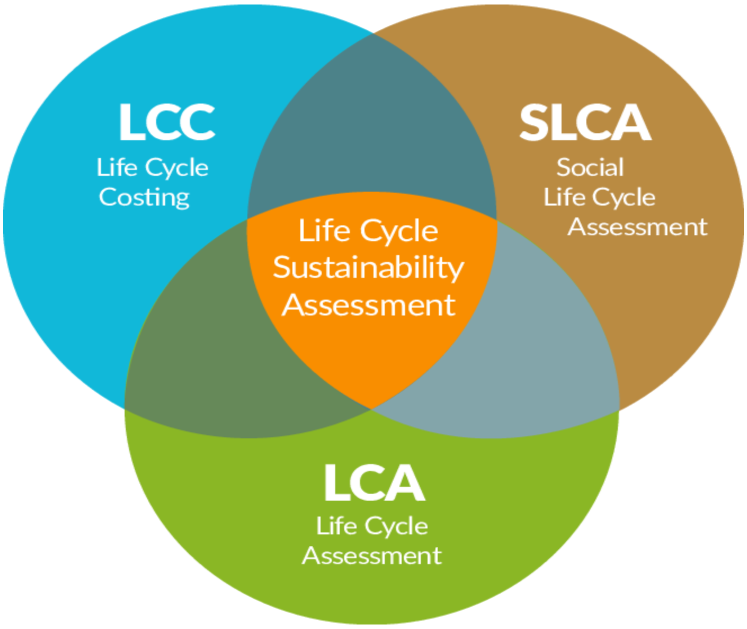


*Figure 10: The three pillars of sustainability*

- ***LCA*** is a widely used tool for assessing the environmental impact of a product, process, or system throughout its life cycle, from cradle to grave. It considers various environmental aspects, such as climate change, resource depletion, and human toxicity, to quantify the environmental impact and identify hotspots.
- ***LCC*** is an economic tool that evaluates the life cycle cost of a product, process, or system. It considers all the costs associated with the life cycle stages, including acquisition, use, maintenance, and disposal, to determine the most cost-effective option.
- ***S-LCA*** is a social tool that evaluates the social impact of a product, process, or system throughout its life cycle, from cradle to grave. It considers various social aspects, such as human rights, labour practices, and community involvement, to identify the social hotspots and improve the social performance of the product, process, or system.

Integrating these three pillars of sustainability provides a comprehensive view of the sustainability performance of a product, process, or system. It allows decision-makers to make informed decisions based on a holistic understanding of the sustainability performance and identify opportunities for improvement. Several studies have applied LCSA to different products, processes, and systems, such as biofuels (Olguin-Maciel et al., 2020), buildings (Llatas et al., 2020), and wastewater treatment plants (Zhou et al., 2020). The results have shown that LCSA can provide valuable insights into the sustainability performance and help identify the most sustainable option.

In conclusion, LCSA is a comprehensive approach to assess the sustainability of a product, process, or system across its life cycle, integrating environmental, economic, and social dimensions of sustainability. LCA, LCC, and S-LCA are the three pillars of LCSA, providing a holistic view of sustainability performance and identifying opportunities for improvement.

### II.2.2. Multicriteria decision analysis methods

Multi-criteria decision analyse (MCDA) can be used to evaluate and compare different options based on multiple criteria, its allow decision-makers to consider different aspects of sustainability simultaneously and can help to identify trade-offs between different criteria. MCDA methods can be classified into different categories, such as outranking methods, value-based methods, and goal programming methods. Each method has its strengths and weaknesses, depending on the decision context and the preferences of the decision-makers. For example, outranking methods, such as the Analytic Hierarchy Process (AHP), the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), are based on pairwise comparisons of alternatives against each criterion, using expert judgments or stakeholder feedback (Siksnelyte-Butkiene et al., 2020). AHP decomposes the problem into a hierarchical structure of criteria and sub-criteria, and assigns weights to each criterion based on their relative importance (Ghosh et al., 2022). TOPSIS and VIKOR ranks alternatives based on their distance to the ideal solution and the anti-ideal solution, which represent the best and worst performance, respectively, for each criterion (Suganthi, 2018a). However, PROMETHEE is based on the concept of outranking flows, which represent the net flow of outranking relations from one alternative to another (Król et al., 2018).

Value-based methods, such as the Multi-Attribute Utility Theory (MAUT) and the Simple Multi-Attribute Rating Technique (SMART), are based on the aggregation of performance scores across criteria, using weights that reflect the relative importance of each criterion and the preferences of the decision-makers. MAUT uses utility functions to convert performance scores into utility values, which reflect the perceived value of each alternative to the decision-makers. SMART uses linear weights and additive aggregation to calculate a single score for each alternative, based on the performance scores and weights (Fotia et al., 2021)

Goal programming methods, such as the Weighted Goal Programming (WGP) and the Multi-Objective Linear Programming (MOLP), are based on the formulation of optimization models that aim to minimize the deviations from a set of predefined goals or constraints, across multiple criteria. WGP assigns weights to the goals or constraints and uses linear programming to find the optimal solution that meets the goals or constraints with minimal deviations (Jayaraman et al., 2015). MOLP formulates the problem as a set of linear equations and inequalities that represent the constraints and objectives, and uses linear programming to find the optimal solution that satisfies all constraints and maximizes or minimizes the objectives (Jeong et al., 2016).

#### II.2.3. Combining life cycle sustainability assessment and multicriteria decision analysis

LCSA and MCDA are powerful methods that can be used to evaluate the sustainability of different systems in various domains. LCSA is a comprehensive approach that considers the environmental, economic, and social impacts of a system throughout its entire life cycle (Myllyviita et al., 2012). This approach can help decision-makers identify the hotspots of their systems and implement measures to improve their sustainability performance. On the other hand, MCDA is a decision-making approach that allows stakeholders to assess different alternatives based on multiple criteria and to rank them according to their preferences. This approach can help decision-makers identify the most sustainable option based on their priorities and values (Fernández-Tirado et al., 2021).

When combined, LCSA and MCDA can provide a powerful tool for evaluating the sustainability of different systems. The combination of the two approaches allows decision-makers to consider a wide range of criteria and to identify the most sustainable option based on a comprehensive evaluation of environmental, economic, and social aspects. This approach can help promote a more sustainable future by integrating sustainability considerations into decision-making processes in various domains (Ren et al., 2015).

Several studies have applied LCSA and MCDA methods to evaluate the sustainability of different production systems in different domains. For example, Agriculture (Milutinović et al., 2017), Energy (Vogt Gwerder et al., 2019), Construction (Figueiredo et al., 2021), Production (Wulf et al., 2021), Waste management (Nubi et al., 2022), Transportation (Kügemann & Polatidis, 2022), Healthcare (Puška et al., 2022).

Those studies demonstrate the powerful combination of LCSA and MCDA for evaluating the sustainability of different systems in various domains. These methods offer a holistic approach that considers environmental, economic, and social aspects of systems and allows decision-makers to identify the most sustainable option based on their priorities and values.

## II.3. Research method: The search strategy

This section of the chapter aims to elucidate the process of conducting bibliometric research on various agricultural configuration. To ensure the replicability and updateability of the research in other areas or future studies, a systematic literature review was conducted, (See Figure 11) using previous reviews outlined by Mengist et al., (2020). The research was divided into five steps:

- Step 1: Identifying the research questions (RQs).
- Step 2: Material collection.
- Step 3: Descriptive analysis.
- Step 4: Category selection.
- Step 5: Material evaluation

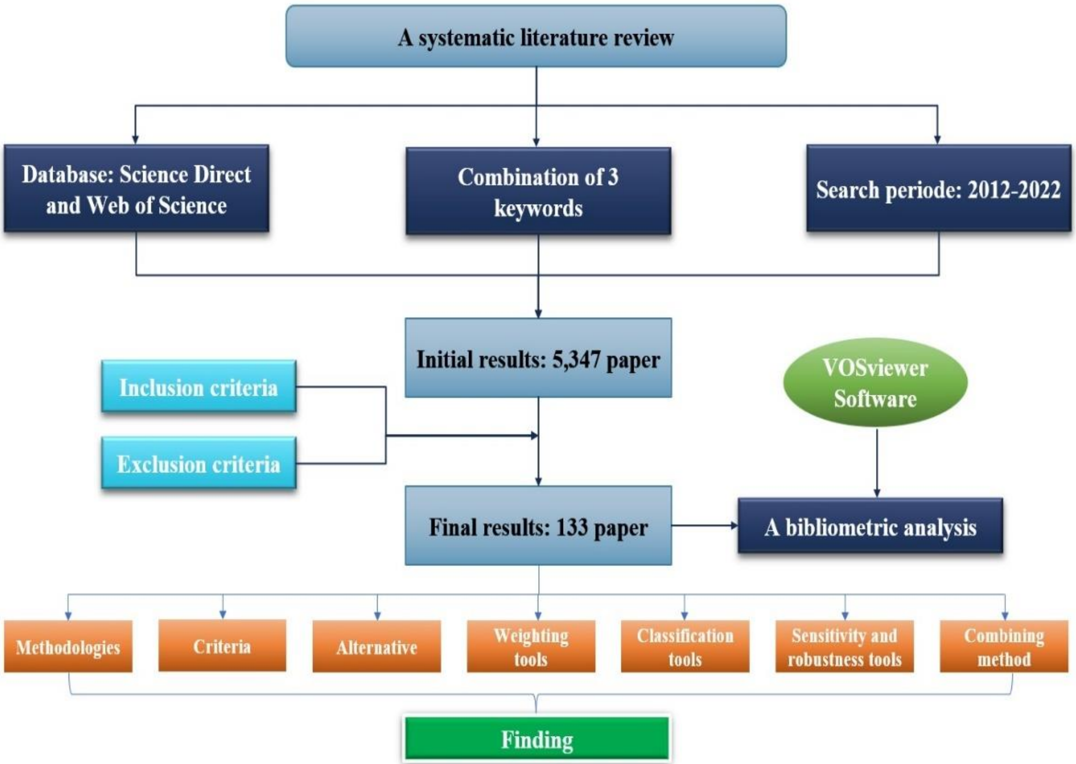


*Figure 11: Methodological steps of the review process*

### II.3.1. Step 1: Research questions

The aim of this study is to evaluate the current state of research on sustainability issues in agriculture. To achieve this objective, a set of RQs have been formulated to guide the review process. The RQs are designed to explore the various aspects of sustainability in agriculture:

- RQ1: What are the agriculture life cycle decision levels addressed in each phase of the life cycle?
- RQ2: What is the significance and novelty of combining MCDA and LCSA methods?
- RQ3: Which circular alternatives have been most commonly used to study sustainability issues in the agriculture life cycle?
- RQ4: What criteria have been most frequently used to study sustainability issues in the agriculture life cycle?
- RQ5: Which weighting methods have been most commonly used to study sustainability issues in the agriculture life cycle?
- RQ6: What multicriteria approaches have been employed to identify the most sustainable solutions for proposed problems in the agriculture life cycle?
- RQ7: What methods have been most commonly used to study the sensitivity and robustness of sustainability issues in the agriculture life cycle?

By answering these research questions, this study aims to provide a comprehensive overview of the current state of research on sustainability  and CE issues in agriculture.

### II.3.2. Step 2: Material collection

The second stage of our research involved defining the selection steps and identifying the appropriate databases for paper selection. We obtained an initial list of relevant papers from various publishers such as Springer, ScienceDirect and Taylor & Francis,. To facilitate the search and selection of papers, the keywords were grouped into three categories, The keywords in each group were connected using Boolean operators, with “AND” separating the keyword groups and “OR” separating the words within each group. All keywords summarized in table 4.

*Table 4: Keywords used during this study*

| Group | Keywords |
|---|---|
| **Group 1** | "Sustainable" OR "Sustainability" OR "Life cycle assessment" OR "Sustainability life cycle assessment " |
| **AND \ OR** | |
| **Group 2** | "Multicriteria decision" OR "multicriteria evaluation" OR "multi-criteria evaluation" OR "multi-criteria decision" OR "multi-criteria analysis" OR "multicriteria analysis" OR "multi-attribute decision" "multiobjective decision" OR "multiobjective analysis" |
| **AND** | |
| **Group 3** | "Agriculture" OR "Olive" OR "Grapes" |

After applying the inclusion and exclusion criteria (See Table 5), the initial set of 5347 papers was narrowed down to 133 relevant papers for our research study. The criteria for selection were based on the focus and relevance of the papers to the objectives of this chapter, which include the evaluation of sustainability and circular economy principles in the agriculture supply chain. The filter applied ensured that only the most relevant papers were selected for review and analysis, while eliminating any irrelevant ones. In the next sections, we will present a comprehensive synthesis of the results from these 133 papers, providing insights into the current trends and research gaps in the area of sustainable and circular agriculture supply chain.

*Table 5: Inclusion and exclusion criteria*

| **Criteria** | | **Justification** |
|---|---|---|
| **Inclusion** | Papers published between 2012 and 2022 | Focus on recent publications |
| | English language | Most of the excellent journals are in English only |
| | Publications in peer-reviewed journals and conference papers | To concentrate on high quality articles |
| | Papers focused on the sustainable and circular agriculture supply chain: MCDA and/or LCSA studies | To emphasize the works related to the sustainable and circular agriculture supply chain |
| **Exclusion** | Papers focus only on the combining MCDA and LCSA methods for the agriculture issue | The purpose of this study is to review the existing literature on the combining MCDA and LCSA methods for the agriculture issue |
| | Working papers, technical reports and book Chapters. | To ensure the quality of the review, only peer-reviewed journal articles are included |
| **Final selected articles: 133** | | |

### II.3.3. Step 3: Descriptive analysis

In Step 3 of the study, a descriptive analysis is conducted on the selected papers. This includes an examination of the distribution of the papers by their year of publication and the journals in which they were published. Additionally, a co-occurrence analysis of frequency keywords used in the literature is performed using the bibliometric method and the VOS viewer software, version 1.6.18. The use of this software is chosen due to its ability to visualize bibliometric networks and analyse large data sets. The analysis of these data sets will provide insights into the current trends and patterns in the field of sustainable and circular agriculture supply chain.

### II.3.4. Step 4: Category selection

Based on the research questions presented in the first step, the selected papers have been analysed and synthesized according to the following structural dimensions:

- ***Methodologies:*** The different methodologies used (MCDA or LCSA or both) to solve the agriculture sustainability issue.
- ***Criteria:*** The different criteria used to study the agriculture sustainability issue.
- ***Alternative:*** The different alternatives used to study the agriculture sustainability issue.
- ***Weighting tool:*** This refers to the type of weighting method used by the authors to calculate the weight of each criteria.
- ***Classification tools:*** This refers to the type of MCDA method used by the authors to rank the different alternatives based on the weight of each criteria.
- ***Sensitivity and robustness tools:*** This refer to the different methods used to study the sensitivity and robustness of the proposed method.
- ***Combining method:*** Assessing the effectiveness of a combined tool for evaluating the sustainability of diverse agriculture systems.

### II.3.5. Step 5: Material evaluation

In this step, we carry out the evaluation of the selected papers according to their identified structural dimensions. Within the analysed literature, a critical analysis, based on the answer to RQs, is performed by identifying the main existing research gaps, the proposals and future research.

In the following sections, we will provide a comprehensive analysis of the main findings presented in tables and figures based on the categorization criteria mentioned in the research questions. This in-depth analysis will allow us to gain insight into the current trends in designing a circular and sustainable agriculture supply chain and also identify the research gaps in this field.

## II.4. Findings from the literature review

### II.4.1. Publishing frequency

The data presented in figure 12 shows the rate of publication on MCDA and LCSA in the agricultural field in different countries around the world. Italy has the highest rate of publications, accounting for 29% of the total publications. Spain is the second highest with 14%, followed by Iran at 8%, and China at 7%. The rest of the countries listed have a rate of publication ranging from 2% to 5%. Other countries not specified in the data set account for 14% of the total publications.

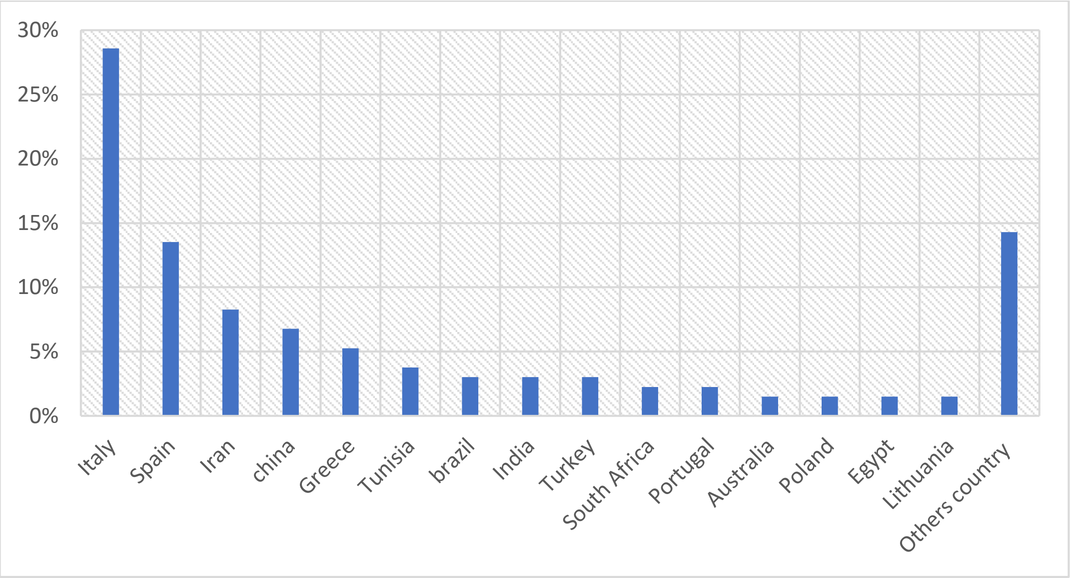


*Figure 12: Geographic distribution of the case studies*

The high rate of publications in Italy suggests that the country is a leader in research in the agricultural field. This could be due to the country's strong agricultural sector, as well as its investment in research and development in the field. The high rate of publications in Spain, Iran, and China also suggests that these countries are actively engaged in research in agriculture. On the other hand, the relatively low rate of publications in countries such as South Africa, India, Brazil, and Turkey suggests that there is a potential for more research and development in these areas. It is possible that these countries face challenges in terms of funding, infrastructure, or other factors that limit their ability to conduct research in the field. Nevertheless, the presence of publications from these countries highlights the potential for growth and development in the field of MCDA and LCSA in agriculture.

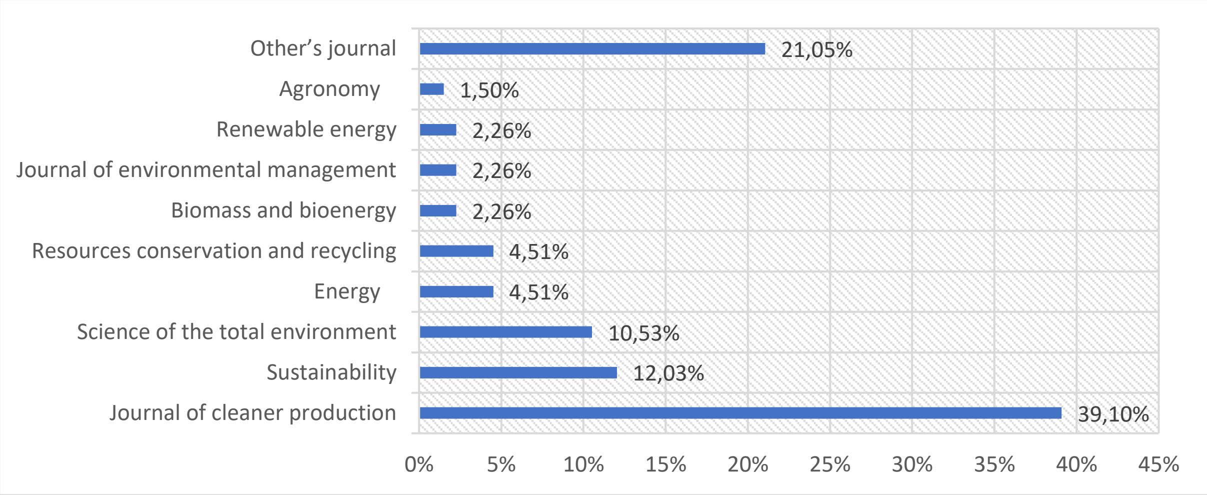


*Figure 13: Rate of publications per journal*

The data represented in figure 13 reveals that the Journal of Cleaner Production has the highest number of publications at 52, which accounts for 39.10% of the total publications. This journal covers topics related to sustainable production and consumption, environmental management, and CE. Given the growing awareness and concern for sustainable development, it is reasonable to assume that research in these areas is in high demand, resulting in a higher rate of publications.

Sustainability and Science of the Total Environment are the second and third most published journals with 16 and 14 publications, respectively, accounting for 12.03% and 10.53% of the total publications. Sustainability covers a broad range of topics related to sustainability and sustainable development, including renewable energy, climate change, and environmental policy. Science of the Total Environment focuses on the impact of human activities on the environment, including pollution, environmental degradation, and ecosystem management. It is likely that these journals have a high rate of publications due to the growing interest in sustainability and the environment, as well as the urgency of addressing environmental issues at the global level.

Finally, other's journal, which includes journals not specified in the data set, has a relatively high rate of publications at 21.05%. It is possible that this category includes newly established or smaller journals that specialize in more specific areas of the field, which may attract researchers looking for more niche topics to publish their work.

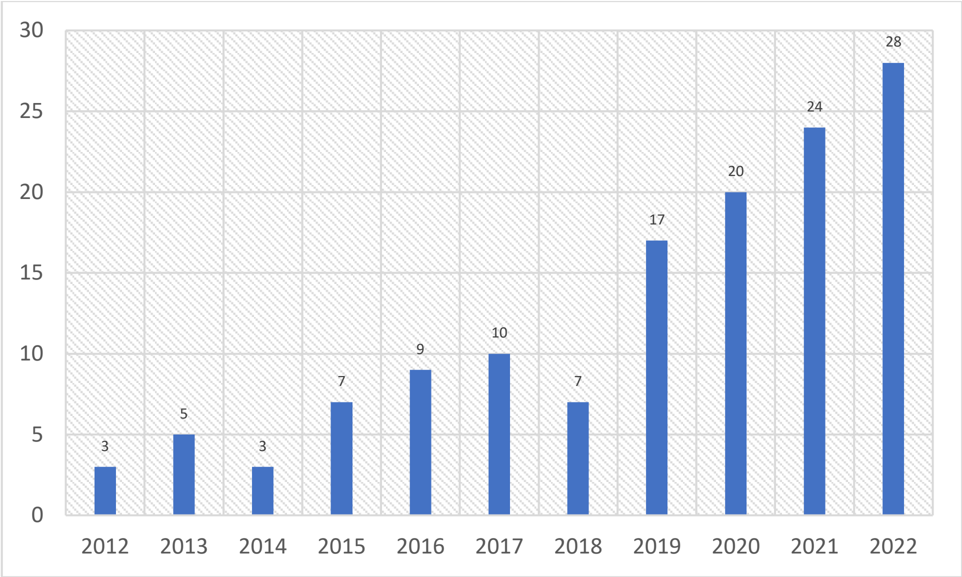


*Figure 14: Overview of the chronological distributions of LCSA*

The data presented in figure 14 shows a clear increasing trend in the number of publications on MCDA and LCSA in the agricultural field over time. The number of publications started with 3 in 2012, and gradually increased each year, with a significant increase in 2019, where the number of publications doubled from the previous year to 17. The trend continued to accelerate in 2020, with 20 publications, and in 2021, with 24 publications. The number of publications is projected to continue to increase, with 28 publications expected in 2022.

The increasing trend in the number of publications suggests a growing interest and investment in research on MCDA and LCSA in the agricultural field. This may be due to a range of factors, including the increasing awareness of the importance of sustainability in agriculture, the need for better decision-making tools in agriculture, and the development of new technologies and methodologies for MCDA and LCSA.

The increasing trend in the number of publications also indicates that research in this field is becoming more popular and competitive, which could have implications for researchers and policymakers. The growing body of research may help to inform policy decisions and drive innovation in the agricultural sector. At the same time, the increasing competition for publication may make it more challenging for researchers to publish their work and highlight the need for rigorous and high-quality research in the field. Overall, the trend in the number of publications suggests that MCDA and LCSA in the agricultural field will continue to be an important area of research in the years to come.

### II.4.2. Keyword analysis

To find studies that could be references in the area of applying multicriteria models in agriculture sustainability, it was become important to determine if there were any patterns in the keywords the authors used. Figure 15 shows the distribution of the network of keywords in four clusters considering that each keyword present in the network has at least two citations.

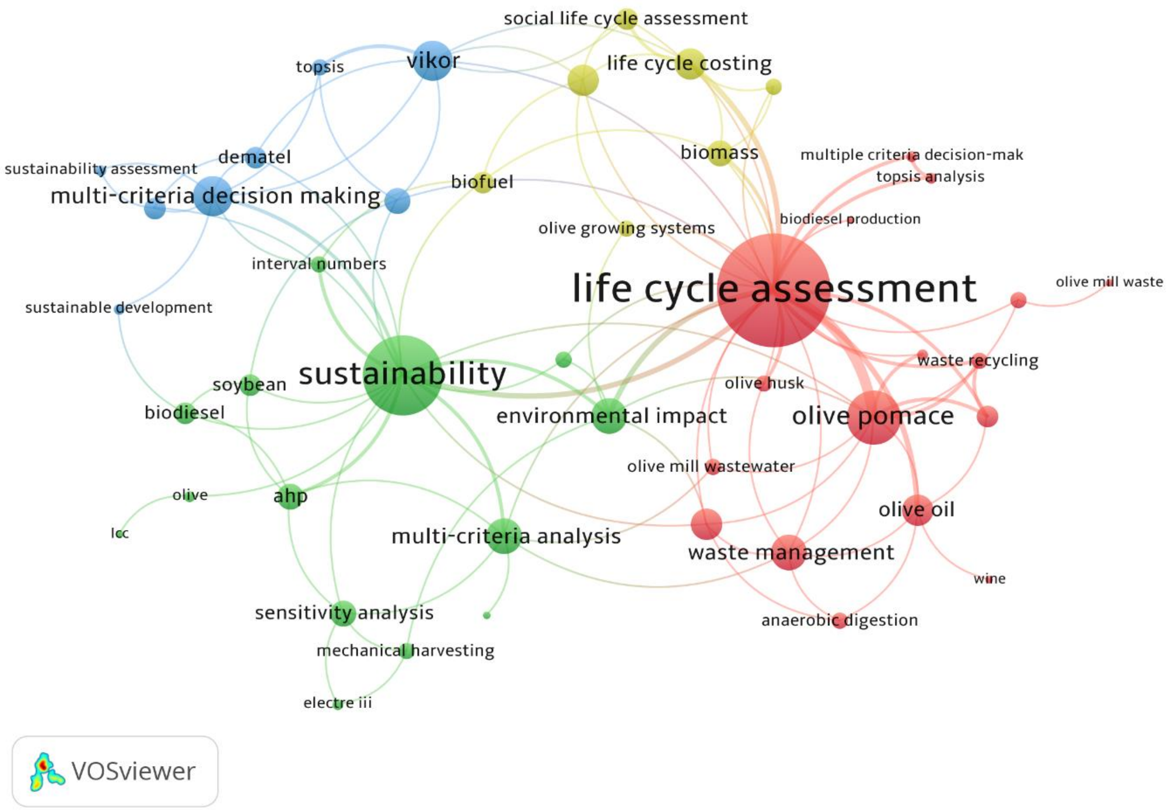


*Figure 15: Network of keywords analyzed based on clusters*

The presence of the words "Sustainability", "Life Cycle Assessment", "Multi-Criteria Decision Making", "Olive pomace" and "Life Cycle Sustainability Assessment" suggests that these topics are highly relevant in the literature, and that researchers are using these concepts to frame their studies (See Figure 15). The fact that "Multi-Criteria Decision Making" appears in multiple clusters indicates that it is a common approach used in many different areas of research related to sustainability.

The identification of specific multicriteria methods such as "AHP", "ELECTRE", "TOPSIS", "DEMATEL" and "VIKOR" suggests that researchers are applying a variety of decision-making methods to address sustainability issues, and that these methods are being used in different contexts and disciplines. Overall, these findings suggest that sustainability and decision-making are important topics in the literature, and that researchers are using a variety of methods to approach these issues. By identifying these trends and themes, researchers can gain a better understanding of the current state of the literature and the directions that future research may take.

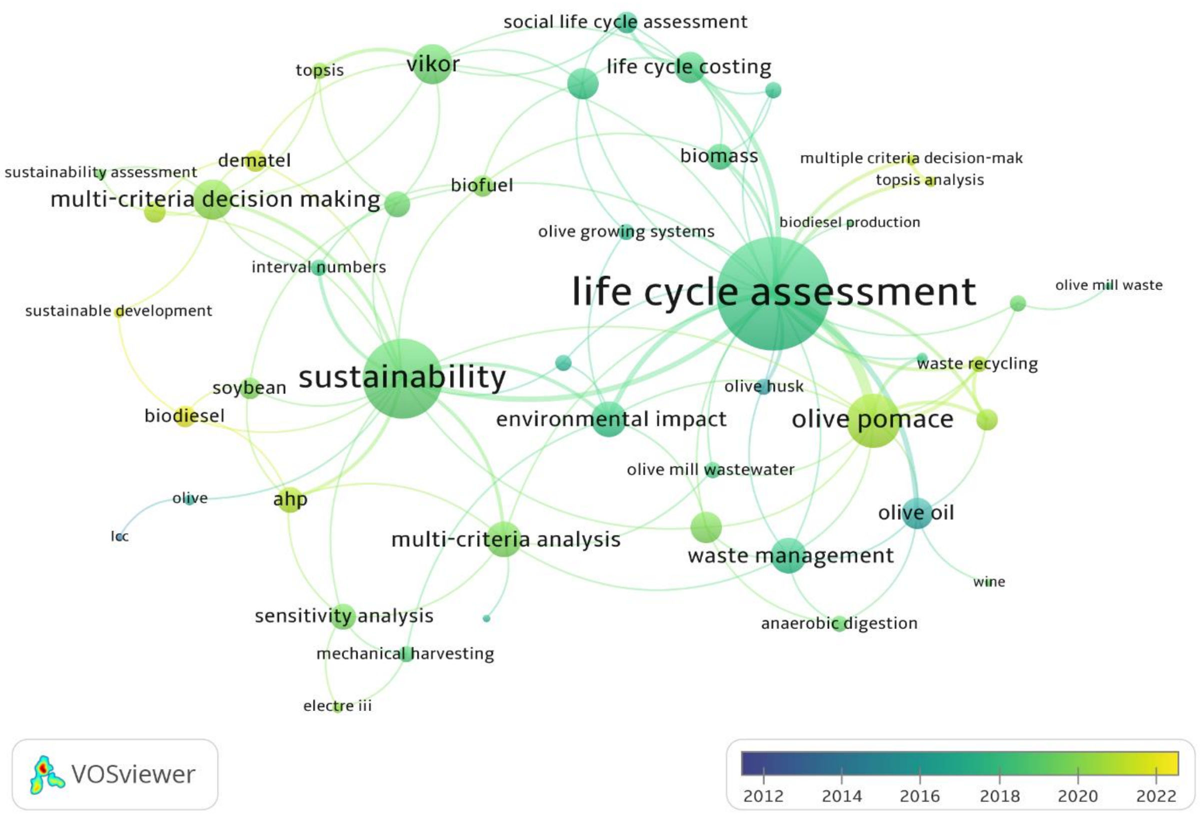


*Figure 16: Network of keywords analyzed over time*

The same network of words analyzed over time also offers an indication of how the authors have referenced their papers (See Figure 16). It is interesting to note that there has been an increase in the use of keywords such as "Life Cycle Assessment and Sustainability" and "Multi-Criteria Decision Making" from 2019 onwards. This suggests that there is growing interest in these topics, and that researchers are increasingly using these terms to frame their studies.

The fact that these keywords are becoming more visible on the Web of Science database is also significant, as it suggests that these studies are more likely to be found and cited by other researchers. This, in turn, can help us to increase the impact and visibility of the research in the field of sustainability and decision-making.

Overall, these findings indicate that sustainability and decision-making are important and growing areas of research, and that researchers are using specific keywords to frame their studies and increase their visibility in the literature. By understanding these trends, we can gain a better understanding of the current state of the literature and identify opportunities for our research in the agriculture areas.

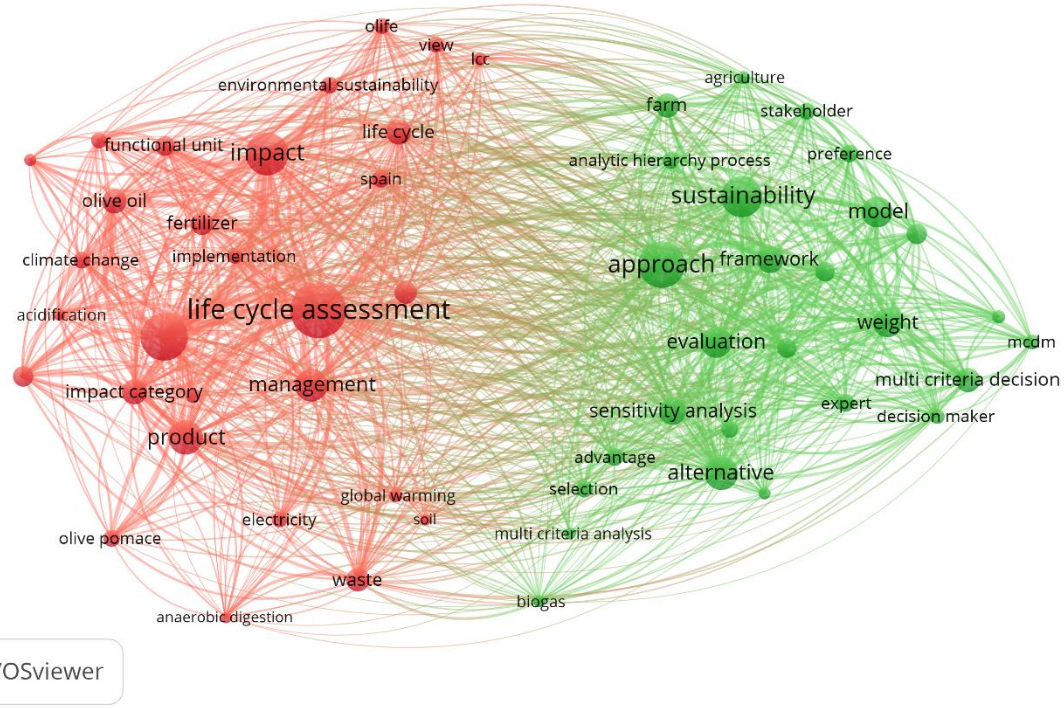


*Figure 17: Co-occurrence of keywords based on clusters*

A graph of keywords recurrent in abstract can provide valuable insight into the current state of research on a particular topic. By visualizing the most commonly used keywords in abstracts, we can identify important themes and trends in the literature, as well as potential gaps (See Figure 17). The graph can also help us to identify potential collaborators or interdisciplinary research opportunities by highlighting which keywords are commonly used by researchers in related fields. it seems in figure 17 there are two clusters of keywords, one related to "Multi-Criteria Decision Making" and the other related to "Life Cycle Assessment".

The use of keywords related to "Multi-Criteria Decision Making" such as "evaluation," "expert," "AHP," "weight," and "sensitivity analysis" indicates that researchers are employing a variety of decision-making methods to address sustainability issues. Some researchers may be using qualitative approaches that involve expert opinions or specialized knowledge, while others may be using quantitative methods such as AHP and weight to assign priority to different criteria. In addition, the inclusion of "sensitivity analysis" suggests that researchers are considering the potential impact of uncertainties in the decision-making process.

The keywords related to "Life Cycle Assessment" such as "impact", "life cycle", "impact category", "LCC", and "environmental sustainability" suggest that researchers are interested in understanding the environmental impact of different products or processes throughout their life cycle. The use of "impact category" suggests that researchers are categorizing different types of environmental impacts, such as greenhouse gas emissions or water usage. The use of "LCC" suggests that some researchers may also be considering the economic costs associated with different life cycle stages. Finally, the presence of "environmental sustainability" indicates that researchers are concerned with the long-term environmental implications of different products or processes.

Overall, this graph suggests that there are two important and interconnected areas of research related to sustainability decision-making and LCA. By understanding the different approaches and methods used by researchers in these areas, it may be possible to identify new opportunities for interdisciplinary research that can lead to more sustainable and environmentally friendly products and processes.

### II.5.Data analysis

Data analysis is a crucial component of any research project, and is especially important when it comes to analysing large amounts of data. In this section of thesis, we will be discussing the results of analysis of a table which includes various pieces of information related to different case studies.

The table 6 contains several columns, each of which provides important data about the case studies included in the analysis. The first column is the ID of the paper, which serves as a unique identifier for each study. The second column lists the authors of each paper, providing insight into the individuals responsible for conducting the research. The third column of the table includes the year of publication for each study, which can provide valuable information about the timeline of research in a particular field. Additionally, the fourth column lists the country of the case study, which can be important in understanding how different regions may have unique challenges or opportunities related to the research topic. The fifth column of table 6 provides information about the methodologies applied in each study, specifically whether the authors utilized the Life-Cycle Assessment method, Multi-Criteria Analysis method, or both.

This can be valuable in understanding how researchers approach their work and which methods may be most effective in different scenarios.

By examining this data and applying various analytical techniques, we will be able to draw conclusions about the overall trends and themes present across the different case studies. We conducted in this section an extensive literature review, analysing a total of 133 articles. Through this table 6, we will be able to gather a vast amount of data related to the topic of interest, including a variety of case studies from around the world.

Overall, the data analysis conducted in this section provides valuable insights into the research landscape surrounding the topic of interest. By carefully examining the data and applying a rigorous analytical approach, we will be able to identify important patterns and trends that will be useful for informing future research in this area.

*Table 6: The 133 article analyzed during our study*

| ID | Authors | Year | Country | Methodologies applied | |
|---|---|---|---|---|---|
| | | | | LCSA | MCDA |
| 1 | (De Gennaro et al., 2012) | 2012 | Italy | x | |
| 2 | (Salomone & Ioppolo, 2012a) | 2012 | Italy | x | |
| 3 | (Myllyviita et al., 2012) | 2012 | Finland | x | x |
| 4 | (Chatzisymeon et al., 2013) | 2013 | Greece | x | |
| 5 | (Cossu,l'Innocenti, et al., 2013) | 2013 | Italy | x | |
| 6 | (Hjaila et al., 2013) | 2013 | Tunisia | x | |
| 7 | (Iraldo et al., 2014) | 2013 | Italy | x | |
| 8 | (Pergola et al., 2013) | 2013 | Italy | x | |
| 9 | (Rajaeifar et al., 2014) | 2014 | Iran | x | |
| 10 | (Mohamad et al., 2014) | 2014 | Italy | x | |
| 11 | (von Doderer & Kleynhans, 2014) | 2014 | South Africa | x | x |
| 12 | (De Luca et al., 2015) | 2015 | Italy | x | |
| 13 | (El Hanandeh, 2015) | 2015 | Australia | x | |
| 14 | (G. Russo et al., 2015) | 2015 | Italy | x | |
| 15 | (Tsarouhas et al., 2015) | 2015 | Greece | x | |
| 16 | (Cobuloglu & Büyüktahtakin, 2015) | 2015 | USA | | x |
| 17 | (Ren et al., 2015) | 2015 | China | x | x |
| 18 | (Riesgo & Gallego-Ayala, 2015b) | 2015 | Spain | | x |
| 19 | (Christoforou & Fokaides, 2016) | 2016 | Greece | x | |
| 20 | (El Hanandeh & Gharaibeh, 2016) | 2016 | Jordan | x | |
| 21 | (Kylili et al., 2016) | 2016 | Greece | x | |
| 22 | (Pattara et al., 2016) | 2016 | Italy | x | |
| 23 | (Rajaeifar et al., 2016) | 2016 | Iran | x | |
| 24 | (C. Russo et al., 2016) | 2016 | Italy | x | |
| 25 | ,(Egea & Pérez y Pérez, 2016) | 2016 | Spain | | x |
| 26 | (Falcone et al., 2016) | 2016 | Italy | x | x |
| 27 | (Grošelj et al., 2016) | 2016 | Slovenia | | x |
| 28 | (Arzoumanidis et al., 2017) | 2017 | Italy | x | |
| 29 | (Battista et al., 2017) | 2017 | Italy | x | |
| 30 | (Benavente et al., 2017) | 2017 | Spain | x | |
| 31 | (De Marco et al., 2017) | 2017 | Italy | x | |
| 32 | (Romero-Gámez et al., 2017) | 2017 | Spain | x | |
| 33 | (Cappelletti et al., 2017) | 2017 | Italy | | x |
| 34 | (Khishtandar et al., 2017) | 2017 | Iran | | x |
| 35 | (Angelo et al., 2017) | 2017 | brazil | x | x |
| 36 | (Milutinović et al., 2017) | 2017 | Serbia | x | x |
| 37 | (Wang et al., 2017) | 2017 | China | | x |
| 38 | (Bernardi et al., 2018) | 2018 | Italy | x | |
| 39 | (De Luca et al., 2018a) | 2018 | Italy | x | x |
| 40 | (De Luca et al., 2018b) | 2018 | Italy | x | |
| 41 | De Luca et al., 2018c | 2018 | Italy | x | x |

| | | | | | |
|---|---|---|---|---|---|
| 42 | (Parascanu et al., 2018) | 2018 | Spain | x | |
| 43 | (Dekamin et al., 2018) | 2018 | Iran | x | x |
| 44 | (Król-Badziak et al., 2021) | 2018 | Poland | | x |
| 45 | (Batuecas et al., 2019) | 2019 | Italy | x | |
| 46 | (Castellani et al., 2019) | 2019 | Italy | x | |
| 47 | (D'Adamo et al., 2019) | 2019 | Italy | x | |
| 48 | (Frascari et al., 2019) | 2019 | Italy | x | |
| 49 | (Guarino et al., 2019) | 2019 | Italy | x | |
| 50 | (Rajabi Hamedani et al., 2019) | 2019 | Italy | x | |
| 51 | (Stillitano et al., 2019a) | 2019 | Italy | x | |
| 52 | (Stillitano et al., 2019b) | 2019 | Italy | x | |
| 53 | (Tziolas & Bournaris, 2019) | 2019 | Greece | x | |
| 54 | (Deepa et al., 2019) | 2019 | India | | x |
| 55 | (Lerche et al., 2019) | 2019 | Germany | | x |
| 56 | (Miglietta et al., 2019) | 2019 | Italy | | x |
| 57 | (Nieder-Heitmann et al., 2019) | 2019 | South Africa | x | x |
| 58 | (Nikkhah et al., 2019) | 2019 | Iran | x | x |
| 59 | (Pereira et al., 2019b) | 2019 | Portugal | | x |
| 60 | (Rocchi et al., 2019) | 2019 | Italy | x | x |
| 61 | (Van Schoubroeck et al., 2019) | 2019 | Belgium | x | x |
| 62 | (Alonso-Fariñas et al., 2020) | 2020 | Italy | x | |
| 63 | (Duman et al., 2020) | 2020 | Turkey | x | |
| 64 | (Khdair & Abu-Rumman, 2020) | 2020 | Mena region[1] | x | |
| 65 | (Iofrıda et al., 2020) | 2020 | Italy | x | |
| 66 | (Maffia et al., 2020) | 2020 | Italy | x | |
| 67 | (Uceda-Rodríguez et al., 2020) | 2020 | Spain | x | |
| 68 | (Valenti et al., 2020b) | 2020 | Spain | x | |
| 69 | (Balezentis et al., 2020) | 2020 | Lithuania | | x |
| 70 | (Bartzas & Komnitsas, 2020) | 2020 | Greece | x | x |
| 71 | (Florindo et al., 2020) | 2020 | Brazil | x | x |
| 72 | (Gómez-Limón et al., 2020) | 2020 | Spain | | x |
| 73 | (Lin et al., 2020a) | 2020 | China | | x |
| 74 | (Lin et al., 2020b) | 2020 | China | x | x |
| 75 | (Y. Liu et al., 2020) | 2020 | China | x | x |
| 76 | (Mokarram et al., 2020) | 2020 | Iran | | x |
| 77 | (Puig-Gamero et al., 2020) | 2020 | Spain | | x |
| 78 | (Rediske et al., 2020) | 2020 | Brazil | | x |
| 79 | (Ren et al., 2020) | 2020 | china | x | x |
| 80 | (Rodríguez Sousa et al., 2020) | 2020 | Spain | | x |
| 81 | (Zhou et al., 2020) | 2020 | China | x | x |

[1] "Mena region" stands for Middle East and North Africa. It includes countries from western Asia to northern Africa, sharing cultural and economic ties. Commonly used in discussions about politics and economics.

| | | | | | |
|---|---|---|---|---|---|
| 82 | (Ben Abdallah et al., 2021) | 2021 | Tunisia | x | |
| 83 | (Benalia et al., 2021) | 2021 | Italy | x | |
| 84 | (Bernardi et al., 2021) | 2021 | Italy | x | |
| 85 | (Espadas-Aldana et al., 2021) | 2021 | France | x | |
| 86 | (Fernández-Lobato et al., 2021) | 2021 | Spain | x | |
| 87 | (Fotia et al., 2021) | 2021 | Greece | x | |
| 88 | (Khounani et al., 2021) | 2021 | Iran | x | |
| 89 | (López-garcía et al., 2021) | 2021 | Spain | x | |
| 90 | (Maesano et al., 2021) | 2021 | Italy | x | |
| 91 | (Puig-Gamero et al., 2021) | 2021 | Spain | x | |
| 92 | (Erses Yay et al., 2021) | 2021 | Turkey | x | |
| 93 | (Abdel-Basset, Gamal, & ELkomy, 2021) | 2021 | Egypt | | x |
| 94 | (Abdel-Basset, Gamal, Chakrabortty, et al., 2021) | 2021 | Egypt | | x |
| 95 | (Büyüközkan et al., 2021) | 2021 | Turkey | | x |
| 96 | (Duan et al., 2021) | 2021 | Australia | | x |
| 97 | (Fernández-Tirado et al., 2021) | 2021 | Spain | x | x |
| 98 | (Firouzi et al., 2021) | 2021 | Iran | | x |
| 99 | (García-Cascales et al., 2021) | 2021 | Spain | | x |
| 100 | (Issaoui et al., 2021) | 2021 | Tunisia | | x |
| 101 | (Jellali et al., 2021) | 2021 | Tunisia | | x |
| 102 | (Król-Badziak et al., 2021) | 2021 | Poland | x | x |
| 103 | (Lim et al., 2021) | 2021 | Malaysia | x | x |
| 104 | (Noori et al., 2021) | 2021 | Iran | | x |
| 105 | (Saraswat & Digalwar, 2021) | 2021 | India | | x |
| 106 | (John & Naharudin, 2022) | 2022 | Malaysia | | x |
| 107 | (Ilieva & Yankova, 2022) | 2022 | Bulgaria | | x |
| 108 | (Bathrinath et al., 2022) | 2022 | India | | x |
| 109 | (Zhao et al., 2022) | 2022 | China | | x |
| 110 | (M. Liu et al., 2022) | 2022 | China | x | x |
| 111 | (Emeksiz & Yüksel, 2022) | 2022 | Turkey | | x |
| 112 | (Mobarak et al., 2022) | 2022 | Saudi Arabia | | x |
| 113 | (Juanpera et al., 2022) | 2022 | Spain | | x |
| 114 | (Hagos et al., 2022) | 2022 | Ethiopia | | x |
| 115 | (Ghosh et al., 2022) | 2022 | India | | x |
| 116 | (Rahmani et al., 2022) | 2022 | Iran | x | |
| 117 | (Cunha et al., 2022) | 2022 | Portugal | | x |
| 118 | (Shadeed et al., 2022) | 2022 | Palestine | | x |
| 119 | (Illankoon et al., 2023) | 2022 | Sri Lanka | | x |
| 120 | (Ramesh et al., 2022) | 2022 | India | x | x |
| 121 | (Iqbal et al., 2022) | 2022 | Pakistan | | x |
| 122 | (Parra-López et al., 2022) | 2022 | Spain | | x |
| 123 | (Rahmani et al., 2022) | 2022 | Afghanistan | | x |
| 124 | (Ramos & Ferreira, 2022) | 2022 | Portugal | x | |

| | | | | | |
|---|---|---|---|---|---|
| 125 | (Volkov et al., 2022) | 2022 | Lithuania | | x |
| 126 | (Dolores Mainar-Toledo et al., 2022) | 2022 | Spain | | x |
| 127 | (Heidari et al., 2022) | 2022 | Iran | x | x |
| 128 | (Nedeljković, 2022) | 2022 | Republika Srpska | | x |
| 129 | (Barbosa Junior et al., 2022) | 2022 | Brazil | | x |
| 130 | (Scuderi et al., 2022) | 2022 | Italy | | x |
| 131 | (Thakur et al., 2022) | 2022 | Italy | | x |
| 132 | (Puška et al., 2022) | 2022 | Italy | | x |
| 133 | (Ben Abdallah et al., 2022) | 2022 | Tunisia | x | x |

The output of the table revealed that out of the 133 articles analyzed, 56 studies utilized the Life-Cycle Assessment method, 51 studies utilized the Multi-Criteria Analysis method, and 26 studies combined both methods in their analysis (See Figure18).

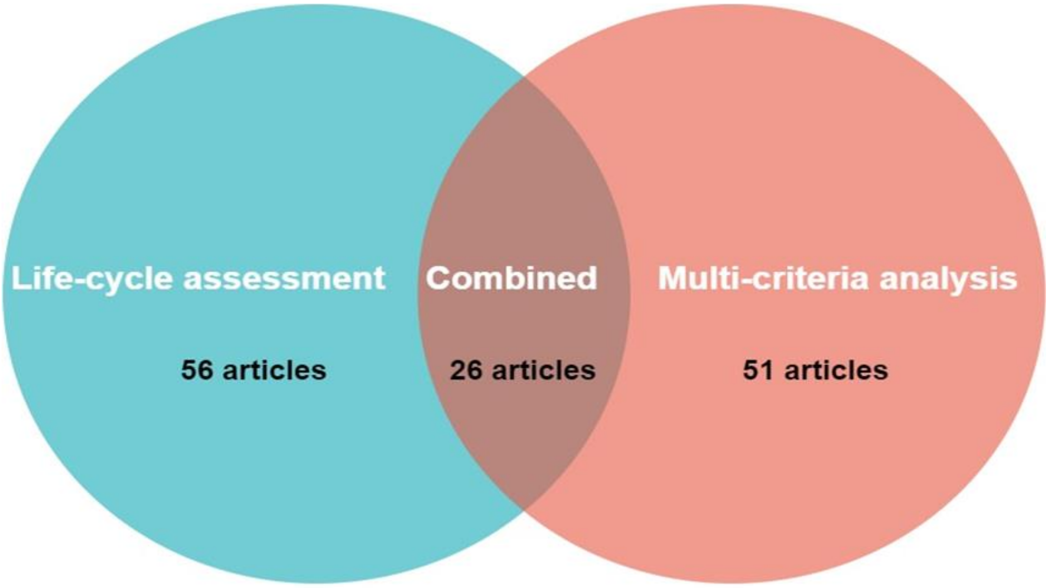


*Figure 18: Distribution of articles*

The high number of studies utilizing the Life-Cycle Assessment method suggests that this approach is widely accepted and commonly used in research related to the topic of interest. Also, the large number of studies using the MCDA method also highlights the importance of this approach in conducting comprehensive analyses of complex systems.

The 26 studies that combined both methods indicate a growing trend towards using multiple analytical approaches to gain a more complete understanding of the research topic. This approach can be particularly useful when dealing with complex systems or when attempting to identify the most effective strategies for addressing specific challenges. Overall, the output of the table provides valuable insights into the different approaches and methodologies utilized by researchers in different agriculture field. By identifying the prevalence of different methods and analyzing the case studies used in each, it is possible to gain a better understanding of the strengths and weaknesses of each approach and to identify areas where future research may be needed.

The upcoming sections will focus on three important topics in sustainable agriculture: Agricultural life cycle sustainability, MCDA tools, and the integration of these two approaches. Firstly, we will explore the concept of Agricultural life cycle sustainability (II.5.1) which involves analyzing the entire life cycle of agricultural products. Next, we will discuss MCDA tools (II.5.2), which provide a structured approach to decision-making, allowing us to consider multiple factors and criteria when evaluating different options in the agricultural sector. Finally, we will examine how the integration of these two approaches can provide a comprehensive framework for sustainable decision-making in agriculture (II.5.3).

### II.5.1. Agricultural life cycle sustainability

Agricultural sustainability has become a critical concern in recent years, as the world faces increasing challenges related to climate change, resource depletion, and food security. In response to these challenges, the concept of LCSA has emerged as a valuable tool for evaluating the environmental, social, and economic impacts of agricultural production systems throughout their entire life cycle. It should be noted that we found 58 articles whose objective focuses on studying the life cycle analysis of olive oil. This indicates a growing interest in understanding the environmental impacts of olive oil production and consumption, as well as identifying opportunities for improving sustainability across the entire supply chain. The fact that so many studies exist on this topic suggests that there are complex environmental issues associated with olive oil production that require attention.

Subsequently, the 58 article reviewed in this section aims to explore the criteria and alternatives used in olive oil LCSA, in order to identify the most significant factors and potential gaps in the existing research. The first subtopic of this section focuses on the criteria used in olive oil life cycle, which can vary widely depending on the specific goals and scope of the assessment. Through analyzing the existing literature, this review seeks to identify the most commonly used criteria and assess their relevance and significance in different contexts.

The second subtopic of this section focuses on the alternatives evaluated in olive oil life cycle, including different production systems, technologies, and management practices. By examining the available literature, this review aims to identify the most commonly evaluated alternatives and assess their relative sustainability performance.

Overall, the objective of this section is to provide a comprehensive understanding of the criteria and alternatives used in olive oil life cycle, in order to identify the most significant factors and potential gaps in the existing literature. The findings of this review will help to inform future research and policy decisions aimed at promoting sustainable agricultural practices.

#### *II.5.1.1. Criteria*

To gain a comprehensive understanding of the impact of product life cycles, an analysis of 58 articles was conducted. Each of these articles contained valuable information about the product life cycle phases, criteria used, country of origin, and the goals and scope of the study. To synthesize the information from these articles, a table 7 was created that included all-encompassing pertinent pieces of information.

- The ID of the article is a unique identifier that distinguishes it from other studies. The reference of the article refers to the source material that was used in the study.
- The study used three phases: agriculture, production, and waste management. These phases are critical components of the product life cycle and were likely examined to determine the impact of each phase on the environment, economy, and society.
- The country in which the study was conducted is an important factor in understanding the applicability of the study results. Different countries have different regulations, policies, and social norms that can affect the impact of the product life cycle.
- The goal and scope of the article refer to the overall purpose of the study and the boundaries within which the study was conducted. The goal may have been to evaluate the environmental, economic, and social impact of a specific product or process, while the scope may have defined the system boundaries, functional unit, and time frame of the study.
- Finally, the criteria used in the article refer to the specific methods and metrics used to evaluate the impact of the product life cycle. LCA evaluates the environmental impact of the product, LCC assessment evaluates the economic impact, and S-LCA evaluates the social impact. These criteria may have been used individually or in combination to provide a comprehensive evaluation of the product life cycle.

The table provides a valuable tool for policymakers, businesses, and individuals who are interested in understanding the impact of product life cycles. By synthesizing the information from multiple studies, the table provides a more comprehensive and holistic view of the impact of products and processes. This can help inform decision-making and guide the development of more sustainable practices and policies.

*Table 7: Criteria used during the 58 articles*

| ID | Reference | Phases: | | | Country | Goal and Scope | Criteria |
|---|---|---|---|---|---|---|---|
| | | Phase 1 | Phase 2 | Phase 3 | | | |
| 1 | De Gennaro et al., 2012 | x | | | Italy | Innovative olive-growing models | LCA, LCC |
| 2 | Salomone and Ioppolo, 2012 | x | x | x | Italy | Improvement and optimization of the olive oil production chain | LCA, LCC, S-LCA |
| 4 | Chatzisymeon et al., 2013 | | | x | Greece | olive mill wastewater treatment | LCA |
| 5 | Cossu et al., 2013 | | | x | Italy | Valorisation of waste generated from the olive oil industry | LCA |
| 6 | Hjaila et al., 2013 | | | x | Tunisia | Activated carbon production process from olive-waste cakes | LCA |
| 7 | Iraldo et al., 2013 | x | | | Italy | Optimization of olive practices | LCA |
| 8 | Pergola et al., 2013 | x | | | Italy | Alternative management for olive orchards grown | LCA, LCC |
| 9 | Ali Rajaeifar et al., 2014 | x | x | x | Iran | Olive oil production | LCA, LCC |
| 10 | Mohamad et al., 2014 | x | | | Italy | Optimization of olive agriculture practices | LCA, LCC |
| 12 | De Luca et al., 2015 | x | | | Italy | Innovative agricultural systems | LCA, LCC, S-LCA |
| 13 | El Hanandeh, 2015 | | | x | Australia | Valorisation of waste generated from the olive oil industry | LCA |
| 14 | Russo et al., 2015 | x | | x | Italy | Sustainability of different soil management techniques in olive orchard | LCA |
| 15 | Tsarouhas et al., 2015 | x | | | Greece | Olive oil production | LCA |
| 19 | Christoforou and Fokaides, 2016 | | | x | Greece | Olive husk valorisation | LCA |
| 20 | El Hanandeh and Gharaibeh, 2016 | x | | | Jordan | Olive oil production chain | LCA |
| 21 | Kylili et al., 2016 | | | x | Greece | Environmental evaluation of biomass pelleting | LCA |
| 22 | Pattara et al., 2016 | x | x | | Italy | Olive oil production chain | LCA |
| 23 | Rajaeifar et al., 2016 | | | x | Iran | olive pomace oil biodiesel production and consumption | LCA |
| 24 | Russo et al., 2016 | x | | | Italy | Comparison of European Olive agriculture practices Systems | LCA |
| 28 | Arzoumanidis et al., 2017 | x | x | x | Italy | Olive oil production chain | LCA |
| 29 | Battista et al., 2017 | x | x | x | Italy | Management of wastes generated from the extra virgin olive oil production | LCA |
| 30 | Benavente et al., 2017 | | | x | Spain | Hydrothermal carbonization of olive mill waste | LCA |
| 31 | De Marco et al., 2017 | | | x | Italy | Olive pomace processing | LCA |
| 32 | Romero-Gamez et al., 2017 | x | | | Spain | Optimization of olive growing practices | LCA |
| 38 | Bernardi et al., 2018 | x | | | Italy | Harvesting machines | LCA, LCC |
| 40 | De Luca et al., 2018b | x | | | Spain | Olive Oil Processing Innovations | LCA, LCC |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 42 | Parascanu et al., 2018 | | | x | Spain | Olive pomace valorisation through two different thermochemical processes | LCA |
| 45 | Batuecas et al., 2019 | | | x | Italy | Waste disposal from olive oil production | LCA |
| 46 | Castellani et al., 2019 | | | x | Italy | Composting of olive mill waste | LCA |
| 47 | D’Adamo et al., 2019 | | | x | Italy | A Social Analysis of the Olive Oil Sector with the development of CE | S-LCA |
| 48 | Frascari et al., 2019 | | | x | Italy | Valorisation of olive mill wastewater | LCA, LCC |
| 49 | Guarino et al., 2019 | x | | | Italy | Olive oil production chain | LCA |
| 50 | Hamedani et al., 2019 | | | x | Italy | Pellet production from olive woody biomass | LCA |
| 51 | Stillitano et al., 2019a | | x | | Italy | Innovative Technologies in Extra Virgin Olive Oil Extraction | LCA, LCC |
| 52 | Stillitano et al., 2019b | | x | | Italy | Innovative technologies of olive extraction | LCA, LCC |
| 53 | Tziolas et al., 2019 | x | | | Greece | Implications of Innovative agricultural practices | LCA, LCC |
| 62 | Alonso-Fariñas et al., 2020 | | | x | Italy | Olive mill solid waste Valorisation | LCA |
| 63 | Duman et al., 2020 | | | x | Turkey | Olive pomace valorisation | LCA |
| 64 | Khdair and Abu-Rumman, 2020 | | x | x | MENA | Valorisation of Olive Mill By products | LCA |
| 65 | Lofrida et al., 2020 | x | | x | Italy | Impacts of organic | LCC, S-LCA |
| 66 | Maffia et al., 2020 | x | | | Italy | Comparison between Organic and Integrated Olive-Oil Systems | LCA |
| 67 | Uceda-Rodríguez et al., 2020 | | | x | Spain | Olive Pomace valorisation | LCA |
| 68 | Valenti et al., 2020 | | | x | Spain | Agro-industrial by-product reuse | LCA |
| 82 | Ben Abdallah et al., 2021 | x | | | Tunisia | Environmental sustainability in olive growing | LCA |
| 83 | Benalia et al., 2021 | | | x | Italy | Olive Mill Wastewater recovery | LCA, LCC |
| 84 | Bernardi et al., 2021 | x | | | Italy | Harvesting mechanization | LCA, LCC |
| 85 | Espadas-Aldana et al., 2021 | | | x | France | Olive Pomace valorisation | LCA |
| 86 | Fernandez-Lobato et al., 2021 | x | x | x | Spain | Olive oil production chain | LCA |
| 87 | Fotia et al., 2021 | x | | | Greece | Comparison between the different strategies of olive cultivation | LCA |
| 88 | Khounani et al., 2021 | | | x | Iran | The different biorefinery platforms | LCA |
| 89 | López-García et al., 2021 | | | x | Spain | Ceramic brick manufacturing process incorporating olive pomace | LCA |
| 90 | Maesano et al., 2021 | x | | | Italy | Olive oil production chain | LCA, LCC |
| 91 | Puig-Gamero et al., 2021 | | | x | Spain | Methanol from olive pomace | LCA |
| 92 | Yay et al., 2021 | | | x | Turkey | Hydrothermal carbonization of olive pomace | LCA |
| 116 | Rahmani et al., 2022 | x | | | Iran | Comparison between the different methods of olive production | LCA |
| 124 | Ramos et al., 2022 | | | x | Portugal | Olive co-products valorisation | LCA, LCC |

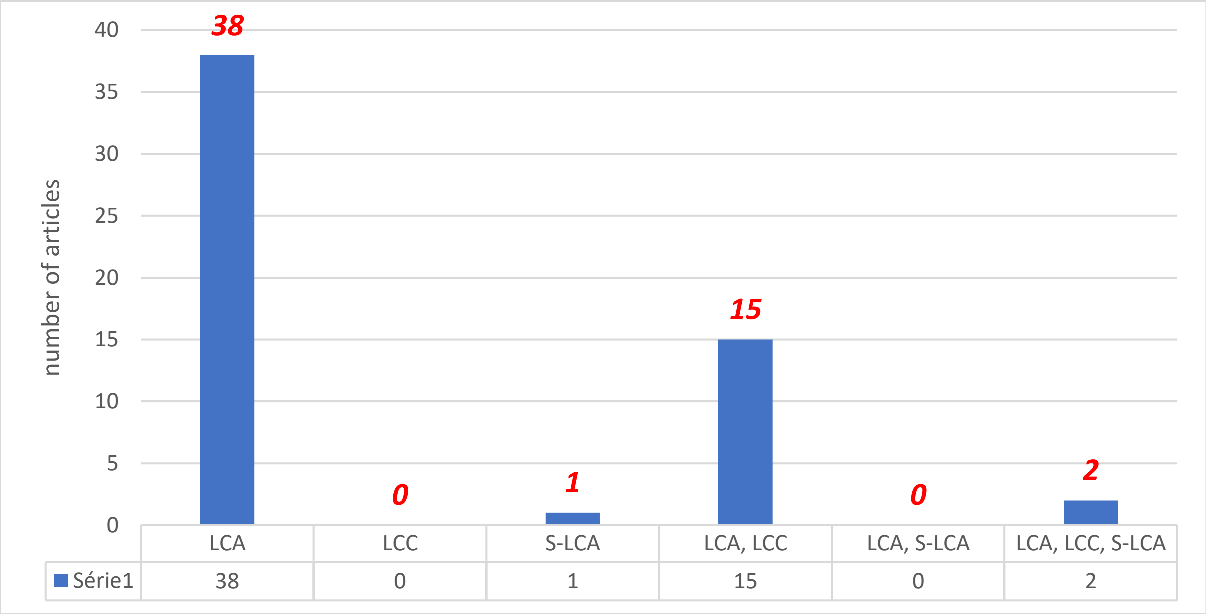


*Figure 19: Criteria used during the 58 article*

Our literature review revealed that among the articles that assess Life Cycle Sustainability (See Figure 19), 38 studies used criteria based on LCA methodology. This is not unexpected since LCA is a well-established methodology that evaluates the environmental impacts of products, processes, and services throughout their life cycle. However, it was notable that none of the articles used criteria based on LCC, evaluates the costs associated with a product or service over its entire life cycle. Incorporating LCC criteria is important to ensure the long-term economic viability of a product or service.

Additionally, only one article out of the total used S-LCA criteria evaluates the social impacts of a product or service throughout its life cycle. S-LCA criteria are important to ensure that products and services are socially responsible and sustainable. Interestingly, our review found that 15 articles combined LCA and LCC criteria, indicating a positive trend towards more comprehensive sustainability assessments. Furthermore, two articles combined LCA, LCC, and S-LCA criteria, which represents an even more comprehensive approach to sustainability assessment.

In summary, while LCA remains the most commonly used methodology in LCSA, there is a need to incorporate LCC and S-LCA criteria to provide a more comprehensive picture of sustainability. Incorporating these criteria will enable decision-makers to make informed choices that support sustainable development.

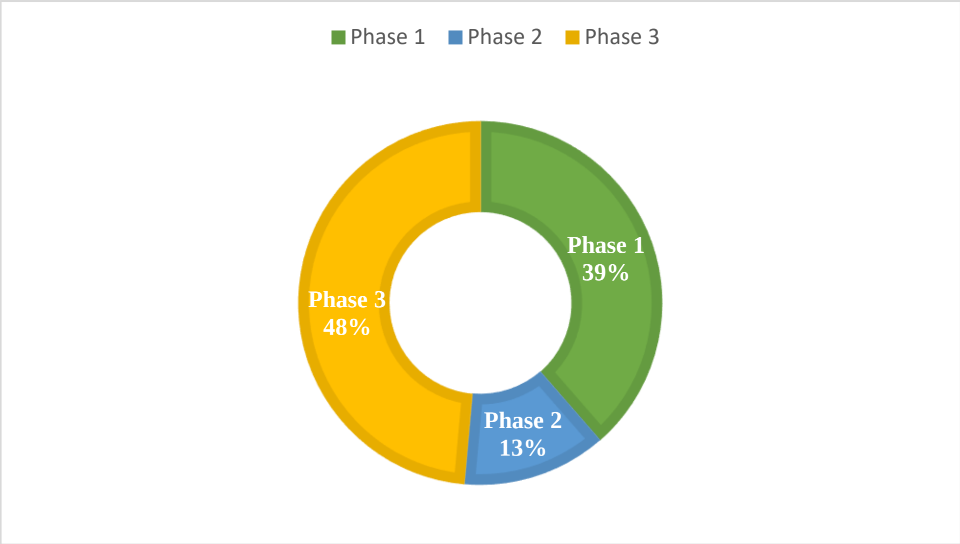


*Figure 20: The different phases used during the 58 articles*

The literature review revealed that there is a variation in the rate of use of different phases in LCSA (See Figure 20). Phase 1, which includes the alternative used to assess different agricultural practices, was the second most frequently assessed phase, with a rate of 39%. This is likely because agriculture is one of the most important sectors contributing to environmental impacts and social challenges.

Phase 2, which includes the criteria used to assess the different extraction systems used, was the least frequently assessed phase, with a rate of 13%. This phase is important to assess as it enables a more comprehensive understanding of the sustainability of products and services.

The most frequently assessed phase was phase 3, with a rate of 48%. This phase includes the alternative used to assess the different valorisation waste used in the literature. Waste management is a critical issue in achieving sustainability, and thus, it is promising to see that phase 3 is frequently assessed.

However, more attention should be paid to the assessment of phase 2 criteria to ensure a more comprehensive sustainability assessment of products.

#### *II.5.1.2. Alternatives*

In addition to the table summarizing the information from the 58 articles, there is another table that focuses on the different phases and processes involved in product life cycles. This table includes the ID of the article and the three phases: agriculture phase, production phase, and waste management phase.

In the agriculture phase, there are several processes that were identified as important components of the product life cycle. These processes include agricultural practices, irrigation, soil management, pruning, harvesting, fertilization, pesticides, and herbicides. Each of these processes has the potential to impact the environment, economy, and society in different ways, and studying their impact is critical to developing more sustainable practices (Salomone & Ioppolo, 2012a).

The production phase involves several different systems, including traditional systems, 2-phase systems, and 3-phase systems. These systems represent different methods of processing the raw materials and producing the final product. Each system has its own advantages and disadvantages in terms of environmental impact, cost, and efficiency (Duman et al., 2020).

Finally, the waste management phase includes several processes for treating different types of waste. These processes include treatment of pomace, treatment of wet pomace, treatment of waste water from the mills, and treatment of size residues. Each of these processes is important for reducing the environmental impact of the product life cycle and ensuring that waste is handled in a responsible and sustainable manner(Alonso-Fariñas et al., 2020). Additionally, applying the principles of CE to this waste management process can further reduce environmental impacts and help to valorise waste. By using CE practices, waste can be transformed into valuable resources, such as energy or raw materials, rather than being discarded as useless. This not only helps to reduce environmental harm, but also creates economic and social benefits by promoting resource efficiency and reducing waste (Keskes, Zouari, Lehyani, et al., 2022).

Table 8 serves as a valuable resource for gaining a better understanding of the various phases and processes that make up the product life cycle. With this knowledge, policymakers, businesses, and individuals can work collaboratively to develop sustainable practices and mitigate the negative impact that product life cycles can have on the environment, economy, and society. By identifying the areas in which these cycles can be improved, such as reducing waste and increasing efficiency, stakeholders can take actionable steps towards building a more sustainable future. Through the implementation of these sustainable practices, we can work towards developing a more resilient and equitable society that balances the needs of the present with those of future generations.

*Table 8: Different alternatives used during the literature review*

| Phases: | | Agricultural Phase | | | | | | | Production Phase | | | Waste Management Phase | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Life cycle of olive oil production. | | Agricultural Practices | Irrigation | Soil Management | Pruning | Harvest | Fertilization | Pesticides and Herbicides | Traditional System | 2-Phase System | 3-Phase System | Pomace Treatment | Wet Pomace Treatment | Mill Wastewater Treatment | Pruning Residue Treatment |
| **ID** | **Reference** | | | | | | | | | | | | | | |
| **1** | **De Gennaro et al., 2012** | x | x | x | x | x | x | x | | | | | | | |
| **2** | **Salomone and Ioppolo, 2012** | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| **4** | **Chatzisymeon et al., 2013** | | | | | | | | | | | x | | x | |
| **5** | **Cossu et al., 2013** | | | | | | | | | | | | x | x | |
| **6** | **Hjaila et al., 2013** | | | | | | | | | | | x | | x | |
| **7** | **Iraldo et al., 2013** | | x | x | x | x | x | x | | | | | | | |
| **8** | **Pergola et al., 2013** | x | x | x | x | x | x | x | | | | | | | |
| **9** | **Ali Rajaeifar et al., 2014** | | x | x | x | x | x | x | x | | | | | | |
| **10** | **Mohamad et al., 2014** | x | x | x | x | x | x | x | | | | | | | |
| **12** | **De Luca et al., 2015** | x | x | x | x | x | x | x | | | | | | | |
| **13** | **El Hanandeh, 2015** | | | | | | | | | | | | x | x | |
| **14** | **Russo et al., 2015** | | | x | | | x | | | | | x | | x | |
| **15** | **Tsarouhas et al., 2015** | x | x | x | x | x | x | x | | | | | | | |
| **19** | **Christoforou and Fokaides, 2016** | | | | | | | | | | | x | | | |
| **20** | **El Hanandeh and Gharaibeh, 2016** | x | x | x | x | x | x | x | | | | | | | |
| **21** | **Kylili et al., 2016** | | | | | | | | | | | x | | | |
| **22** | **Pattara et al., 2016** | | x | x | x | x | x | x | x | x | x | | x | | |
| **23** | **Rajaeifar et al., 2016** | | | | | | | | | | | x | | | |
| **24** | **Russo et al., 2016** | x | x | x | x | x | x | x | | | | | | | |
| **28** | **Arzoumanidis et al., 2017** | | x | x | x | x | x | x | | x | | | x | x | |
| **29** | **Battista et al., 2017** | | x | x | x | x | x | x | | | x | | x | x | |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **30** | **Benavente et al., 2017** | | | | | | | | | | | x | | x | |
| **31** | **De Marco et al., 2017** | | | | | | | | | | | x | | | |
| **32** | **Romero-Gamez et al., 2017** | x | x | x | x | x | x | x | | | | | | | |
| **38** | **Bernardi et al., 2018** | | | | | x | | | | | | | | | |
| **40** | **De Luca et al., 2018b** | x | x | x | x | x | x | x | | | | | | | |
| **42** | **Parascanu et al., 2018** | | | | | | | | | | | x | | | |
| **45** | **Batuecas et al., 2019** | | | | | | | | | | | | x | x | |
| **46** | **Castellani et al., 2019** | | | | | | | | | | | x | | x | |
| **47** | **D'Adamo et al., 2019** | | | | | | | | | | | x | | x | |
| **48** | **Frascari et al., 2019** | | | | | | | | | | | x | | x | |
| **49** | **Guarino et al., 2019** | x | x | x | x | x | x | x | | | | | | | |
| **50** | **Hamedani et al., 2019** | | | | | | | | | | | | | | x |
| **51** | **Stillitano et al., 2019a** | | | | | | | | | x | | | | | |
| **52** | **Stillitano et al., 2019b** | | | | | | | | | x | x | | | | |
| **53** | **Tziolas et al., 2019** | x | x | x | x | x | x | x | | | | | | | |
| **62** | **Alonso-Fariñas et al., 2020** | | | | | | | | | | | x | | x | |
| **63** | **Duman et al., 2020** | | | | | | | | x | x | x | x | x | x | |
| **64** | **Khdair and Abu-Rumman, 2020** | | | | | | | | x | x | x | x | x | x | |
| **65** | **lofrida et al., 2020** | x | x | x | x | x | x | x | | | | | x | | |
| **66** | **Maffia et al., 2020** | x | x | x | x | x | x | x | | | | | | | |
| **67** | **Uceda-Rodríguez et al., 2020** | | | | | | | | | | | x | | | |
| **68** | **Valenti et al., 2020** | | | | | | | | | | | x | | x | x |
| **82** | **Ben Abdallah et al., 2021** | x | x | x | x | x | x | x | | | | | | | |
| **83** | **Benalia et al., 2021** | | | | | | | | | | | x | | x | |
| **84** | **Bernardi et al., 2021** | x | x | x | x | x | x | x | | | | | | | |
| **85** | **Espadas-Aldana et al., 2021** | | | | | | | | | | | | x | | |
| **86** | **Fernandez-Lobato et al., 2021** | | x | x | x | x | x | x | | x | | x | | x | |
| **87** | **Fotia et al., 2021** | x | x | x | x | x | x | x | | | | | | | |
| **88** | **Khounani et al., 2021** | | | | | | | | | | | x | | x | |
| **89** | **López-García et al., 2021** | | | | | | | | | | | x | | | |
| **90** | **Maesano et al., 2021** | x | x | x | x | x | x | x | | | | | | | |
| **91** | **Puig-Gamero et al., 2021** | | | | | | | | | | | x | | | |
| **92** | **Yay  et al., 2021** | | | | | | | | | | | x | | | |
| **116** | **Rahmani et al., 2022** | x | x | x | x | x | x | x | | | | | | | |
| **124** | **Ramos et al., 2022** | | | | | | | | | | | x | | x | x |

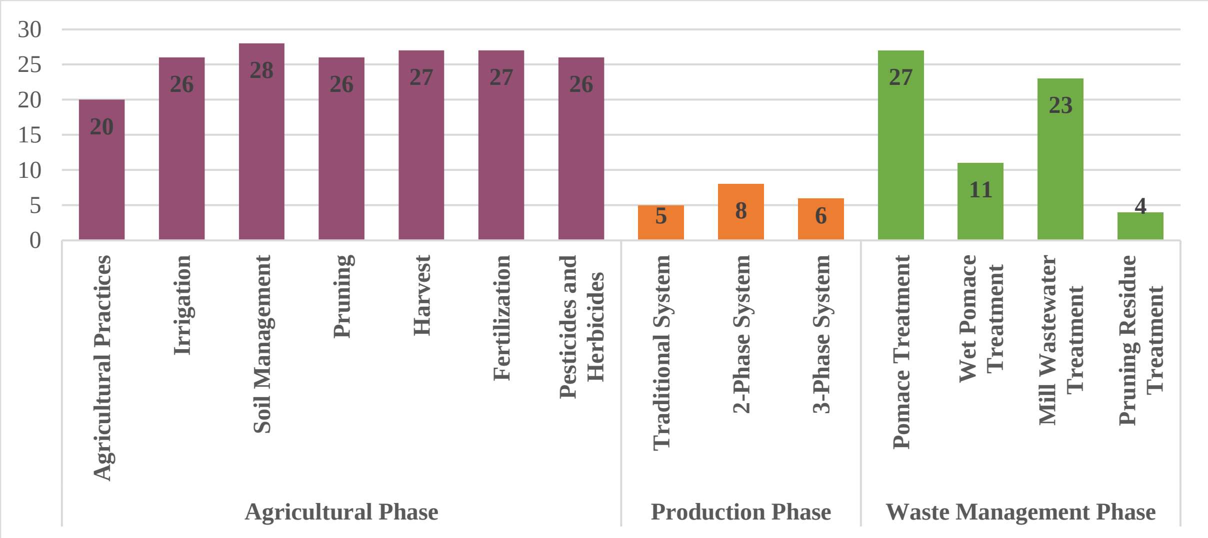


*Figure 21:The outputs of the different alternative used in the literature review*

The literature review highlighted that the literature on agriculture products, particularly olive oil, focused on three main phases: the agricultural phase, extraction phase, and waste management phase. However, it was found that these phases received varying levels of attention in the literature (refer to Figure 21). For the agricultural phase, the problematic related to soil management was the most frequently assessed, with a rate of 28 articles. The other sub-phases that received considerable attention in the literature were irrigation, pruning, harvesting, fertilization, pesticides, and herbicides, with rates ranging from 26 to 27 articles.

For the extraction phase, the most frequently assessed sub-phase was the 2-phase extraction system, with a rate of 8 articles. This finding is not surprising, as several authors have cited the 2-phase extraction system as the most sustainable method for olive oil extraction. This extraction system involves using a decanter to separate the olive paste into oil and pomace without adding any water, thus reducing the amount of waste generated and minimizing the use of water resources. Additionally, this system requires less energy and generates fewer greenhouse gas emissions than other extraction methods, making it a more environmentally-friendly option. Overall, the 2-phase extraction system is a popular choice among sustainable olive oil producers due to its numerous benefits for both the environment and the bottom line. The other sub-phases that received attention in the literature were the 3-phase extraction system and traditional extraction system, with rates ranging from 5 to 6 articles.

For the waste management phase, the most frequently assessed sub-phase was the pomace valorisation problem, with a rate of 27 articles. The other sub-phases that received attention in the literature were the Mill Wastewater valorisation problem and the Wet pomace valorisation problem, with rates of 23 and 11 articles, respectively. The size residues valorisation problem was the least frequently assessed, with only 4 articles.  It should be noted that the integration of all three phases of the LCA for agriculture, along with their respective sub-phases, is a complex and challenging task. A literature review revealed that only one study by Salomone and Ioppolo (2012) was found to have integrated all phases and sub-phases of the LCA for agriculture. This study is therefore an important contribution to the field, highlighting the need for further research and integration of all phases and sub-phases of LCA to provide a more holistic understanding of the sustainability of agriculture. It should be noted that the study only considers environmental impacts. Therefore, the study results are limited in their ability to provide a definitive solution as the findings can be contradictory and difficult to interpret. To address this limitation, it may be beneficial to integrate MCDA methods in future studies to enable a more holistic and comprehensive assessment that includes economic and social aspects in addition to environmental impacts.

These findings suggest that there is a need for further attention to be paid to the less frequently assessed sub-phases to achieve a comprehensive sustainability assessment of agricultural products.

### II.5.2. Multi-criteria decision making tools

To gain a deeper understanding of the MCDA tools used in promoting sustainable product life cycles, a table was developed to analyse the different configurations of these tools. The table includes the ID of the article, the authors, and the criteria used in the article, which includes environmental, social, and economic considerations. Additionally, the table provides information on whether a group of decision-makers was involved in the article, and whether the data used in the study included interval data or linguistic variables. It also includes details on the weighting and ranking methods used in the articles, as well as whether sensitivity and robustness analyses were performed. By examining the different configurations of MCDA tools used in the articles, stakeholders can gain valuable insights into the most effective ways to promote sustainability in product life cycles. This information is especially important for policymakers who is seeking to make informed decisions that balance environmental, social, and economic considerations. Overall, table 9 is a valuable resource for researchers and practitioners in the field of sustainable product life cycles. By identifying the most effective decision-making tools and techniques, we can work towards creating more sustainable and equitable product life cycles that benefit of our planet.

*Table 9: The multi-criteria decision making tools*

| ID | Authors | Criteria | | | Group decision | Interval | Linguistic variables | Weighting method | Ranking method | Sensitivity analysis | Robustness analysis |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Env | Eco | Soc | | | | | | | |
| **16** | Cobuloglu and Büyüktahtakın, 2015 | x | x | x | x | | x | AHP | AHP | Weight variations | - |
| **18** | Riesgo et al., 2015 | x | x | x | x | | | AHP | TOPSIS | - | - |
| **25** | Egeaa and Pérez, 2016 | x | x | x | x | | | - | ANP | - | - |
| **27** | Grošelj et al., 2016 | x | x | x | x | | x | AHP | ANP | | fuzzy TOPSIS |
| **33** | Cappelletti et al., 2017 | x | x | x | x | | x | Weighted Sum Model | TOPSIS | Different combinations of Dms and Criteria | - |
| **34** | Khishtandar et al., 2017 | x | x | x | x | x | x | Holistic approach weights | HFLTS | Weight variations | - |
| **37** | Wang et al., 2017 | x | x | x | | x | x | Best-Worst Method | TOPSIS | Weight variations | - |
| **44** | Król et al., 2018 | x | x | x | | | | AHP | PROMETHEE | - | - |
| **54** | Deepa et al., 2019 | x | | | x | | | simple additive weight (SAW) | VTOPES | - | Yield Ranks GRA ranks |
| **55** | Lerche et al., 2019 | x | x | x | | | x | AHP | PROMETHEE | - | - |
| **56** | Miglietta et al., 2019 | x | x | | x | | | AHP | ELECTRE III | Varying the parameters | - |
| **60** | Rocchi et al., 2019 | x | x | x | x | | | PROMETHEE | PROMETHEE I & II | Weight variations | |
| **69** | Balezentis et al., 2020 | x | x | | | | | Simple Additive Weighting) | TOPSIS | Weight variations | EDAS |
| **72** | Gómez-Limón et al., 2020 | x | x | x | x | | | BWM AHP | BWM AHP | - | - |
| **73** | R.Lin et al., 2020a | x | x | x | | x | | AHP | Goal programming interval GRA | Weight variations | TOPSIS |
| **76** | Mokarram et al., 2020 | | x | | | | x | AHP | ANP | - | - |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **77** | Puig-Gamero et al., 2020 | x | x | | | | | AHP | AHP | Weight variations | |
| **78** | Rediske et al., 2020 | x | | | | | | AHP | TOPSIS | - | Multi-Attribute Utility Theory |
| **80** | Sousa et al., 2020 | x | x | x | | | | AHP | AHP | Weight variations | - |
| **93** | Abdel-Basset et al., 2021 | x | x | x | x | | x | DEMATEL | EDAS method | Weight variations | Step-wise Weight Assessment Ratio Analysis, COmplex PRoportional Assessment |
| **94** | Abdel-Basset et al., 2021b | x | x | x | x | x | | Neutrosophic DEMATEL | Neutrosophic vikor | Weight variations | AHP-TOPSIS |
| **95** | Büyükozkan et al., 2021 | x | x | x | x | | x | Pythagorean Fuzzy Choquet Integral | Pythagorean Fuzzy Choquet Integral | - | TOPSIS-MABAC-AHP-ELECTRE |
| **96** | Duan et al., 2021 | x | x | x | x | | x | AHP | AHP | - | - |
| **98** | Firouzi et al., 2021 | x | | | x | | | Weighted Aggregates SumProduct Assessmen | TOPSIS | - | - |
| **99** | García-Cascales et al., 2021 | x | x | x | x | | | AHP | TOPSIS-VIKOR | - | - |
| **100** | Issaoui et al., 2021 | x | x | | x | | x | AHP | AHP | - | - |
| **101** | Jellali et al., 2021 | x | x | x | x | | x | TOPSIS | TOPSIS | - | - |
| **104** | Noori et al., 2021 | x | | | x | | x | Weighted Sum Model | ELECTRE III | Weight variations | Fuzzy TOPSIS Fuzzy AHP |
| **105** | Saraswat et al., 2021 | x | x | x | | | x | Shan's entropy method | Fuzzy AHP | Weight variations | TOPSIS-VIKOR PROMETHEE II-WSM- WPM-WASPAS |
| **106** | John and Naharudin, 2022 | x | x | x | | | x | AHP | GIS | - | - |
| **107** | Ilieva and Yankova, 2022 | X | | | | | x | Fuzzy values | NEW MABAC | | Meets the customers' preferences |
| **108** | Bathrinath et al., 2022 | x | x | x | x | | | AHP | Delphi | - | BWM |
| **109** | Zhao et al., 2022 | x | x | x | | | x | SAW | Fuzzy TOPSIS | Weight variations | TOPSIS, and ELECTRE |
| **111** | Emeksiz et al., 2022 | x | x | x | | | | Entropy method + Multi Attribute Utility Theory | Multi Attribute Utility Theory | - | - |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **112** | Mobarak et al., 2022 | x | | | | | x | AHP | GIS | - | - |
| **113** | Juanpera et al., 2022 | x | x | x | | x | x | Aggregating all experts' opinions | Fuzzy distances | Weight variations | - |
| **114** | Hagos et al., 2022 | x | x | x | | | x | AHP | GIS | - | - |
| **115** | Ghosh et al., 2022 | x | x | x | | | x | AHP | GIS | - | - |
| **117** | Cunha et al., 2022 | x | x | | | x | | PROMETHEE | PROMETHEE | Weight variations | TOPSIS |
| **118** | Shadeed et al., 2022 | x | | | | | x | AHP | GIS | - | - |
| **119** | Illankoon et al., 2022 | x | x | x | | | | AHP | AHP | Weight variations | - |
| **121** | Iqbal et al., 2022 | x | | x | | | | Simple Multi-attribute Rating Technique (SMART) | Simple Multi-attribute Rating Technique (SMART) | - | - |
| **122** | Parra-L´opez et al., 2022 | x | x | x | | | x | AHP | AHP | Weight variations | - |
| **123** | Rahmani et al., 2022 | x | x | x | | | x | AHP | AHP | Weight variations | - |
| **125** | Volkov et al., 2022 | x | x | x | | | | TOPSIS | TOPSIS | - | - |
| **126** | Mainar-Toledo et al., 2022 | x | x | x | | | x | AHP | AHP | - | - |
| **128** | Nedeljković et al., 2022 | x | x | x | | | x | TOPSIS | TOPSIS | - | - |
| **129** | Junior et al., 2022 | x | x | x | | | x | Fuzzy DEMATEL | Fuzzy DEMATEL | - | - |
| **130** | Scuderi et al., 2022 | x | x | x | | | x | NAIADE | NAIADE | - | - |
| **131** | Thakur et al., 2022 | x | x | x | x | | x | COPRAS method | COPRAS method | Weight variations | |
| **132** | Puška et al., 2022 | x | x | x | x | x | x | LMAW(Logarithm Methodology of AdditiveWeights) | (Compromise Ranking of Alternatives from Distance to Ideal Solution)CRADIS | Weight variations | - |

#### *II.5.2.1. Inputs for Decision-Making*

Agriculture is a complex and ever-changing field that requires effective decision-making to ensure its sustainability and profitability. Decision-makers in agriculture face a range of challenges, including uncertain weather patterns, changing market conditions, and evolving technologies. To address these challenges, researchers have developed various decision-making methods that can help DMs make informed and effective decisions (Noori et al., 2021; Thakur et al., 2022). This study aimed to explore the use of group decision-making methods, interval inputs, and linguistic variables in agricultural issue. The findings of this study (See Figure 22) shed light on the potential of these methods to address the complex and uncertain problems faced by decision-makers in agriculture filed especially.

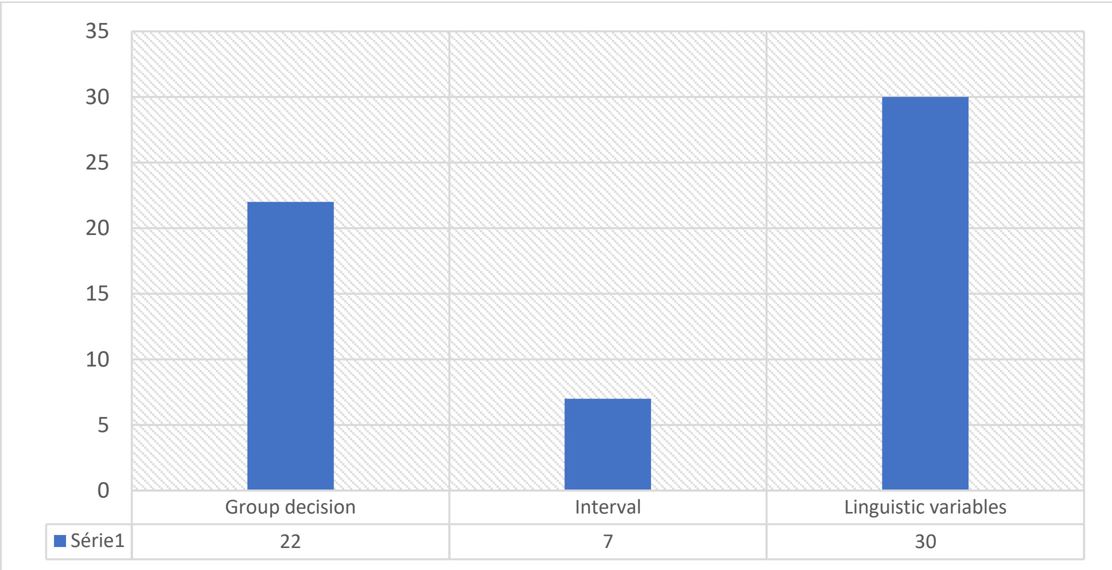


*Figure 22: Inputs for decision-making*

The findings of this study reveal that a group decision-making approach is frequently used to address various issues related to agriculture. A total of 22 articles reviewed in this study employed group decision methods to evaluate the performance of agriculture-related decisions. Group decision-making methods allow for the inclusion of multiple perspectives and can lead to more effective and informed decisions.

Furthermore, the study also found that 7 articles used interval inputs to address the challenge of DMs who hesitate to make decisions due to the uncertainty and complexity of the problem. Interval inputs allow DMs to express their preferences in a range of values instead of a single value, which can help reduce uncertainty and increase the accuracy of the decision-making process.

Finally, the review showed that 30 articles used linguistic variables as a means to help DMs express their judgment. Linguistic variables allow DMs to use natural language to express their preferences instead of using numerical values, which can be challenging for those without technical expertise. By using linguistic variables, DMs can express their preferences in a more intuitive and natural way, which can lead to a more effective and efficient decision-making process.

In conclusion, the use of group decision-making methods, interval inputs, and linguistic variables are all important tools for addressing the complex and uncertain problems related to agriculture. By employing these methods, decision-makers can make more informed decisions that consider multiple perspectives and account for uncertainty and complexity.

#### *II.5.2.2. Criteria*

The criteria used in MCDA play a crucial role in determining the outcomes of the decision-making process. These criteria define the objectives of the decision and provide a framework for evaluating alternatives. They can be broadly classified into environmental, social, and economic criteria. Environmental criteria consider the impact of alternatives on the environment, including factors such as water and air pollution, and biodiversity loss. Social criteria consider the impact on social well-being, including factors such as working condition and safety at work (Puška et al., 2022). Economic criteria consider the financial costs and benefits of alternatives, including factors such as investment costs, operating costs, and revenue generation. It is important to carefully select and prioritize criteria in MCDA based on the specific decision context and the values and preferences of relevant stakeholders. Moreover, it is important to ensure that the criteria are relevant, comprehensive, and consistent, and that they reflect the overall goals and objectives of the decision (Kügemann & Polatidis, 2022). The criteria used in MCDA should also be transparent and well-defined, so that decision-makers and stakeholders can understand and interpret the results of the analysis. By considering and balancing the different criteria, decision-makers can identify and evaluate alternatives that are more sustainable, efficient, and socially acceptable(García-Cascales et al., 2021).

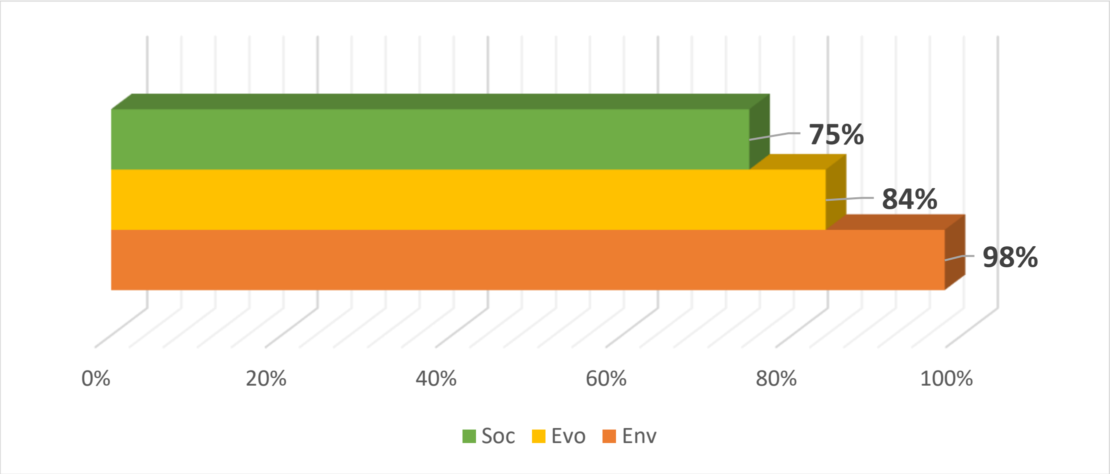


*Figure 23: Criteria used in the literature review*

The results of the literature review (See Figure 23) indicate that there is a growing awareness towards incorporating multiple criteria, including environmental, economic, and social factors, into decision-making processes. Specifically, the review found that 98% of the articles reviewed included environmental criteria in their MCDA, while 84% included economic criteria and 75% included social criteria. Moreover, 72% of the articles reviewed included all three types of criteria in their MCDA. These findings suggest that decision makers are recognizing the interconnectedness of these factors and are taking a more comprehensive approach to decision making. By considering environmental, economic, and social criteria together, decision makers can make more informed and sustainable choices that promote the well-being of both the environment and society. Therefore, it is important for organizations and individuals to recognize the importance of incorporating multiple criteria into their decision-making processes, particularly when it comes to addressing complex environmental and social challenges. This will not only help to ensure the long-term sustainability of our planet, but also promote social stability and economic prosperity.

#### *II.5.2.3. Weighting tools*

Weighting tools play a critical role in MCDA by providing a systematic approach to assigning importance or priority to the different criteria used in decision-making. Weighting tools allow DMs to weigh the relative importance of different criteria, based on their specific context and goals. The weighting process involves assigning numerical values or weights to each criterion, which reflects its relative importance. This allows DMs to evaluate the impact of each criterion on the overall decision and make informed choices that balance environmental, social, and economic considerations(Gómez-Limón et al., 2020).

Weighting tools are especially useful when dealing with complex decisions that involve multiple criteria, as they provide a structured and transparent approach to decision-making. By using weighting tools in MCDA, DMs can ensure that all relevant factors are considered and that the resulting decisions are robust and defensible (Nikkhah et al., 2019).

However, it is important to note that the weighting process is not without its limitations. The choice of weighting method can influence the outcome of the decision and may be influenced by subjective factors. As such, it is important to use a transparent and participatory approach to weighting that involves input from stakeholders and takes into account multiple perspectives(Fernández-Tirado et al., 2021).

In summary, weighting tools are an essential component of MCDA and play a crucial role in promoting sustainable decision-making. By providing a structured approach to weighing criteria and balancing competing objectives, they enable decision-makers to make informed choices that consider the environmental, social, and economic impacts of their decisions.

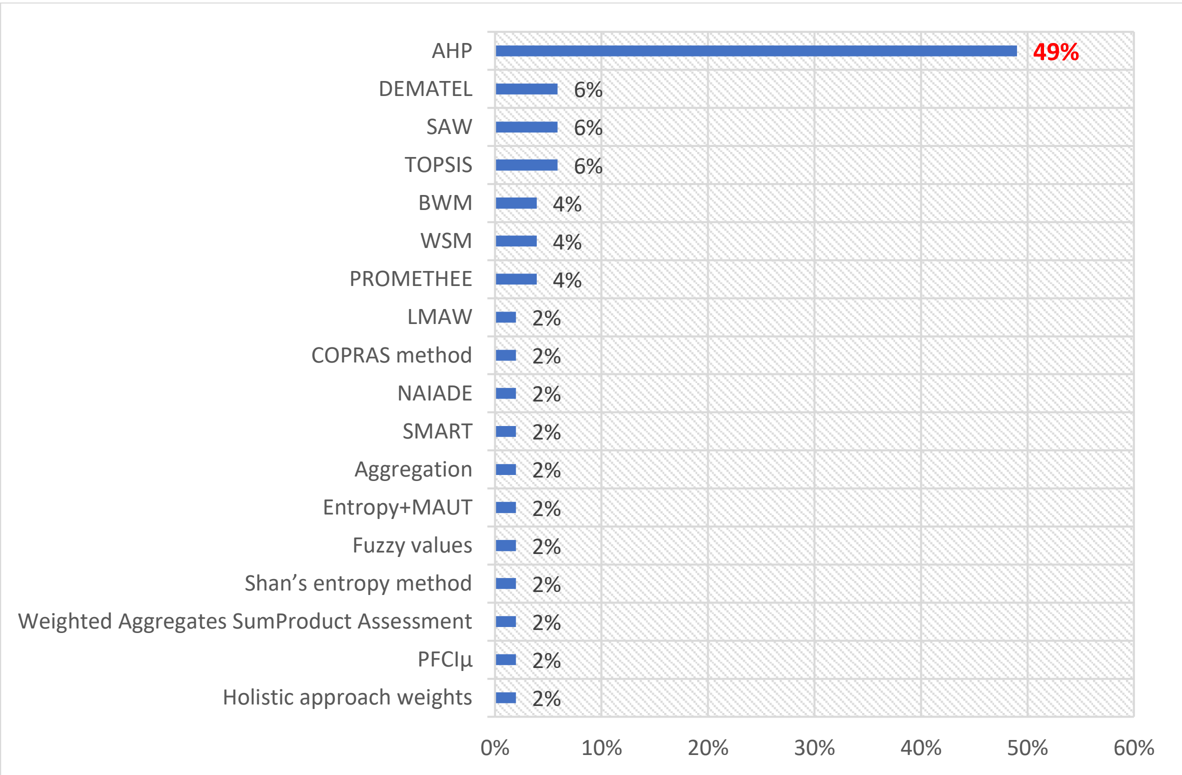


*Figure 24: Weighting tools*

The results of the analysis show that the Analytical Hierarchy Process (AHP) is the most commonly used method for weighting decision-making tools, with 49% of the studies reviewed employing this approach, (See Figure 24). The Decision-Making Trial and Evaluation Laboratory (DEMATEL), Simple Additive Weighting (SAW), Best-Worst Method (BWM), and Weighted Sum Model were used in 6% of the studies each.

AHP is a method that decomposes a complex decision problem into a hierarchy of sub-problems and assigns weights to the criteria and alternatives based on their relative importance. This approach is widely used in various fields to evaluate decision alternatives and prioritize actions. While AHP was the most commonly used method for weighting decision-making tools, the review also revealed the use of other methods summarized in Figure 24. This demonstrates the diversity of methods available for weighting decision-making tools and highlights the importance of selecting the appropriate method based on the decision problem at hand. One of the alternative methods is to determine the subjective and objective criteria weights using a combined approach, which has numerous advantages over traditional methods. By combining these weights, this approach can provide more accurate and comprehensive results, reduce bias and uncertainty, and increase stakeholder participation in the decision-making process. Therefore, it is important to consider and evaluate all available methods when selecting a decision-making tool and to choose the most suitable one for the specific context and needs of the decision problem.

In conclusion, the findings of this study provide insights into the most commonly used methods for weighting decision-making tools. By employing appropriate methods, DMs can more effectively evaluate decision alternatives and make informed decisions.

#### *II.5.2.4. Classification tools*

Ranking tools play a critical role in MCDA by allowing DMs to compare and prioritize alternatives based on their performance against multiple criteria. These tools allow users to assign weights to each criterion and rank alternatives according to their overall score (Ren et al., 2019). By using ranking tools, DMs can evaluate the trade-offs between criteria and identify the best performing alternatives based on their relative importance. However, it is important to use a transparent and participatory approach to ranking and consider the limitations of different ranking methods. Moreover, it is important to ensure that the ranking process reflects the values and preferences of all relevant stakeholders and is based on objective and reliable information (Ren et al., 2015).

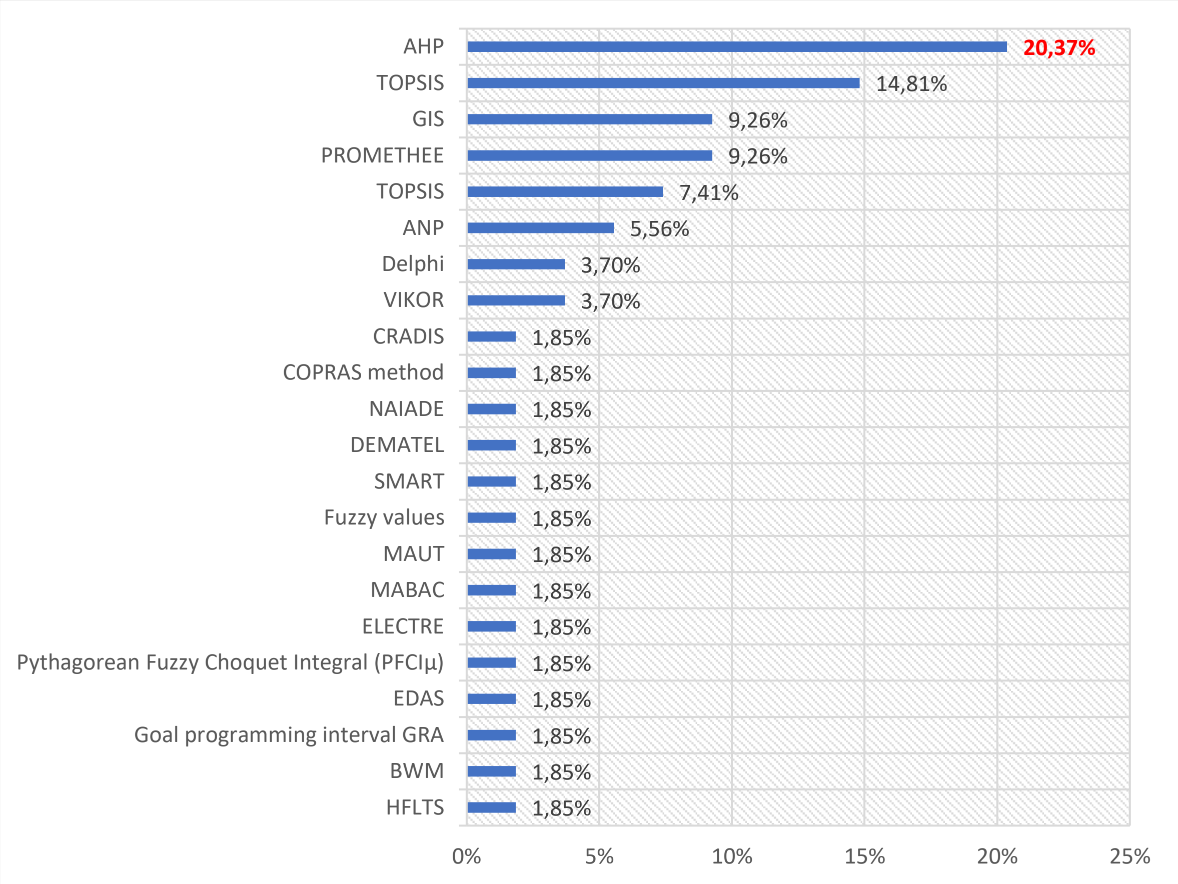


*Figure 25: Classification tools*

The results of the analysis show that the AHP is the most commonly used method for ranking alternatives, with 20% of the studies reviewed using this approach. TOPSIS was the second most commonly used method, with 15% of the studies employing this approach. The Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) and (GIS) was used in 9% of the studies, while TOPSIS was used in 7% of the studies. The Delphi and VIKOR methods were used in 4% of the studies each, (See Figure 25).

These findings suggest that AHP and TOPSIS are the most popular MCDA methods for ranking alternatives. AHP is a method that decomposes a complex decision problem into a hierarchy of sub-problems and compares the alternatives at each level of the hierarchy. TOPSIS is a decision-making approach that identifies the best alternative by comparing each alternative with an ideal solution and a negative solution. While TOPSIS and AHP were the most commonly used MCDA methods, the review also revealed the use of other methods summarized in Figure 25. This demonstrates the diversity of MCDA methods available and highlights the importance of selecting the appropriate method based on the decision problem at hand. To assist in this selection process, table 10 summarize the advantages and disadvantages of each method. By carefully evaluating the strengths and weaknesses of each method, decision-makers can make a more informed choice and increase the likelihood of achieving their desired outcomes.

*Table 10: Advantages and disadvantages of MCDM methods, (Siksnelyte-Butkiene et al., 2020)*

| Method | Advantages | Disadvantages | Source |
|---|---|---|---|
| **AHP** | • Can be easily applied to solve different problems<br>• The computation process is quite simple compared with other methods<br>• Results are obtained quite quickly compared to other methods<br>• The method has a comprehensible logic<br>• The method is based on a hierarchical structure; therefore, it has a better focus on each criterion used in the calculations | • Interdependence between alternatives and objectives can lead an inaccurate/wrong result<br>• Additional analysis is required to verify the results<br>• The more decision-makers that are involved, the more complex the assigning weights are<br>• Requires data collected based on experience | (Siksnelyte-Butkiene et al., 2020)<br><br>(Suganthi, 2018b) |
| **TOPSIS** | • Works with a fundamental ranking<br>• The method completely uses allocated information<br>• The information need not be independent<br>• The method has a rational and comprehensible logic, and the concept is in a quite simple mathematical form<br>• The computation process is quite simple compared with other methods<br>• Results are obtained quite quickly compared to other methods | • In principle, the method works based on Euclidean distance and<br>• negative and positive values do not influence calculations<br>• A strong deviation of one indicator from the ideal solution strongly influences the results<br>• The method is suitable when the indicators of alternatives do not vary very strongly | (Jellali et al., 2021)<br><br>(Riesgo & Gallego-Ayala, 2015)<br><br>(Siksnelyte-Butkiene et al., 2020) |
| **PROMETHEE** | • The method is especially useful when there are alternatives that are diffcult to harmonize<br>• The method works with qualitative and quantitative information | • The computation process is quite long compared with other methods<br>• Calculations are very complicated; therefore, the | (Król et al., 2018)<br><br>(Siksnelyte-Butkiene et al., 2020) |

| | | | |
|---|---|---|---|
| | • Uncertain and fuzzy information can be incorporated into calculations | method is only suitable for experts | |
| **VIKOR** | • Provides a compromise solution that balances conflicting criteria<br>• Considers both the best and worst outcomes for each alternative<br>• Takes into account the relative importance of criteria<br>• Can handle both quantitative and qualitative criteria<br>• Allows decision-makers to adjust the importance of criteria | • Requires consistent and complete data<br>• Does not account for uncertainty or risk<br>• Can be time-consuming and complex for large decision problem<br>• | (Suganthi, 2018) (Siksnelyte-Butkiene et al., 2020) |

In conclusion, the findings of this study provide insights into the most commonly used MCDA methods for ranking alternatives and the different advantages and disadvantages of each method. By employing appropriate MCDA methods, decision makers can more effectively evaluate alternatives and make informed decisions.

#### *II.5.2.5. Sensitivity and robustness tools*

Sensitivity and robustness tools play a critical role in MCDA by assessing the reliability and stability of the decision outcomes. These tools enable decision-makers to evaluate the impact of uncertainties and variations in criteria weights, ranking methods, and data inputs on the final decision outcomes (Abdel-Basset, Gamal, & ELkomy, 2021). By conducting sensitivity and robustness analyses, decision-makers can identify the most critical factors that affect the decision outcomes and evaluate the potential risks and trade-offs associated with different alternatives. These tools help decision-makers to enhance the credibility and transparency of the decision-making process and to develop more robust and reliable decision outcomes (Saraswat & Digalwar, 2021).

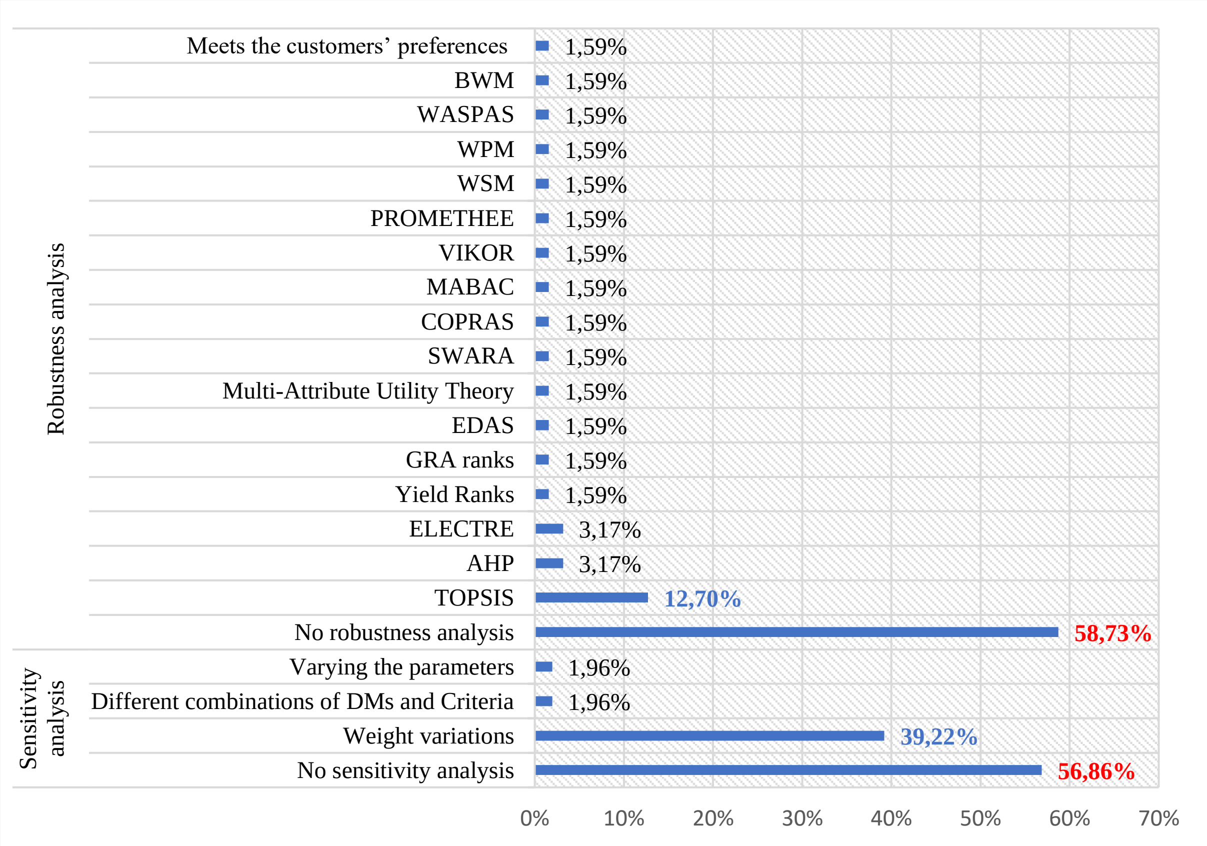


*Figure 26: Sensitivity and robustness tools*

The results of the analysis show that Weight Variations is the most commonly used method for sensitivity analysis, with 40% of the studies reviewed employing this approach, (See Figure 26). Weight Variations involves varying the weights of the criteria to evaluate the impact on the ranking of alternatives. This approach is widely used in various fields to assess the sensitivity of a decision-making process to changes in the weightings of the criteria. While Weight Variations was the most commonly used method for sensitivity analysis, the review also revealed the use of other methods summarized in Figure 26. This demonstrates the diversity of methods available for conducting sensitivity analysis and highlights the importance of selecting the appropriate method based on the decision problem at hand. However it is important to note that, 57% of the studies reviewed did not use sensitivity analysis. This is concerning because sensitivity analysis is a crucial step in any MCDA study as it enables the assessment of the strength of the results and identifies the criteria that are most influential in the decision-making process. Failure to conduct sensitivity analysis could cause in unreliable results and ultimately lead to insignificant decision by (DMs).

In terms of robustness analysis, the results showed that the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was the most commonly used method, with 13% of the studies reviewed employing this approach. The Analytical Hierarchy Process (AHP) was used in 3% of the studies for robustness analysis.

While TOPSIS and AHP were the most commonly used methods for robustness analysis, the review also revealed the use of other methods summarized in Figure 26. This demonstrates the diversity of methods available for conducting robustness analysis and highlights the importance of selecting the appropriate method based on the decision problem at hand. It is concerning that 59% of the reviewed studies did not use a robustness analysis, as this is a critical component in ensuring the reliability and validity of the MCDA results.

In conclusion, the findings of this study provide insights into the most commonly used methods for sensitivity and robustness analysis. By employing appropriate methods, decision makers can more effectively evaluate the sensitivity and robustness of a decision-making process and make informed decisions.

#### II.5.3. Combining the agricultural life cycle sustainability tools and multi-criteria decision making tools

In recent years, the sustainability in the agricultural area has become a growing concern worldwide. To address this issue, various tools and methods have been developed to evaluate the sustainability of agricultural systems throughout their life cycles. Additionally, MCDA methods have been increasingly used to assess complex problems with multiple criteria and conflicting objectives.

In appendix B, we present a collection of articles that explore the combination of agricultural life cycle sustainability tools with MCDA methods. The table includes three columns: ID, author name, and scope of the article. The ID column refers to the unique identifier assigned to each article in our database. The author name column lists the names of the authors who conducted the study. Then the scope of the article column briefly describes the focus and objectives of each article. Finally, the limitation of each article was mentioned in the last column.

By compiling and analyzing these studies, we aim to identify the key features of successful combinations of agricultural life cycle sustainability tools and MCDA methods. This information can provide insights into developing effective approaches to sustainable agricultural management that account for environmental, economic, and social factors.

The articles listed describe studies that involve the combination of LCA with other methods such as the AHP, MCDA, LCC, and S-LCA to assess the environmental, economic, and social sustainability of various systems and scenarios. The studies were conducted in various fields, including biomass production, bioenergy systems, wine-growing, solid waste management, olive growing scenarios, water footprint evaluation, tobacco production system, poultry production systems, and sustainability analysis of biobased chemicals in Europe. The studies aimed to identify and weight impact categories, assess environmental impacts, rank and prioritize alternatives based on sustainability criteria, identify hotspots, evaluate soil management practices, evaluate the suitability of production systems to address human food needs, and develop consensus rankings among experts on sustainability indicators.

While the 26 articles included in the literature review provide valuable insights into the use of MCDA methods in sustainable decision-making, there is still a gap in the literature in terms of incorporating the sustainability of the life cycle into MCDA methods. Traditional MCDA methods typically consider a limited number of criteria, such as cost, quality, and time, without taking into account the environmental, social, and economic impacts of a decision over the entire life cycle of a product or service. This narrow focus can lead to unintended consequences, such as increased environmental pollution or social inequalities.

Through a comprehensive review that explore the sustainability of agricultural systems, several limitations have been identified. Many of the studies relied on a single decision-making tool, such as LCA or AHP, to evaluate the sustainability of agricultural systems. Additionally, while some studies considered multiple criteria such as economic, environmental, and social factors, others focused on only one or two of these criteria. Moreover, most of the reviewed articles used case studies from specific regions or countries, limiting the generalizability of their findings.

Therefore, there is a need to develop new MCDA methods that can explicitly account for the sustainability of the life cycle. These new methods would need to incorporate a wider range of criteria that reflect the impacts of a decision over the entire life cycle of a product, including factors such as resource use, carbon emissions, social equity, economic viability and the CE adaptability.

By developing MCDA methods that explicitly account for the sustainability of the life cycle, decision-makers can make more informed and sustainable choices that align with their environmental, social, and economic goals.

## II.6. Interpretations

Based on the literature review results provided, the following interpretations can be made:

- The LCA and MCA methodologies indicates their importance in conducting comprehensive analyses of complex systems. The combination of both methods is also becoming more popular, highlighting the need for multiple analytical approaches to gain a complete understanding of research topics.
- While LCA remains the most commonly used methodology in LCSA, there is a need to incorporate LCC and S-LCA criteria to provide a more comprehensive picture of sustainability. The variation in the rate of use of different phases in LCSA also shows the need for more attention to be paid to the assessment of different phases in the life cycle to ensure a more comprehensive sustainability assessment of products and services.
- The three main phases of the agriculture life cycle - agricultural phase, extraction phase, and waste management phase - received different levels of attention in the literature. The most frequently assessed sub-phases for each phase were soil management, 2-phase extraction system, and Pomace valorization problem, respectively. However, integrating all phases and sub-phases of LCSA for agriculture still a complex task that requires further research and integration of MCDA methods to provide a more holistic understanding of the sustainability of agriculture.
- Decision-making in agriculture is complex and challenging, and requires effective methods to ensure sustainability and profitability. Group decision-making methods, interval inputs, and linguistic variables are all important tools for addressing the complex and uncertain problems related to agriculture. The criteria used in MCDA play a crucial role in determining the outcomes of the decision-making process, and by considering and balancing environmental, economic, and social criteria together,

decision makers can make more informed and sustainable choices that promote the well-being of both the environment and society.

- Weighting tools are also an essential component of MCDA and play a crucial role in promoting sustainable decision-making. By providing a structured approach to weighing criteria and balancing competing objectives, they enable decision-makers to make informed choices that consider the environmental, social, and economic impacts of their decisions. Overall, the findings highlight the importance of employing effective decision-making methods that can address the challenges and complexities of decision-making in agriculture and beyond.
- The study highlights the importance of using appropriate ranking methods in MCDA to evaluate the trade-offs between criteria and identify the best performing alternatives based on their relative importance. The study reveals that TOPSIS and AHP are the most commonly used MCDA methods for ranking alternatives. However, decision-makers should consider the limitations of different ranking methods and ensure that the ranking process reflects the values and preferences of all relevant DMs and is based on objective and reliable information. By employing appropriate MCDA methods, decision-makers can more effectively evaluate alternatives and make informed decisions.
- The study emphasizes the importance of using sensitivity and robustness tools to assess the reliability and stability of the decision outcomes in MCDA. Weight variations and TOPSIS are the most commonly used methods for sensitivity and robustness analysis, respectively. However, the study also highlights the diversity of methods available for conducting sensitivity and robustness analysis and the importance of selecting the appropriate method based on the decision problem at hand. By employing appropriate methods, decision-makers can more effectively evaluate the sensitivity and robustness of a decision-making process and make informed decisions.

In summary, the literature review highlights the importance of using appropriate tools and methods in MCDA analysis to evaluate alternatives and make informed decisions. DMs should consider the limitations and diversity of different tools and methods and ensure that the decision-making process reflects the values and preferences of all relevant stakeholders and is based on objective and reliable information.

Also, incorporating CE principles is also crucial in conducting a comprehensive and sustainable analysis of complex systems, including agriculture. By minimizing waste and maximizing resource efficiency through strategies such as recycling, reusing, and reducing, CE can help to mitigate the environmental impact of agricultural practices and promote sustainable agriculture. However integrating CE principles into MCDA analysis can also provide decision-makers with a more comprehensive understanding of the environmental, economic, and social impacts of their choices and help them to make more informed and sustainable decisions. Therefore, it is essential to consider the principles of CE in the assessment of sustainability and in decision-making processes to promote a more sustainable future.

## II.7. Conclusion

The literature review highlights the importance of employing appropriate tools and methods in LCSA and MCDA to evaluate the sustainability of agriculture and make informed decisions. The study suggests that combining LCA and MCDA methodologies is becoming more popular to gain a comprehensive understanding of research topics. The study also emphasizes the need to incorporate LCC and S-LCA criteria in LCSA to provide a more comprehensive picture of sustainability. The review highlights the importance of effective decision-making methods to address the complexities and uncertainties of decision-making in agriculture. Also, we suggest the appropriate ranking methods, sensitivity, and robustness tools should be used to evaluate alternatives and make informed decisions that reflect the values and preferences of all relevant stakeholders. Overall, the review highlights also the importance of integrating CE principles into agricultural sustainability assessment and decision-making processes to ensure a more sustainable and resilient agriculture sector.

# Chapter III: A New Multi-Criteria, Multi-Phase and Multi-Decision Makers Approach for the Agricultural Sustainability Problem

## III.1. Introduction

For a long time, agricultural research has focused on practices aimed at improving the productivity of land and crops. In recent decades, the primary focus has shifted to sustainability issues, such as minimizing environmental damage and reducing agriculture's ecological footprint (Struik et al., 2014). Agricultural manufacturing is one of the largest industrial sectors in the world, and it is responsible for a large amount of greenhouse gas emissions due to the high energy consumption, and this exacerbates the global warming issue (Roy et al., 2009). As a result, decision makers (DMs) in this field have become more aware and sensitive, leading policymakers to prioritize a new set of standards: safe, ethical and environmentally friendly agricultural output (de Luca et al., 2017).

Among the principles of sustainable development is the CE (Ahmed et al., 2022), this economy is based on the transformation of waste into a resource: recycling and limiting waste by giving a second life to objects, waste or more broadly to products (Keskes, et al., 2022). By applying the principles of the CE, we can identify the different life cycle scenarios of an asset. By implementing Environmental Life Cycle Assessment (E-LCA), Life Cycle Cost Analysis (LCCA) and S-LCA, it is possible to assess LCSA on each scenario related to the processes of the production chain in the agricultural value chain.

## III.2. Problem and objectives

In general, in the agricultural field, there are different and important phases (Agricultural phase, Production phase, Waste management phase, and Transportation between phases). In fact, all those phases contribute and characterise the entire life cycle of any product (Olive, Grape, …). Each phase has its own DM and each decision maker has its own specific method among several methods of production of agricultural products. Each method has a specific impact on the environment, economy and society. For this reason, DMs are always faced with conflicting and difficult choices. Therefore, we are faced with several problems:

- **Multi-Phase Problem➔** There are different phases in the life cycle of any agricultural product.
- **Multi-Criteria Problem➔** Different and contradictory criteria must be studied.
- **Multi-Decision Makers' Problem➔** DMs intervene in different phases of the life cycle of the agricultural product.
- **Circular and Sustainable Problem➔** The highest priority is given recently to environmental and sustainable aspects of the agricultural field.

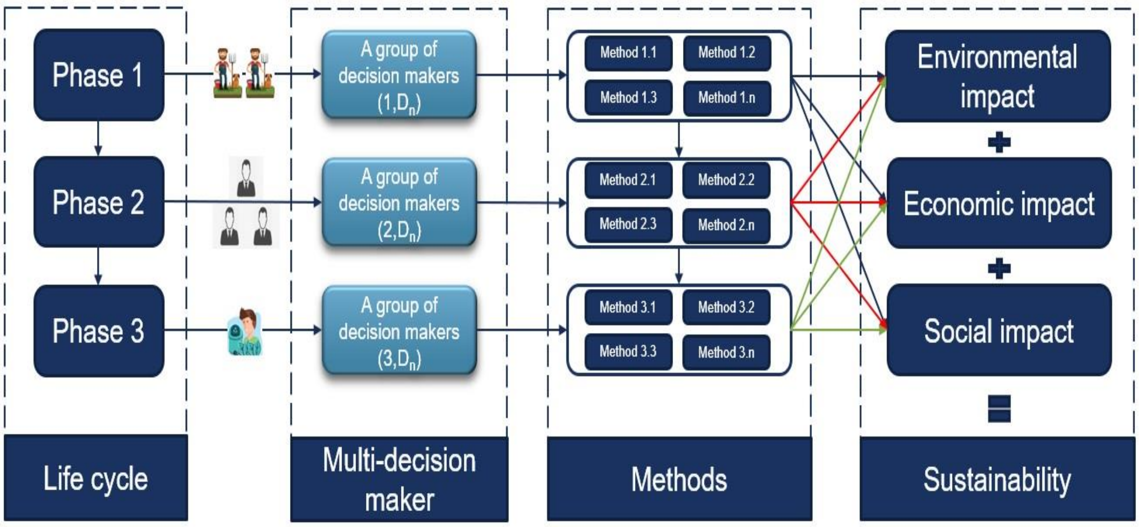


*Figure 27: Summary of the main proposal of the chapter*

The objective of this chapter is to support DMs in choosing the most sustainable agricultural practices, extraction methods and waste recovery management methods so that the entire product life cycle becomes circular and sustainable. To achieve this goal, we propose a new multi-criteria framework to help DMs compare and rank different life cycle scenarios, (See Figure 27).

## III.3. Preliminaries

### III.3.1. Structured analysis and design technique

Structured analysis and design technique (SADT) is a leading tool used in the design of computer-integrated manufacturing systems, including flexible manufacturing systems. Inputs are elements that are transformed by an activity. Output is the result of activity conditions and rules that describe how an activity is performed and represented by control arrows (See Figure 28).

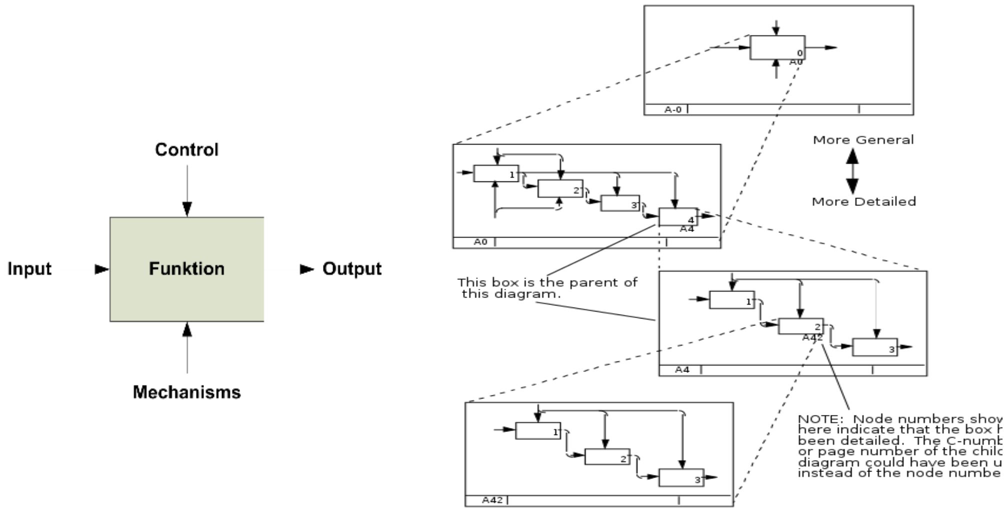


*Figure 28: SADT tool*

Our contribution in this step is to integrate SADT to support the implementation of the CE concept. SADT is a suitable tool to analyze the processes and sub-processes of each phase of the life cycle of any product. The first step is identifying the "Waste" or what is called according to the CE concept the "Return loops". The next step is to propose new processes to exploit the return loops results while adding a new phase to the life cycle called the waste recovery management phase in order to integrate the concept of the CE.

### III.3.2. The 2-tuple linguistic representation model

The 2-tuple linguistic approaches is a computational model with words for various decision making problems. This linguistic representation model was developed in the year 2000 by Herrera and Martínez in order to simply and facilitate the combining and the computation of linguistic and numerical data. Each linguistic data is characterized by a syntactical label and a semantic value (Chen, 2015; Wu et al., 2018). A label is a word that belongs to a set of linguistic terms, and a value is a fuzzy subset in the discourse universe. For example, a set of seven terms S, could be given as follows:

$\tilde{y} = \{y_0 = none, y_1 = very\ low, y_2 = low, y_3 = medium, y_4 = high, y_5 = very\ high, y_6 = perfect\}.$

The semantics description of the different terms is given by the fuzzy numbers associated in the [0,1] interval. Only one way to characterize a fuzzy number is by applying a representation that is based on the parameters of its membership function (Herrera & Martínez, 2000). This assignment is described in Figure 29.

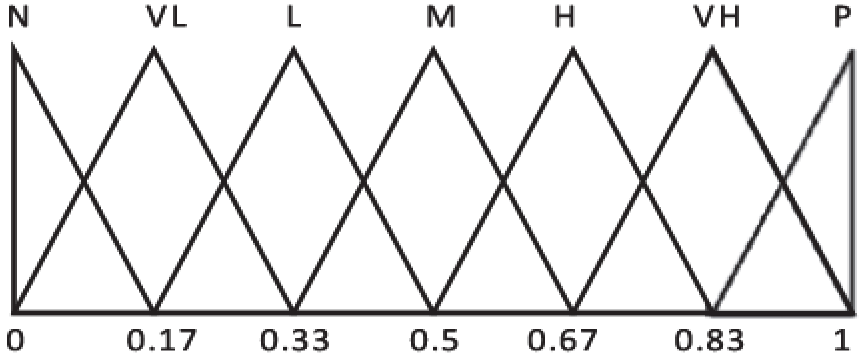


*Figure 29: The assignment Of the 2-tuple linguistic model*

The 2-tuple linguistic description model takes the symbolic aggregation model as its basis (Herrera & Martínez, 2000). In addition, it describes the concept of Symbolic Translation. The latter is used to represent the linguistic information by means of a pair of values called linguistic 2-tuple, ($y$, $c$), where $y$ is a linguistic term and $c$ is a numeric value representing the symbolic translation.

**Definition 1**. Let β be the result of an aggregation of the indexes of a set of labels assessed in a linguistic term set S = {$s_0$,. . . , $s_g$}, i.e., the result of a symbolic aggregation operation. β ∈ [0,g], being $g + 1$ the cardinality of S. Let $i$ = round(β) and α = β - $i$ two values, such that, $i$ ∈ [0,g] and α ∈ [-0.5, 0.5) then α is called a symbolic translation (Herrera et al., 2005).

Based on this concept, (Herrera & Martínez, 2000) develops a linguistic representation model which represents the linguistic information by means of 2-tuples ($s_i$ , α) where $s_i$ ∈ S represents the linguistic label centre of the information and a $\alpha$ ∈ [-0.5, 0.5) is a numerical value that represents the symbolic translation i.e. the translation from the original result β to the closest index label $i$ in the linguistic term set ($S$).

**Definition 2**. Let S = {$s_o$, . . . , $s_g$} be a linguistic term set and $\beta$ ∈ [0, g] a value supporting the result of a symbolic aggregation operation, then the 2-tuple that expresses the equivalent information to β is obtained with the following function where round (.) is the usual round operation, $S_i$ has the closest index label to ‘‘β’’ and ‘‘α’’ is the value of the symbolic translation (Herrera & Martínez, 2000):

$$\Delta : [0, g] \rightarrow S * [-0.5, 0.5).$$

$$\Delta(\beta) = (S_i, \alpha), with \begin{cases} S_i \quad i = round\ (\beta), \\ \alpha = \beta - i \quad \alpha \in [-0.5, 0.5 \end{cases}$$

### III.3.3. Multi-Criteria Group Decision Making

Sustainability assessment methods have been applied in different agricultural areas and have yielded good results. Among these methods, we have the life cycle sustainability analysis that allows us to evaluate the environmental, economic and social impact associated with all the phases of a product's life starting with the extraction of raw materials, manufacturing, transportation, use and disposal (Batuecas et al. 2019). Several authors use Multi-Criteria Group Decision Making (MCGDM) to solve conflicts and contradictions. In order to obtain a common opinion, it is necessary to find an aggregation function of a group of experts to group their evaluations into a matrix (Rani et al., 2022). Hsu and Chen (1996) presented for the first time, an novel method for aggregating expert opinions by applying the consensus index and the position of each expert. They suggested the determination of the consensus index of each expert with respect to other experts score using the similarity measure method.

In addition, it is also essential to implement an appropriate expert weighting method to achieve more consistent results in the process of expert elicitation. This could have an important impact on the accuracy of the evaluation results. The Similarity Aggregation method (SAM) is an efficient approach that has been extensively used to measure the weight of each expert for opinion aggregation (Jianxing et al. 2021a). Both the objective weight of experts and the relative consistency of their opinions are taken into consideration in the SAM. However, it still suffers from the lack of reliability of experts' opinions during the elicitation process. (Yazdi et al. 2019) present a new method to consider the confidence levels of experts. Moreover, they employ this method for the assessment of fires and explosions in a hydrocarbon storage tank. (Ziemba et al. 2020) propose a new methodological framework for the aggregation of experts' opinions in the fuzzy TOPSIS method, considering the degree of agreement of their opinions using SAM and the expert ranking. Moreover, they employed this method in the field of human resource management.

Furthermore, (Jianxing et al. 2021b) propose a new technique using SAM to aggregate experts' opinions, this technique is extensively used to obtain the relative agreement degree for measuring the weight of each expert for a specific assessment case. So, the traditional SAM is modified to be appropriate for the cloud model theory. In addition, this method has been used for risk assessment of submarine pipelines. Similarly, (Guo et al., 2021) study SAM as a method for aggregating fuzzy opinions by considering the consensus degree. However, SAM does not consider the impact of individual differences on consistency, which will bring some degree of uncertainty. Therefore, in their work, they propose an improved SAM based on the FBN (Fuzzy Bayesian network) model to better deal with various types of uncertainty. This methodology makes the prediction results of the storage tank accident more accurate and reliable. As the best of our knowledge, there are no existing studies in the literature that combine SAM with a 2-tuple model. Therefore, our contribution is unique in using the 2-tuple model to consider and facilitate the expression of experts' preferences, while employing the SAM method for aggregating their opinions.

Owing to the development and the increasing complexity of the olive oil production life cycle, it is necessary to study the sustainability issue of this product using new multi criteria method. This will allow us to perform a more comprehensive and systematic analysis of the sustainability of the olive oil production life cycle. Simultaneously, the traditional MCDA has many shortcomings, especially the multi-criteria group decision analysis method for sustainability assessment needs further research with respect to the uncertainty of expert assessment.

## III.4. Proposed methodology

In this section, a new multi-criteria, multi-phase, multi-decision makers’ and sustainable approach is proposed, based on the 2-Tuple model. The proposed approach is provided in six different critical steps, as illustrated in Figure 30.

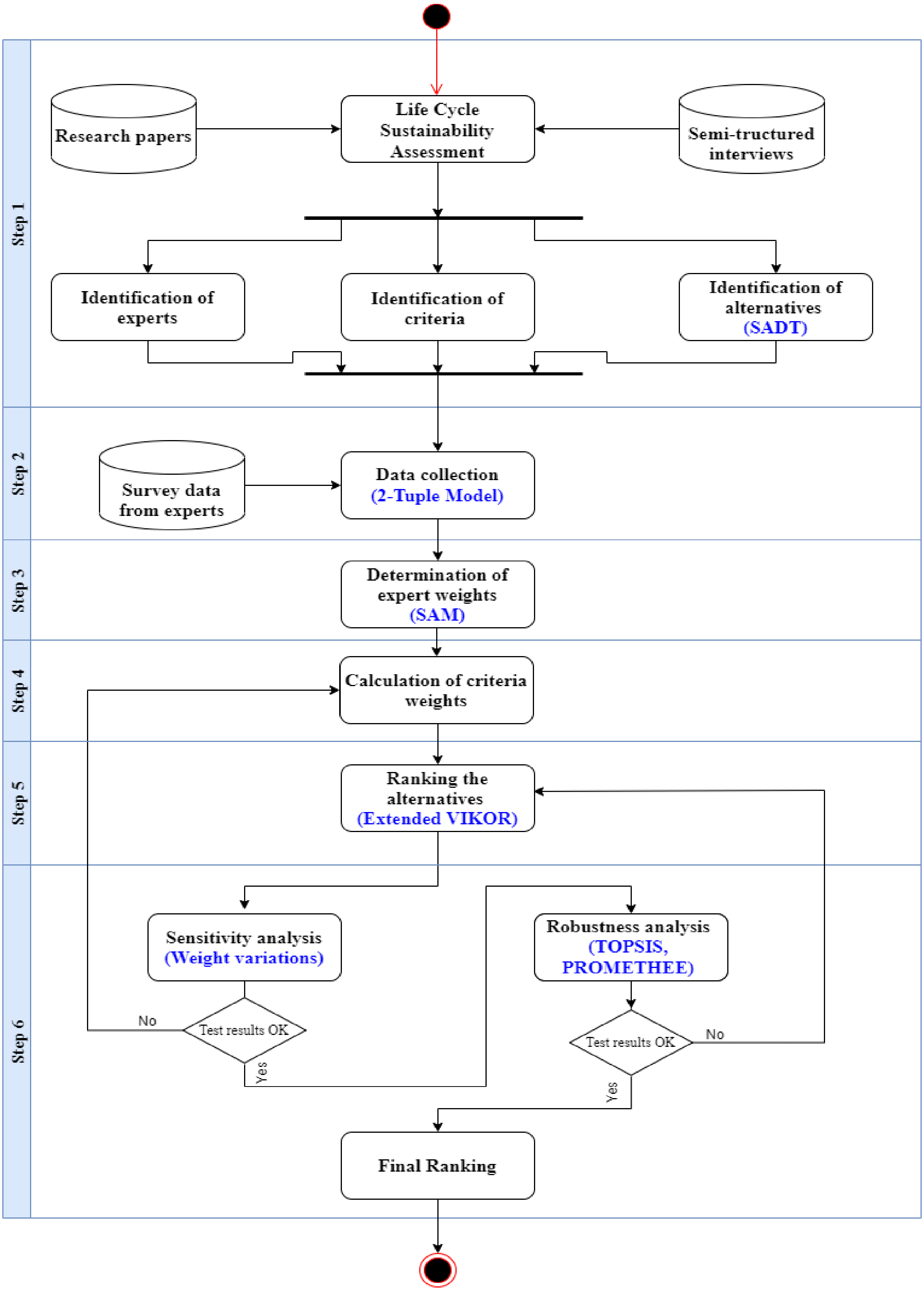


*Figure 30: Process diagram of the proposed framework*

The main superiorities of the proposed method are summed up as follows: (1) Our objective in the first step, is to build sustainable scenarios under the CE thinking. To achieve this goal, the SADT tool has been integrated to close and value the waste loops for each scenario. (2) The uncertainty of the evaluation process, especially the randomness and fuzziness, can be comprehensively resolved by the 2-Tuple model, which reduces the influence of uncertainty on the evaluation results. (3) An improved synthetic dynamic weighting algorithm, which considers the confidence level of expert opinions, is proposed to better manage the multiplicity and uncertainty of different degrees and types of knowledge. This Algorithm considers the confidence level of experts' opinions depending on their background and the phase they intervene in. (4) An integrated weighting method is used to calculate the subjective and objective weights of the criteria by assigning more reasonable weights for a comprehensive evaluation. (5) The typical VIKOR method is extended with the 2-Tuple model to calculate the sustainability of each scenario for the olive oil life cycle, which offers a compromise in considering multiple scenarios in our multi-criteria framework. The next section describes the six steps in detail:

### III.4.1. Identifying the decision-making team, the scenario and the criteria (Step 1)

#### I.4.1.1. Establishing the decision-making team

First, due to the uncertainty of a complex agricultural system and the limited knowledge of a single expert, it is necessary to establish an expert team composed of multiple DMs in the agricultural field to improve the objectivity and accuracy of the assessment results. The constitution of the expert team should meet the following three principles:

- Ability of the experts: The team of DMs must be engaged in the agriculture, extraction, and waste recovery phases. In addition, they must be familiar with the field of agriculture and be able to give reasonable and real judgments (Cai et al., 2013).
- Number of experts: To confirm the reliability and rationality of the assessment results, the number of DMs team members should not be extremely small. Based on existing research, 3–10 experts are typically selected to form a team to provide relatively credible assessments of agricultural sustainability based on expert knowledge (Yazdi et al., 2020; Zarei et al., 2021).
- Diversification of expert profiles: A heterogeneous team of DMs should be constituted while considering their different knowledge levels and backgrounds to avoid extreme convergence

of judgment. Experts should have different positions, knowledge, expertise, experiences and skills, specialize in different life cycle phases and have divergent viewpoints on the same issue, to enhance the objectivity and comprehensiveness of assessments.

We ensured the accuracy of expert judgments by carefully selecting qualified experts, providing structured guidelines, obtaining multiple opinions, and conducting a sensitivity analysis. These measures aimed to minimize biases and inaccuracies, resulting in a robust decision-making framework.

#### I.4.1.2. Identifying the scenario and the criteria

We include the literature review (Research papers, (Keskes, Zouari, Houssin, et al., 2022) and field studies (Semi-Structured Interviews) necessary to build a comprehensive understanding of a product's life cycle. The objective of this phase is to extract the appropriate scenarios and criteria for the study. For the scenarios, a SADT has been integrated to have a broader version using a top-down analysis of successive levels. This tool allows us to specify with greater accuracy the role of each element of the system, and to close the waste loop for each scenario. Our contribution is to build a sustainable scenario and set of criteria while adhering to the CE concept.

### III.4.2. Collection and conversion of linguistic assessment, (Step 2)

During the sustanabilty assessment, the decision maker expresses their decision in qualitative linguistic terms to offer sensitive and real assessment data. In this process, experts evaluate each scenario sequentially for each criterion through a survey with a decision maker.

For a precise assessment question, it is assumed that there are *m* scenarios, where *i= 1,2, …,m*, while *n* criteria where *j= 1, 2, …, n*, and *l* decision maker where *k= 1,2, …, l* selected for assessment. $\tilde{y}_{ij}^{k} = (y_{ij}^{k}, c_{ij}^{k})$ represents the assessment results of the *k*th expert ($E_k$) for the *i*th scenario ($Sc_i$) concerning the *j*th criterion (*Crj*). The symbol $y_{ij}^{k}$ signifies the linguistic commentary of the scenario $Sc_i$ from the assessment terms set *T*, and can be transformed into a corresponding standard assessment 2-tuple model. The assessment matrix $Y^K$ can be designed by creating the linguistic term values of each decision maker. The symbol $C_{ij}^{k}$ is a numerical value representing the symbolic translation *Ek* on its own linguistic comment $y_{ij}^{k}$ , with a range of [0,1].

### III.4.3. Determination of expert weights and aggregation of judgments, (Step 3)

In this phase, the weight of the assessment given by each decision maker is obtained through the proposed synthetic dynamic weight algorithm. Then, 2-tuple assessment models are combined based on the synthetic weight and aggregation operator to obtain the synthetic assessment 2-tuple matrix. In the proposed synthetic dynamic weight algorithm, the influence of members in the decision-making team is determined by considering two aspects, namely, their personal status and their observations for the specific assessment case. Personal status can represent the level of a person's experience, while their observations can be used to measure their weight in the specific case by comparing them to others according to democratic principles. Therefore, the individual weights of experts related to their identities are constant for all assessment cases. We then aggregate the relative agreement degree of the comments to obtain a unified decision matrix. To do that, we follow the next 4 steps:

#### III.4.3.1. Acquiring the individual weights of the experts

DMs are selected from different phases of a product's life cycle, with different experiences, skills and viewpoints. In this study, four criteria are selected to identify the authority or the weight of each expert: Professional Position, Service Time, Education Level and Age (Jianxing et al., 2021). Depending on the individual status of each expert and the judgment criteria listed in Table 11, the individual score $S_{iwe}^{k}$ of each expert is obtained. Thereafter, the individual weight $W_{iwe}^{k}$ of each expert $E_k$ is calculated as follows:

$$w_{iwe}^{k} = \frac{S_{inf}^{k}}{\sum_{k=1}^{l} S_{iwe}^{k}} \text{ with } k = 1, 2, \dots, l \quad (1)$$

*Table 11: Weighting criteria and expert scores,* (Jianxing et al., 2021)

| Parameters and Classification | Score |
|---|---|
| ***Professional position:*** | |
| Senior academic (Researcher) | 5 |
| Junior academic | 4 |
| Engineer | 3 |
| Technician | 2 |
| Worker | 1 |
| ***Service time:*** | |
| > 30 years | 5 |
| 20–30 | 4 |
| 10–20 | 3 |
| 6–9 | 2 |
| < 6 years | 1 |
| ***Education level:*** | |
| PhD | 5 |
| Master | 4 |
| Bachelor | 3 |
| HND | 2 |
| School-level | 1 |
| ***Age:*** | |
| > 50 | 4 |
| 40–50 | 3 |
| 30–39 | 2 |
| < 30 | 1 |

#### III.4.3.2. Calculating the degree of relative agreement

The judgment of each expert also affects the importance of the comments because the most frequent judgments are considered the most credible. At the same time, extreme judgments are allowed. Nevertheless, popular judgments receive a greater degree of trust based on majority law. Consequently, the judgment that favors the opinions of the majority is assigned a higher weight, which is confirmed by the relative agreement degree of the comments (Guo et al., 2021). As an effective technique to aggregate expert opinions, the Similarity Aggregation method (SAM) is extensively used to obtain the relative agreement degree for measuring the weight of each expert for a specific assessment case (Jianxing et al., 2021). In this study, the traditional SAM is modified to be adapted to the 2-tuple theory. The computational process of the 2-tuple model-based SAM is as follows:

First, the distance between the 2-tuple assessment of any pair of experts is calculated. (Pei-de, 2009) defined a linguistic distance as follows:

$$\tilde{y}_1=(y_k, c_k)$$

$$\tilde{y}_2=(y_v, c_v)$$

$$d\ (\tilde{y}_1, \tilde{y}_2)= \Delta[(|\Delta^{-1}(\tilde{y}_1 - \tilde{y}_2)|)]$$

$$d(\tilde{y}_1, \tilde{y}_2) = \Delta[(|\Delta^{-1}(y_k, c_k) - \Delta^{-1}(y_v, c_v)|)] \quad (2)$$

$d(\tilde{y}_1, \tilde{y}_2)$:is called the linguistic distance between 2-tuple $(\tilde{y}_1, \tilde{y}_2)$.

Second, the average distance $Ad^k$ between an expert and all other experts is obtained.

$$Ad^k = \frac{1}{l-1} \sum_{\substack{v=1 \\ v \neq k}}^{l} d(\tilde{y}_1, \tilde{y}_2), \qquad with\ k = 1,2, \dots, l \qquad (3)$$

Third, the average agreement $AA^k$ of the experts is determined by taking the reciprocal of $Ad^k$.

$$AA^k = \frac{1}{Ad^k}, with\ k = 1,2, \dots, l \quad (4)$$

Finally, the relative agreement degree $RA^k$of each expert is calculated by the normalization method.

$$RA^k = \frac{AA^k}{\sum_{k=1}^{l} AA^k}, \text{with } k = 1,2, \dots, l \quad (5)$$

### III.4.3.3. Obtaining the synthetic dynamic weight of each expert

The proposed synthetic dynamic weight algorithm improves the traditional SAM based on the 2-tuple theory, and considers the influence of the confidence of experts' comments to improve the reliability of aggregated results. Therefore, the synthetic dynamic weight $w_{ij}^k$ of each expert is determined by considering the personal status and agreement degree, using the following formula:

$$w_{ij}^k = \alpha w_{iwe}^k + \beta RA_{ij}^k, \text{with } i = 1,2, \dots, m\ ;\ j = 1, 2, \dots, n, \text{and } k = 1,2, \dots, l \quad (6)$$

where $\alpha$ and $\beta$ are the relaxation factors that reflect the relative importance of the three weight indices. These parameters could be determined by the decision-makers, and they typically satisfy $\alpha$, $\beta \in [0,1]$ and $\alpha + \beta = 1$.

### III.4.3.4. Aggregating the 2-tuple assessment

In this step, the aggregaton of expert opinions is conducted to construct a collective 2-Tuple linguistic decision matrix.

Thus, each evaluation $\tilde{y}_{ij}^{k}$ is transformed into a new weighted $B_{ij}^{k}$ by the scalar multiplication operator as follows:

$$B_{ij}^{k} = w_{ij}^{k} * \tilde{y}_{ij}^{k}$$

$$\tilde{y}_{ij}^{k} = \Delta\left[ {}^{1}/_{l} * \sum_{k=1}^{l} \Delta^{-1}\, \tilde{y}_{ij}^{k} \right], with\ i= 1,2,\ldots,m\ ;\ j= 1,2,\ldots,n, and\ k= 1,2,\ldots,l \quad (7)$$

For all the criteria and the scenarios, the synthetic 2-Tuple assessment can be computed using the aggregation operator, and a synthetic 2-Tuple assessment matrix $\tilde{Y}$ will be obtained, expressed as follows:

$$\tilde{Y} = \begin{bmatrix} \tilde{y}_{11} & \tilde{y}_{12} & \cdots & \tilde{y}_{1n} \\ \tilde{y}_{21} & \tilde{y}_{22} & \cdots & \tilde{y}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{y}_{m1} & \tilde{y}_{m2} & \cdots & \tilde{y}_{mn} \end{bmatrix} \quad (8)$$

### III.4.4. Calculating criteria weights, (Step 4)

Fourth, criteria weights can be given directly by the decision-maker; this fact assumes that the decision-maker is able to weigh the criteria appropriately, at least when the number of criteria is not too large (Cicciù et al., 2022). Furthermore, these weights can be determined via the integration of other multi-criteria methods, such as AHP (Darko et al., 2019), and the hybridization of AHP and Fuzzy logic (Rajasekhar et al., 2019), Best Worst method (Rezaei, 2015a), the fuzzy two-stage logarithmic goal programming method (Ren, 2018), etc. For this study, we will determine the subjective and the objective weights of the criteria. The subjective approach determines weights purely based on the consideration or judgments of DMs, while the objective approach selects weights through mathematical calculations, which neglect the subjective judgment information of the DMs (Paramanik et al., 2022). Since either the subjective or objective approach has its advantages and disadvantages, an integrated or combined method seems more desirable in the determination of criteria weights (H. C. Liu et al., 2013)

#### III.4.4.1. Determining subjective criteria weights

Based on the aggregated criteria weights ($w_j$, $\alpha_{wj}$), *j = 1, 2, . . ., n,* the normalized subjective criteria weights $w_j^s$ can be obtained using the following equation:

$$w_j^s = \frac{\Delta^{-1}(w_j,\alpha_{wj})}{\sum_{j=1}^{n}\Delta^{-1}(w_j,\alpha_{wj})}, \text{ with } j = 1, 2, \ldots, n \quad (9)$$

#### III.4.4.2. Determining the objective criteria weights

In this section, the decision information is expressed by 2-tuples, such as $z_{ij}^k = (y_{ij}^k, c_{ij}^k)$ representing that the performance of a scenario on a criterion is between 2-tuples $(y_{ij}^k, c_{ij}^k)$. Inspired by the works of (H. C. Liu et al., 2013), the concept of statistical variance is used to determine the objective criteria weights.

Thus, the objective criteria weights $w_j^0$ can be computed by the following equation:

$$w_j^0 = \frac{\Delta^{-1}(\sigma_j^2)}{\sum_{j=1}^{n}\Delta^{-1}(\sigma_j^2)}, \text{ with } j = 1, 2, \ldots, n. \quad (10)$$

Where

$$\sigma_j^2 = \Delta(\tfrac{1}{m}\textstyle\sum_{i=1}^{m}(\Delta^{-1}\, d\left(z_{ij}^k, \bar{X}_j\right)^2),\ j = 1, 2, \ldots, n.$$

$$and \Rightarrow d(z_{ij}^k, \bar{X}_j) = \Delta\left[\left(\left|\Delta^{-1}(y_{ij}^k - \bar{X}_j\right|\right)\right]$$

$$\bar{X}_j = \Delta\left[\frac{1}{m}\sum_{i=1}^{m}\Delta^{-1}(y_{ij}^k, c_{ij}^k)\right], j = 1, 2, \ldots, n.$$

#### III.4.4.3. Combining methods for the determination of criteria weights

In the final step of the decision-making process, it is necessary to combine these subjective and objective weights to arrive at a set of final criteria weights. This is typically done using a formula that takes into account both types of weights and produces a single value for each criterion. One commonly used formula for combining subjective and objective weights is as follows:

$$w_j^c = \boldsymbol{\alpha_S} * w_j^s + \boldsymbol{\alpha_O} * w_j^0, j = 1, 2, \ldots, n (11)$$

where $w_j^c$ is the final weight for criterion $j$, $w_j^s$ is the subjective weight for criterion $j$, and $w_j^0$ is the objective weight for criterion j. The values of $\boldsymbol{\alpha_S}$ and $\boldsymbol{\alpha_O}$ represent the relative importance of the subjective and objective weights in the final formula, and they are typically chosen based on the preferences of the decision-makers and the context of the decision-making process.

The coefficient $\boldsymbol{\alpha_S}$ represents the weight given to the subjective weight of the criteria, while the coefficient $\boldsymbol{\alpha_O}$ represents the weight given to the objective weight of the criteria. These coefficients are typically chosen based on the context of the decision-making process and the preferences of the decision-makers.

The formula (11) allows decision-makers to balance the subjective and objective factors that influence the final criteria weights, based on their own preferences and the context of the decision-making process. The coefficients $\boldsymbol{\alpha_S}$ and $\boldsymbol{\alpha_O}$can be adjusted to reflect the importance of subjective and objective factors, respectively, and the final weights for all criteria will add up to 1.

Overall, the formula you are using is a powerful tool for decision-makers to take into account both subjective and objective factors in the decision-making process. By considering both the opinions and preferences of the decision-makers and the objective facts about the criteria, this formula can lead to more informed and balanced decisions that take into account all relevant factors.

### III.4.5. Ranking the scenarios with an extended VIKOR, (Step 5)

Finally, the extended VIKOR is used to calculate the priority and rank the different life cycle scenarios. The steps of the proposed approach are described in detail in the following subsections.

#### III.4.5.1. Defining the positive and negative ideal solutions

In this step, we define the positive and negative ideal solutions of the 2-tuple linguistic decision matrix using equation 12 for the positive solution and negative 13 for the cost solution:

$$(y_{ij}^{+}, c_{ij}^{+}) = \begin{Bmatrix} \underset{i}{\text{Max}}\{(y_{ij}, c_{ij})\} & \text{efficiency index} \\ \underset{i}{\text{Min}}\{(y_{ij}, c_{ij})\} & \text{cost index} \end{Bmatrix} \quad (12)$$

$$(y_{ij}^{-}, c_{ij}^{-}) = \begin{Bmatrix} \underset{i}{\text{Min}}\{(y_{ij}, c_{ij})\} & \text{efficiency index} \\ \underset{i}{\text{Max}}\{(y_{ij}, c_{ij})\} & \text{cost index} \end{Bmatrix} \quad (13)$$

#### III.4.5.2. Determining the 2-tuple linguistic distances

According to the Eq. (12) and (13), we compute the normalized 2-tuple linguistic distances.

$$\bar{d}(y_{ij},c_{ij}) = \Delta\left(\frac{\Delta^{-1}d\big((y_{ij}^{+},c_{ij}^{+}),(y_{ij},c_{ij})\big)}{\Delta^{-1}d\ \big((y_{ij}^{+},c_{ij}^{+}),(y_{ij}^{-},c_{ij}^{-})\big)}\right) \quad (14)$$

Where:

$$d\left((y_{ij}^{+},c_{ij}^{+}),(y_{ij},c_{ij})\right) = \Delta\left(\left|\Delta^{-1}(y_{ij}^{+},c_{ij}^{+}) - \Delta^{-1}(y_{ij},c_{ij})\right|\right)$$

$$d\left((y_{ij}^{+},c_{ij}^{+}),(y_{ij}^{-},c_{ij}^{-})\right) = \Delta\left(\left|\Delta^{-1}(y_{ij}^{+},c_{ij}^{+}) - \Delta^{-1}(y_{ij}^{-},c_{ij}^{-})\right|\right)$$

#### III.4.5.3. Computing the 2-tuples $Si$, $Ri$, and Q$i$

Based on the VIKOR method, we calculate the group utility value $(S_i, c_i)$ and individual regret value $(R_i, c_i)$:

$$(S_i, c_i) = \Delta\left(\sum_{j=1}^{n} w_j^c * \Delta^{-1}\bar{d}(y_{ij},c_{ij})\right) \quad (15)$$

$$(R_i, c_i) = \Delta\left(\underset{i}{\text{Max}}\left(w_j^c * \Delta^{-1}\bar{d}(y_{ij},c_{ij})\right)\right) \quad (16)$$

The ideal solution for calculating group utility values $(S_i, c_i)$ and individual regrets $(R_i, c_i)$ is given as follows:

$$\begin{cases}(S^*, c^*) = \underset{i1\leq i\leq m}{\text{Min}}\{(S_i, c_i)\} \\ (S^-, c^-) = \underset{i1\leq i\leq m}{\text{Max}}\{(S_i, c_i)\}\end{cases} \quad (17)$$

$$\begin{cases}(R^*, c^*) = \underset{i1\leq i\leq m}{\text{Min}}\{(R_i, c_i)\} \\ (R^-, c^-) = \underset{i1\leq i\leq m}{\text{Max}}\{(R_i, c_i)\}\end{cases} \quad (18)$$

We calculate the overall 2-tuple linguistic assessment value $(Q_i, c_i)$ of each alternative as follows:

$$(Q_i, c_i) = \Delta\left(\vartheta\frac{\Delta^{-1}(S_i,c_i) - \Delta^{-1}(S^*,c^*)}{\Delta^{-1}(S^-,c^-) - \Delta^{-1}(S^*,c^*)} + (1-\vartheta)\frac{\Delta^{-1}(R_i,c_i) - \Delta^{-1}(R^*,c^*)}{\Delta^{-1}(R^-,c^-) - \Delta^{-1}(R^*,c^*)}\right) \quad (19)$$

when $\boldsymbol{\vartheta}$=0,5 ➔ Two conditions must be satisfed:

- ✓ Condition 1: $(Q(A_2) - Q(A_1) \geq (1/(n-1))$  (20)

- ✓ Condition 2: $A_1$ is the best scenario in the ranked list, it must also be ranked highest by S (utility) or/and R (regret).

Where: $n$= number of scenarios, $A_1$ = best scenario in the ranked list, $A_2$ = the second best scenario in the ranked list.

After these two conditions, VIKOR can rank the scenarios to determine the best scenario with high accuracy (Chang & Ku, 2021; Dong et al., 2017; Zandi & Roghanian, 2013). The 2-tuple linguistic values $S_i$, $R_i$ and $Q_i$ are used to sort the alternative in ascending order, respectively, so that we obtain the sequences of the different scenarios.

### III.4.6.Determining the sensitivity and robustness analysis (Step 6)

In this step, a sensitivity and robustness analysis was conducted in order to analyze the credibility of the study results. The first test is the sensitivity analysis test where we used the "change weight variation"; this tools allows us to change the criteria weights and to discover the effect of this disturbance on our results. We recompute the weights for the sensitivity analysis until the results are valid (stable ranking). The second test is the robustness analysis where we used two differents methods "TOPSIS" and "PROMETHEE" to compare the ranking results with the ranking obtained through the extended VIKOR method. These tests give us the final ranking for our study.

## III.5. Conclusion

In this chapter, we have presented a new multi-criteria, multi-phase, and multi-decision makers approach to the agricultural sustainability problem. We began by introducing the problem and reviewing relevant literature. Then, we discussed two important tools, the Structured Analysis and Design Technique (SADT) and the 2-tuple linguistic representation model, which were used in our proposed methodology. The proposed methodology consists of five steps: identifying the decision-making team, scenario, and criteria, collecting and converting linguistic assessments, determining expert weights and aggregating judgments, calculating criteria weights, and using the Extended VIKOR method to rank scenarios.

Overall, our proposed approach provides a comprehensive framework for decision-makers to evaluate agricultural sustainability scenarios using multiple criteria and expert opinions. This approach can lead to better-informed decisions and more sustainable agricultural practices.

Further research could be conducted to validate and apply this approach in real-world agricultural sustainability contexts.

# Chapter IV: Case Study: Olive Chain in the Region of Sfax

## IV.1. Introduction

This chapter presents a case study of the olive oil supply chain in the region of Sfax-Tunisia, and applies the methodology developed in the previous chapters to assess the sustainability and circularity of the supply chain. The chapter begins with an introduction to the context and background of the case study, and then presents the application of the methodology and the results obtained.

The first section of the chapter provides an overview of the olive oil industry in the region of Sfax, including the main actors and stakeholders involved, the production and processing stages. We also discuss the sustainability issues and circularity potential of the olive oil supply chain in the region, based on the literature review and the stakeholder consultations conducted in the previous chapters. The second section of the chapter presents the application of the methodology developed in the previous chapters to assess the sustainability and circularity of the olive oil supply chain in the region of Sfax. We discuss the data collection and analysis methods used, including the selection of indicators and criteria, the calculation of scores and weights, and the interpretation of results. We also present the results obtained for each of the sustainability and circularity dimensions assessed, and discuss the strengths and weaknesses of the supply chain in terms of sustainability and circularity. The third section of the chapter focuses on the validation and discussion of the results obtained, including the feedback received from stakeholders and experts in the olive oil industry in the region of Sfax. We discuss the relevance and usefulness of the methodology and the results obtained, and highlight the implications and opportunities for improving the sustainability and circularity of the olive oil supply chain in the region.

Finally, the chapter concludes with a summary of the main findings and contributions of the case study, and provides some recommendations for future research and action in the field of sustainable and circular olive oil supply chains.

Overall, this chapter provides a practical demonstration of the application of the methodology developed in this thesis, and illustrates its potential to assess the sustainability performance of complex agricultural supply chains, such as the olive chain in Sfax.

## IV.2. Application of methodology: Case study

Agriculture is a significant part of the economy of Sfax, Tunisia, with the region being one of the main agricultural areas in the country. The climate in Sfax is Mediterranean, with hot and dry summers and mild winters, making it an ideal location for agriculture. The main crops grown in the region include cereals, vegetables, fruits, and forage crops. Cereals, mainly wheat and barley, account for approximately 45% of the total cultivated area, while vegetables and fruits account for around 25% of the total cultivated area. Forage crops are grown to feed livestock, and they account for the remaining 30% of the total cultivated area.

### IV.2.1. Some statistics of olive oil production

Olive oil production is a significant agricultural activity in Sfax, with the region being one of the main olive oil producers in Tunisia. The olive tree is a significant part of the landscape of this city, and it has been cultivated in the region for thousands of years.

In terms of regional production, the governorate of Sfax is the largest producer of olive oil in Tunisia, followed by the governorates of Sidi Bouzid and Kairouan. The regions of, Sousse, and Mahdia are also major producers of olives in the country.

So, the region of Sfax represents roughly 20% of the national area and production of olive oil, with a total area of approximately 351,000 hectares (distributed as described in Table 12).

*Table 12: National area and production of olive oil*

| Plantations | Surface area (in ha) | Percent (%) | Age |
|---|---|---|---|
| **Young plantations** | 53 860 | 15 | **Under 20 years** |
| **Plantations in full production** | 287 788 | 82 | **Between 20 and 70 years old** |
| **Old plantations** | 9 352 | 3 | **Over 70 years** |
| **Total** | **351 000** | **-** | **-** |

Furthermore, the region of Sfax accounts for one-third of the national production of olive oil, containing 22% of the total number of oil mills. Its share in olive oil exports is 68% of the national total. However, the olive tree density in this region is generally low, with 17 olive trees per hectare. Although olive trees in this region are resistant to low precipitation levels, their aging poses a problem for productivity. In fact, producers are hesitant to remove old olive trees without incentives for conversion and rejuvenation of olive groves.

In this region, the oil extraction rates can reach up to 27-30% in some years in some parts of the region and drop to around 18% in poor years. The olive production and oil processing sectors in Sfax provide livelihoods for many people (43% of the total number of people working in the olive sector in Tunisia). The Sfax area ranks first in terms of organic olive oil production. It comprises approximately 26,000 hectares, which accounts for 30% of the total organic olive cultivation area. The size of olive farms is mostly medium to large, with an average parcel size of around 100 hectares.

The olive grove in the Sfax region is distributed as follows: 34% in Menzel Chaker, 12.6% in Bir Ali, 10.8% in El Hencha, 10.1% in Mahrès, and 21% in other delegations, as shown in figure 31 (CRDA, 2019[2]).

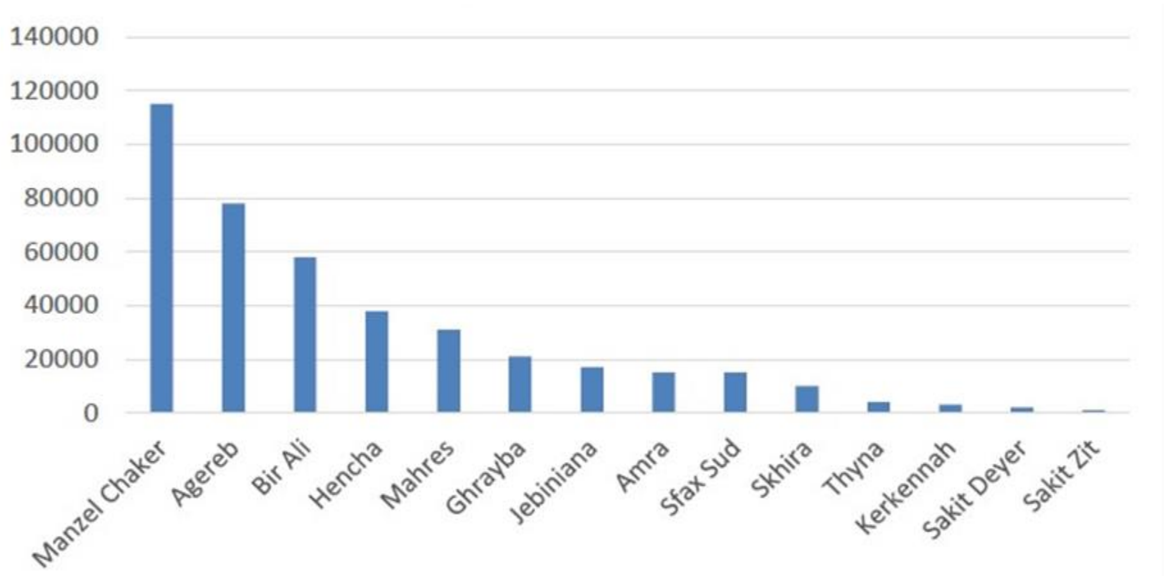


*Figure 31: The olive grove in the Sfax region*

The region has a long tradition of producing olive oil using traditional methods, such as hand-picking the olives and cold-pressing them to extract the oil. However, in recent years, modern

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[2] Commissariat Régional Au Développement Agricole

methods of olive oil production, such as using machinery to harvest the olives and extract the oil, have become more common.

Additionally, the production of olive oil is a vital part of the economy of Sfax, with many farmers and workers involved in the cultivation and production of olives and olive oil. The industry provides jobs for thousands of people in the region and contributes significantly to the local economy. The olive oil produced in Sfax is not only consumed locally but also exported to other parts of Tunisia and the world, making it an essential part of the country's economy and culture. This is due to the high quality of this product, which is characterized by a fruity flavor and low acidity.

The production of olive fruit in this region during the 5 different campaigns is represented in Table 13.

*Table 13: The production of olive fruit in Sfax*

| Year | Olive fruit production |
|---|---|
| *2015/2016* | *69.5 thousand tons* |
| *2016/2017* | *56 thousand tons* |
| *2017/2018* | *343 thousand tons* |
| *2018/2019* | *46 thousand tons* |
| *2019/2020* | *325 thousand tons* |

Also, the production of olive oil in this region during the campaigns is represented in Table 14.

*Table 14: The production of olive oil in Sfax*

| Year | Olive oil production |
|---|---|
| *2015/2016* | *15.5 thousand tons* |
| *2016/2017* | *12 thousand tons* |
| *2017/2018* | *75 thousand tons* |
| *2018/2019* | *10 thousand tons* |
| *2019/2020* | *71 thousand tons* |

These two tables clearly show the fluctuation of olive fruit and olive oil production in Tunisia. We can observe significant variation in olive oil production for the governorate of Sfax, which can range from 10,000 tons to as much as 75,000 tons. This fluctuation is mainly attributed to the amount of rainfall received during that year.

The Sfax region represents 20% of the national olive-growing workforce and 34% of the crushing capacity. Thus, the region of Sfax has about 346 oil mills distributed according to their crushing systems as illustrated in Figure 32.

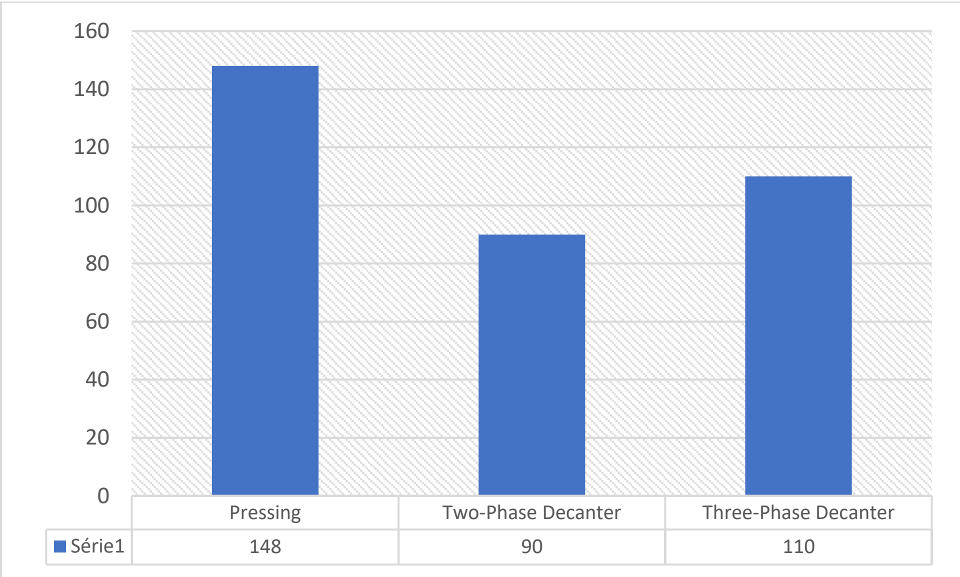


*Figure 32: Distribution of oil mills according to the extraction system*

The functioning of oil mills depends on the rate of olive production. During years of good production, all 346 oil mills can be put into operation. However, there is a considerable drop in their number during years of low production. For example, during the 2013/2014 season, only 81 oil mills were operational due to low olive production caused by the drought that affected the region's various delegations.

Furthermore, the region has 6 refineries located in different delegations. These refineries use all the quantities of pomace provided by the oil mills within the region and also from outside (such as Sousse and Mahdia). Thus, the potential use of this by-product is exclusively destined for export. All of this justifies the choice of the Sfax region for this study.

### IV.2.2. Identifying the decision-making team, the scenarios and the criteria

#### *IV.2.2.1. Establishing the decision-making team*

In this study, the assessment of the olive oil sustainability is conducted. Eight experts from Tunisia were invited to form a team to express their judgments on ten scenarios based on the

understanding of the environmental conditions, economic status, social condition, and the circularity rate of the olive oil production process. All team members have relevant professional backgrounds in the field of agriculture, the extraction process, and the olive oil waste valorization and have abundant agricultural engineering or academic experience in this field.
In this study, we were fortunate enough to receive responses from eight experts in the field of agriculture and olive oil production. Among these experts, three were agricultural engineers, two were affiliated with the Olive Institute in Sfax, one represented the Oil Mills Hedi Fourati in Sfax, one was associated with the CHO company in Sfax, and one was an agricultural worker. The willingness of these experts to participate in our survey and share their insights is greatly appreciated, and their contributions have been invaluable in helping us gain a deeper understanding of the challenges and opportunities in this important sector.

#### *IV.2.2.2. Identifying scenarios*

Ten scenarios were extracted from the scientific literature based on field studies with decision-makers. These scenarios are validated by the experts of the Olive Tree Institute of Sfax. Each scenario involves a complete life cycle of olive oil. Table 15 represents the most widespread situations in the local production chain, including the three main phases of the olive chain: agricultural cultivation, production of olive oil and treatment of waste from these two phases.

For these scenarios, a SADT was integrated to have a broader vision using a top-down analysis of different phases. This tool allows us to specify more precisely the role of each element of the scenario, and also to close the waste loop for each scenario. Our contribution is to build sustainable scenarios while adhering to the CE concept (Appendix C).

In summary, at this point of our proposed methodology aims to develop sustainable scenarios for the olive oil production chain based on field studies and scientific literature. The scenarios cover the complete life cycle of olive oil and are validated by 8 experts. A SADT is used to provide a comprehensive analysis of the scenarios and to ensure that waste is managed effectively. The ultimate goal is to build sustainable scenarios while adhering to the CE concept.

*Table 15: Scenario used in our study*

| | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Agricultural practices** | Conventional | Conventional | Conventional | Conventional | Conventional | Organic | Organic | Organic | Conventional | Conventional |
| **Production system** | Traditional | Traditional | Traditional | Traditional | Traditional | Traditional | Traditional | Traditional | Intensive | Super Intensive |
| **Irrigation** | Dried | Dried | Dried | With irrigation | With irrigation | Dried | With irrigation | With irrigation | With irrigation | With irrigation |
| **Soil management** | Mechanics with use of machines | Mechanics with use of machines | Mechanics with use of machines | Mechanics with use of machines | Mechanics with use of machines | Mechanics with use of machines | Mechanics with use of machines | Mechanics with use of machines | Mechanics with use of machines | Mechanics with use of machines |
| **pruning** | Manual with saws | Manual with saws | Manual with saws | Manual with saws | Manual with saws | Manual with saws | Manual with saws | Manual with saws | Manual with saws | Manual with saws |
| **Harvest** | Manual with workers | Manual with workers | Manual with workers | Manual with workers | Manual with workers | Manual with workers | Manual with workers | Manual with workers | Manual with workers | With olive harvester |
| **Fertilization** | Manure distribution on the ground | Manure distribution on the ground | Manure distribution on the ground | Distribution of manure with NPK on the ground | Distribution of manure with NPK on the ground | Distribution of compost on the ground | Distribution de margine sur le sol | Manure distribution on the ground | Foliar treatment with NPK and microelements + fertigation | |
| **Pesticides and herbicides** | Manual and with insecticides (dimethoate) | Manual and with insecticides (dimethoate) | Manual and with insecticides (dimethoate) | Manual and with insecticides (dimethoate) | Manual and with insecticides (dimethoate) | Nothing | Nothing | Nothing | Herbicide (glyphosate) and insecticides (dimethoate and deltamethrin) | |
| **Extraction method** | Traditional system | 2-phase system | 3-phase system | 2-phase system | 3-phase system | Traditional system | 2-phase system | 3-phase system | 3-phase system | 3-phase system |
| **Packaging method** | Glass bottles | Glass bottles | Glass bottles | Glass bottles | Glass bottles | Glass bottles | Glass bottles | Glass bottles | Glass bottles | Glass bottles |
| **Pomace processing** | Production of heating coal | Nothing | Extraction of pomace oils | Nothing | Extraction of pomace oils | Production of heating coal | Nothing | Extraction of pomace oils | Extraction of pomace oils | Extraction of pomace oils |
| **Treatment of wet pomace** | Nothing | Wet pomace composting with manure | Nothing | Anaerobic digestion | Nothing | Nothing | Anaerobic digestion | Nothing | Nothing | Nothing |
| **Treatment of vegetable waters** | Composting | Application of the margines directly on the fields | Disposal in basins | Application of the margines directly on the fields | Disposal in basins | Composting | Application of the margines directly on the fields | Disposal in basins | Disposal in basins | Disposal in basins |
| **Treatment of pruning residues** | Burning and ash scattering on the fields | Crushing and dispersing on the fields | Burning and ash scattering on the fields | Crushing and dispersing on the fields | Burning and ash scattering on the fields | Burning and ash scattering on the fields | Crushing and dispersing on the fields | Burning and ash scattering on the fields | Crushing and dispersing on the fields | Burning and ash scattering on the fields |

#### *IV.2.2.3. Identifying criteria*

This study takes into account environmental, economic and social goals. A new innovative criterion was added to calculate the waste recovery rate for each scenario. These multiple standards or criteria were then processed through the MCDA process. In this case study, we adopt the extended two-level (Criteria and Sub-criterion) hierarchy shown in Table 16 to carry out the assessment of olive oil.

*Table 16: List of criteria*

| Criteria | Sub-criterion | Description |
|---|---|---|
| **Environmental criteria** | Use of water resources | Amount of water used in a scenario. |
| | Use of abiotic resources | Quantity of abiotic resources (fuel, etc.) used in a scenario. |
| | Pollution | This indicator includes air, water, and soil pollution. |
| **Financial criteria** | Financial performance | It is defined as the financial profitability of a scenario. |
| | Operational costs | All the costs that need to be incurred to carry out a scenario. |
| **Social criteria** | Working conditions | This issue includes hardship, child labor and discrimination (race, sex or other). |
| | Safety at work | This question includes the frequency rate and the severity rate for accidents at work in a scenario. |
| **CE criteria** | Circularity rate | This is the waste recovery rate of a scenario. |

### IV.2.3. Collecting and converting of linguistic assessment

In the real agricultural problem, the choice of the most sustainable scenario is not easy to assess accurately due to the complexity and the contradiction of assessment systems and a lack of knowledge or data about the problem areas.

Therefore, in this study, we define seven grades of assessment information about olive oil sustanibilty issue, which are expressed as linguistic terms T = {‘EL,’‘VL,’ ‘L,’ ‘RL,’ ‘M,’ ‘H,’ ‘VH,’ ‘EH’} (See Table 17).

*Table 17: 2-Tuple Standard assessment*

| Linguistic terms: | Symbols | Semantics value |
|---|---|---|
| Extremely Low | EL | 0 |
| Very low | VL | 0,17 |
| Low | L | 0,33 |
| Medium | M | 0,5 |
| High | H | 0,67 |
| Very High | VH | 0,83 |
| Extremely High | EH | 1 |

Each expert $E^k$ in the team is asked to provide a precise assessment $\tilde{y}_{ij}^{k} = (y_{ij}^{k}, c_{ij}^{k})$ on each scenario following the different criteria, as listed in Appendix D. In this annex, the corresponding eight rows of the elements in the 'Sc1–C1' cell represent the evaluations provided by the experts Ex1–Ex8, respectively.

### IV.2.4. Determining expert weights and aggregation of judgments

#### *IV.2.4.1. Acquiring the individual weights of the experts*

The personal position of each expert in the team is represented in Table 18. Each is allocated a specific score $S_{iwe}$ based on their data (Professional position, Service time, Educational level and Age. The next step is the calculation of the individual weight using Eq. (1) as presented in table 18.

*Table 18: Personal information of the experts*

| No. | Professional position | Service time | Educational level | Age | Score ($S_{iwe}$) | Weight ($W_{iwe}$) |
|---|---|---|---|---|---|---|
| Exp 1 | 4 | 1 | 5 | 1 | 11 | 0,11 |
| Exp 2 | 5 | 2 | 5 | 2 | 14 | 0,14 |
| Exp 3 | 2 | 3 | 4 | 2 | 11 | 0,11 |
| Exp 4 | 5 | 1 | 5 | 4 | 15 | 0,15 |
| Exp 5 | 3 | 3 | 4 | 1 | 11 | 0,11 |
| Exp 6 | 1 | 3 | 3 | 3 | 10 | 0,10 |
| Exp 7 | 4 | 1 | 5 | 2 | 12 | 0,12 |
| Exp 8 | 5 | 3 | 5 | 3 | 16 | 0,16 |

#### IV.2.4.2. *Calculating the relative agreement degree*

The relative agreement degree of an evaluation comment for each scenario with respect to each criterion is determined using Eqs. (2)–(5).

*Table 19:Process for calculating the relative degree of agreement for SC1 \ C1*

| | Exp 1 | Exp 2 | Exp 3 | Exp 4 | Exp 5 | Exp 6 | Exp 7 | Exp 8 |
|---|---|---|---|---|---|---|---|---|
| Exp 1 | 0 | 0 | 0,67 | 0,16 | 0,34 | 0 | 0,17 | 0 |
| Exp 2 | 0 | 0 | 0,67 | 0,16 | 0,34 | 0 | 0,17 | 0 |
| Exp 3 | 0,67 | 0,67 | 0 | 0,83 | 0,33 | 0,67 | 0,5 | 0,67 |
| Exp 4 | 0,16 | 0,16 | 0,83 | 0 | 0,5 | 0,16 | 0,33 | 0,16 |
| Exp 5 | 0,34 | 0,34 | 0,33 | 0,5 | 0 | 0,34 | 0,17 | 0,34 |
| Exp 6 | 0 | 0 | 0,67 | 0,16 | 0,34 | 0 | 0,17 | 0 |
| Exp 7 | 0,17 | 0,17 | 0,5 | 0,33 | 0,17 | 0,17 | 0 | 0,17 |
| Exp 8 | 0 | 0 | 0,67 | 0,16 | 0,34 | 0 | 0,17 | 0 |
| Ad | 0,191 | 0,191 | 0,620 | 0,329 | 0,337 | 0,191 | 0,240 | 0,191 |
| AA | 5,224 | 5,224 | 1,613 | 3,043 | 2,966 | 5,224 | 4,167 | 5,224 |
| RA | 0,160 | 0,160 | 0,049 | 0,093 | 0,091 | 0,160 | 0,127 | 0,160 |

$$Ad^1 = \frac{0 + 0 + 0.67 + 0.16 + 0.34 + 0 + 0.17 + 0}{8-1} = 0,191$$

$$AA^1 = \frac{1}{AA^1} = \frac{1}{0,191} = 5,224$$

$$RA^1 = \frac{5,224}{5,224 + 5,224 + 1,613 + 3,043 + 2,966 + 5,224 + 4,167 + 5,224} = 0,160$$

Considering the comments for the SC1 of C1 for example, seven evaluation values are obtained from experts as follows: {‘L’, ‘L’, ‘EH’, ‘VL’ ‘H’, ‘L’, ‘M’ and ‘L’} which can be transformed into a 2-Tuple model {0,33 ; 0,33 ; 1 ; 0,17 ; 0,67 ; 0,33 ; 0,5 ; 0,33}. Clearly, the assessments offered by experts are inconsistent. The principle that the minority obeys the majority is a convention but the minority is also accounted for in the proposed modified SAM through the relative agreement degree of each. Therefore, for all scenarios and criteria, the following calculation process should be conducted repeatedly, as presented in Table 19.

#### IV.2.4.3. *Obtaining the synthetic dynamic weight of each expert*

The synthetic dynamic weight vector, $w_{11}$= (0,1349 ; 0,1477 ; 0,1333 ; 0,1499 ; 0,1070 ; 0,1186 ; 0,1125 ; 0,1523) is calculated using Eq. (6). Here, relaxation factors α= 0.5, and β= 0.5 are adopted. Similarly, the synthetic dynamic weight vector $w_{ij}^{k}$ of each comment calculated based on the assessment value and the confidence level of the teen assessment cases.

### IV.2.5. Aggregating the 2-Tuple assessment

For the group descion-making problem, the different 2-Tuple assessments of the experts need to be aggregated into one value, using Eq. (7).

The weight of each evaluation should be considered, as well as their order of numerical comparison. The largest and smallest assessments are considered to have relatively low reference values, so they are assigned lower weights. Then, by repeating the previous procedures, a synthetic assessment matrix $\tilde{Y}$is formed as provided in Table 20.

*Table 20: 2-Tuple synthetic assessment matrix*

| | **C1** | **C2** | **C3** | **C4** | **C5** | **C6** | **C7** | **C8** |
|---|---|---|---|---|---|---|---|---|
| **Sc 1** | 0,05869163 | 0,04820473 | 0,06489767 | 0,06033906 | 0,05668121 | 0,06862256 | 0,04875914 | 0,08747944 |
| **Sc 2** | 0,06995024 | 0,07285383 | 0,05091757 | 0,06809189 | 0,08214511 | 0,06463861 | 0,06404074 | 0,09632028 |
| **Sc 3** | 0,06824222 | 0,09277225 | 0,04715783 | 0,06949282 | 0,0696809 | 0,06347239 | 0,06647151 | 0,06900519 |
| **Sc 4** | 0,08402016 | 0,08302332 | 0,04536018 | 0,07924162 | 0,07719927 | 0,05786483 | 0,0704938 | 0,08646426 |
| **Sc 5** | 0,08722484 | 0,10011246 | 0,05913225 | 0,08858024 | 0,07448376 | 0,06158754 | 0,0719962 | 0,06183907 |
| **Sc 6** | 0,06617781 | 0,04650585 | 0,04820941 | 0,07089683 | 0,06216239 | 0,06780897 | 0,07161658 | 0,08350922 |
| **Sc 7** | 0,08328598 | 0,07064838 | 0,06106337 | 0,07253452 | 0,08273748 | 0,07146797 | 0,06848162 | 0,08922241 |
| **Sc 8** | 0,09177391 | 0,07023009 | 0,07527869 | 0,09533878 | 0,07190623 | 0,07034872 | 0,08665663 | 0,06640696 |
| **Sc 9** | 0,11550832 | 0,09623493 | 0,0912335 | 0,09036612 | 0,09012446 | 0,09450007 | 0,09352101 | 0,06434637 |
| **Sc 10** | 0,12197361 | 0,11811867 | 0,09599828 | 0,09554578 | 0,09515484 | 0,09814439 | 0,11238459 | 0,07771352 |

### IV.2.6. Computing sustainability criteria weights

The subjective and objective criteria weights are computed using Eqs. (9)-(11), as shown in Table 21.

*Table 21:Criteria weighting by the subjective, objective and combined weighting methods*

| | **C1** | **C2** | **C3** | **C4** | **C5** | **C6** | **C7** | **C8** |
|---|---|---|---|---|---|---|---|---|
| $w_j^0$ | 0,13636364 | 0,10227273 | 0,13636364 | 0,14772727 | 0,13636364 | 0,09659091 | 0,10227273 | 0,14204545 |
| $w_j^s$ | 0,1591412 | 0,146994397 | 0,086688618 | 0,13191714 | 0,123073095 | 0,105777704 | 0,126868673 | 0,119539202 |
| $w_j^c$ | 0,147752403 | 0,124633562 | 0,111526127 | 0,139822206 | 0,129718366 | 0,101184307 | 0,1145707 | 0,130792328 |

### IV.2.7. Ranking the sustainability scenarios

Based on the criteria ponduration (weighting) provided in Table 22, the ranking of each scenario is determined by the combination of the 2-Tuples model and extended VIKOR method. Eqs. (12) and (13) are used to determine the positive and negative 2-Tuples ideal solution of each criterion.

Each 2-Tuple assessment is compared with the positive and negative ideal solution to measure their distance using the eqs. (2) of (H. C. Liu et al., 2013). Then, based on the integrated weights of the criteria, the maximum group utility $S_i$ and the minimum individual regret $R_i$ of each scenario are computed using Eqs. (15) and (16), and the results are summarized in Table 22.

Then, the ideal solution for calculating group utility values $(S_i, c_i)$ and individual regrets$(R_i, c_i)$ is identified using Eqs. (17) and (18). Finally, the priority index $Q_i$ is calculated using Eq. (19) with parameter $\vartheta$ set to 0.5, and the ranking in ascending order is as listed in Table 22.

*Table 22: Results and ranking of life cycle scenario*

| | $S_i$ | $R_i$ | $Q_i$ | Ranking |
|---|---|---|---|---|
| **Sc 1** | 0,24636715 | 0,13982221 | 0,450 | 6 |
| **Sc 2** | 0,32380253 | 0,10903214 | 0,324 | 4 |
| **Sc 3** | 0,40366907 | 0,10361018 | 0,361 | 5 |
| **Sc 4** | 0,33314552 | 0,06917906 | 0,078 | 1 |
| **Sc 5** | 0,45992166 | 0,13079233 | 0,585 | 8 |
| **Sc 6** | 0,25486089 | 0,0978924 | 0,190 | 2 |
| **Sc 7** | 0,40987525 | 0,09138837 | 0,289 | 3 |
| **Sc 8** | 0,44964662 | 0,11346566 | 0,465 | 7 |
| **Sc 9** | 0,74747971 | 0,13265709 | 0,857 | 9 |
| **Sco 10** | 0,79996365 | 0,1477524 | 1,000 | 10 |

Hence, when $\boldsymbol{\vartheta}$=0.5 ➔ Two conditions represented in Eq. (20) must be satisfied:

- ✓ Condition 1: $(Q(Sc_2) - Q(Sc_1) \geq (1/(n\text{-}1))$ = 0,190 - 0,078 ≥ (1/ (*10*-1)) =0,112 ≥ 0,111 ➔ This condition is verified.
- ✓ Condition 2: $Sc_4$ is the best scenario in the ranked list ($Q_i$), also $Sc_4$ is ranked highest by ($R_i$). ➔ This condition is verified.

After these two conditions, VIKOR is suitable to rank the scenario $Sc_4$ as the most sustainable life cycle of olive oil production with high accuracy.

## IV.3. Validation and discussion

### IV.3.1. Results analysis

In this section, a sustainable olive life cycle for agriculture in Tunisia is proposed in order to achieve circularity objectives and thus ensure a sustainable olive oil production. The proposed life cycle (Scenario 4) involves conventional olive cultivation with irrigation. This type of configuration gives maximum productivity by using an irrigation system, fertilization, Distribution of manure with Azote Phosphore and Potassium (NPK) on the soil, Application of Oil Mill Wastewater directly on the fields and crushing and dispersion on the fields of pruning residues) and using the pesticides and herbicides to produce the agricultural crops.

For the second phase of olive life cycle, the continuous two-phase system was proposed as the most sustainable solution. This type of system produces an olive oil of very good quality and with a better taste (rich in natural antioxidants, polyphenol, etc.) while preserving the environment and ensuring social welfare, however, this method of extraction remains very expensive economically.

For the last phase, our method proposed as the most sustainable scenario to valorize olive oil waste: "Direct application on the soil" for Oil Mill Wastewater and "Anaerobic digestion" for Olive Pomace. Many works have been published on the effects of the spreading of Oil Mill Wastewater on cultivated soils. Agronomic experiments carried out with doses in accordance with fertilization rules have all shown the favorable effect of Oil Mill Wastewater on soil fertility. Indeed, on one hand, they do not contain heavy metals and pathogenic microorganisms, and on the other hand, they are rich in mineral nutrient elements (N, P, K). In addition, as they are made up of organic matter, they represent an excellent substrate for the development of microflora which improves the physicochemical properties of the soil. As well, the extraction system chosen in the second phases produces a small amount of Oil Mill Wastewater compared to other olive processing methods. Therefore, this valorization (recovery) method could be a sustainable solution for this type of waste.

Other works focus on the positive effects of anaerobic digestion on sustainability. In fact, this method has been characterized by a lower environmental impact compared to other methods of recovery of the solid residue. So, the valorization of olive oil waste anaerobic digestion gives Biogas and Organic residue. Biogas can be used for energy and Organic residue can be applied as a soil conditioner.

### IV.3.2. Sensitivity analysis

#### *IV.3.2.1. Control parameter "$\vartheta$"*

The relative importance of the Maximum group utility '$S_i$' and the Minimum individual regret '$R_i$' of the assessment results is managed by $\vartheta$ to generate the sustainability ranking index, as expressed in Eq. (18).

The value choice of $\vartheta$ is [0,1]. Taking $\vartheta$ = 0.1, 0.3, 0.5, 0.7, and 0.9, respectively for Case 1, Case 2, Case 3, Case 4, and Case 5. The obtained results of the sustainability ranking index with the different cases are shown in Figure 33.

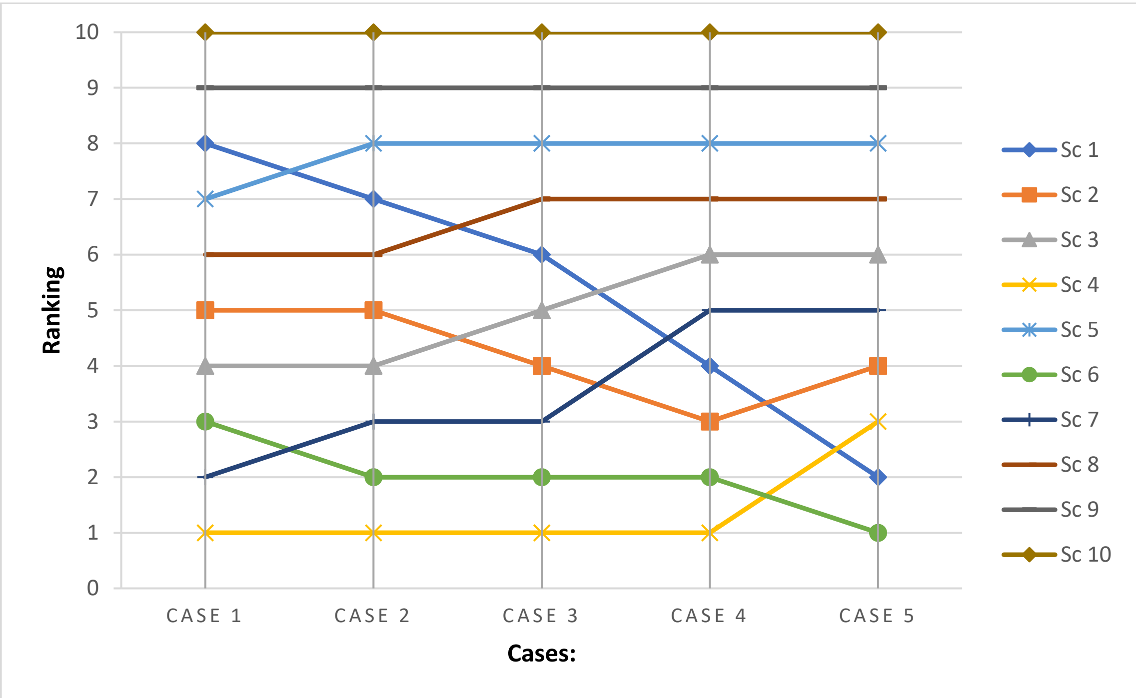


*Figure 33: Sensitivity analysis of the control parameter "$\vartheta$".*

It can be seen from Figure 33 that when the value of the control parameter $\vartheta$ changes, there are some differences in the change of the sustainability priority index, $Q_i$, of each scenario.

It can be seen in Figure 33 that the rankings of the most sustainable and the worst scenarios do not change in many cases (For the most sustainable alternative: Sc 4 in yellow: Case 1, Case 2, Case 3 and Case 4. For the worst scenario alternative Sc 10 in brown: Case 1, Case 2, Case e3, Case 4 and Case 5).

Therefore, in most cases with the change of the value of the control parameter $\vartheta$, we can see that there is no impact on the best and the worst results.

#### *IV.3.2.2. Proportion coefficients $\alpha_S$ and $\alpha_O$*

In Stage 4, the criteria weights are obtained by combining the direct weighting method (subjective weight) and the 2-Tuple method (objective weight). Therefore, proportion coefficients *S* and *O* of the subjective and objective weights, respectively, will directly affect the integrated weights and the scenario ranking results. The range of values for both $\alpha_S$ and $\alpha_O$ is [0,1], and $\alpha_S + \alpha_O = 1$. A sensitivity analysis is performed with S= 0.1, 0.3, 0.5, 0.7, and 0.9, respectively, and the results are illustrated in Figure 34.

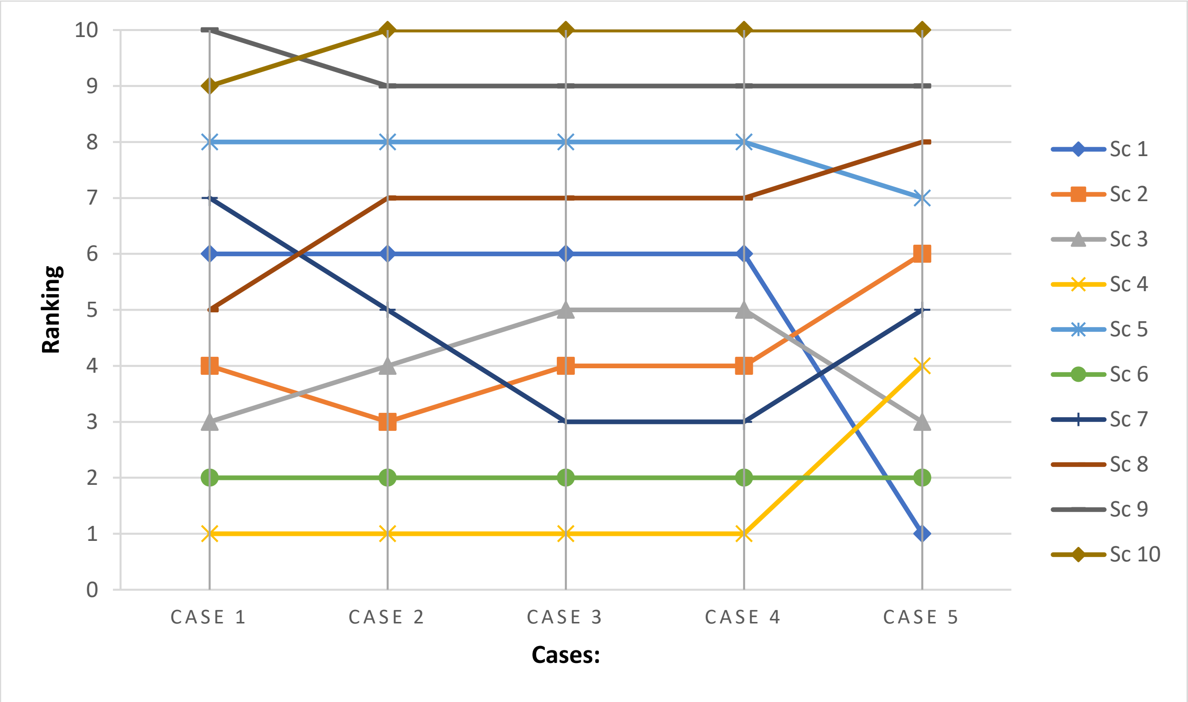


*Figure 34: Sensitivity analysis of the proportion coefficient $\alpha_S$*

When *S* increases from 0.1 to 0.9, the effect of the subjective weight on the integrated weights of the criteria increases gradually, while that of the objective weight decreases, thus resulting in a certain extent of fluctuation in the sustainability ranking of the scenarios, as illustrated in Figure 34.

In comparison, the best and the worst sustainable solutions are almost stable in the different cases, such as scenario 4 is always have the best sustainability results, more specifically in: Case 1, Case 2, Case 3 and Case 4. In addition, scenario 10 and scenario 9 always have the lowest sustainability priorities in: Case 2, Case 3, Case 4 and Case 5. We also note that the sustainability rankings do not change in Cases 3 and 4.

Hence, the overall trend of the assessment results does not change and has a high-ranking stability. It can also be seen that the proportion coefficients are less sensitive to the sustainability ranking results. However, in order to distinguish the sustainability ranking of the different agriculture scenarios, it is necessary to reasonably balance the relative importance of the subjective and objective weight.

#### *IV.3.2.3. Relaxation factors α and β*

The synthetic dynamic weight $w_{ij}^{k}$ of an expert assessment is used to aggregate the 2-Tuple comments It is calculated using the expert individual weight and the relative agreement degree. The relative importance of these two factors is measured by the relaxation factors $\alpha$ and β as expressed in Eq. (6). The relaxation factors satisfy $\alpha$ and $\beta \in [0,1]$ and $\alpha + \beta = 1$.

Their sensitivity is analyzed by selecting 5 cases (S= 0.1, 0.3, 0.5, 0.7, and 0.9, respectively for Case 1, Case 2, Case e3, Case 4 and Case5) with various values of the two relaxation factors in their range and calculating the sustainability priority ranking. The results are shown in Figure 35.

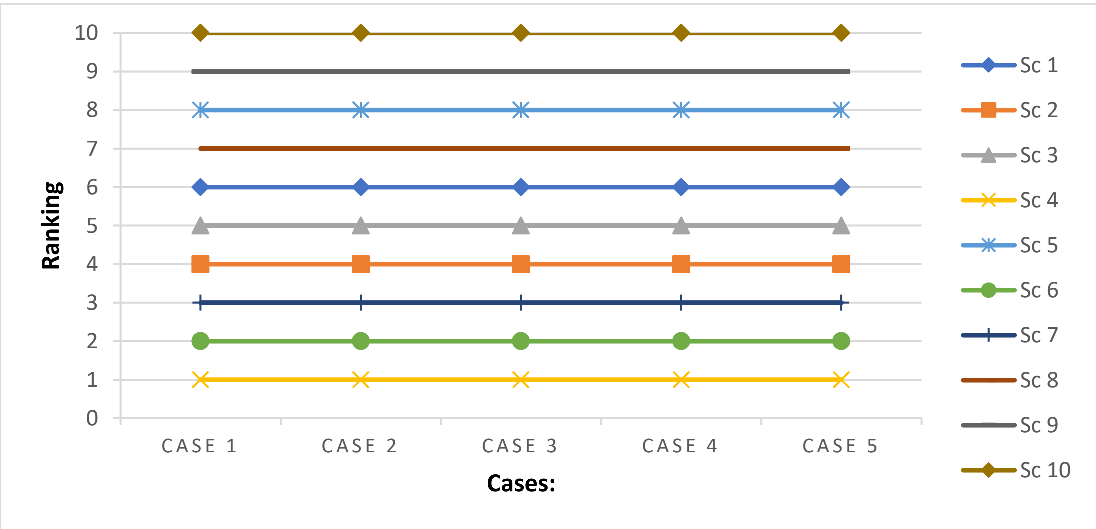


*Figure 35:Sensitivity analysis of relaxation factors (α and β) of the synthetic dynamic weight of experts.*

As shown in Figure 35, when the relaxation factors change, they exhibit stability during the 5 cases. Thus, the ranking result does not vary.

Generally, the sensitivity of the control parameter $\vartheta$ is low, and although the sustainability priority index changes with $\vartheta$, the ranking of the best and the worst results does not vary. Changes in the proportion coefficients $\boldsymbol{\alpha_S}$ and $\boldsymbol{\alpha_O}$ have some impacts on the calculation results of the sustainability priority, especially for the intermediate ranking agricultural scenario. On the contrary, the relaxation factors show significant stability.

In comparison, the scenario of the highest and lowest sustainability priority has little impact, which does not change the overall trend of the ranking results. Therefore, the proposed method presents good robustness.

### IV.3.3. Comparison analysis

To validate the rationality and advancement of the proposed method, a sustainability assessment is conducted by the TOPSPS and PROMRTHEE methods with the current evaluation data from the experts. The results are compared with those obtained by the proposed method, as shown in Figure 36.

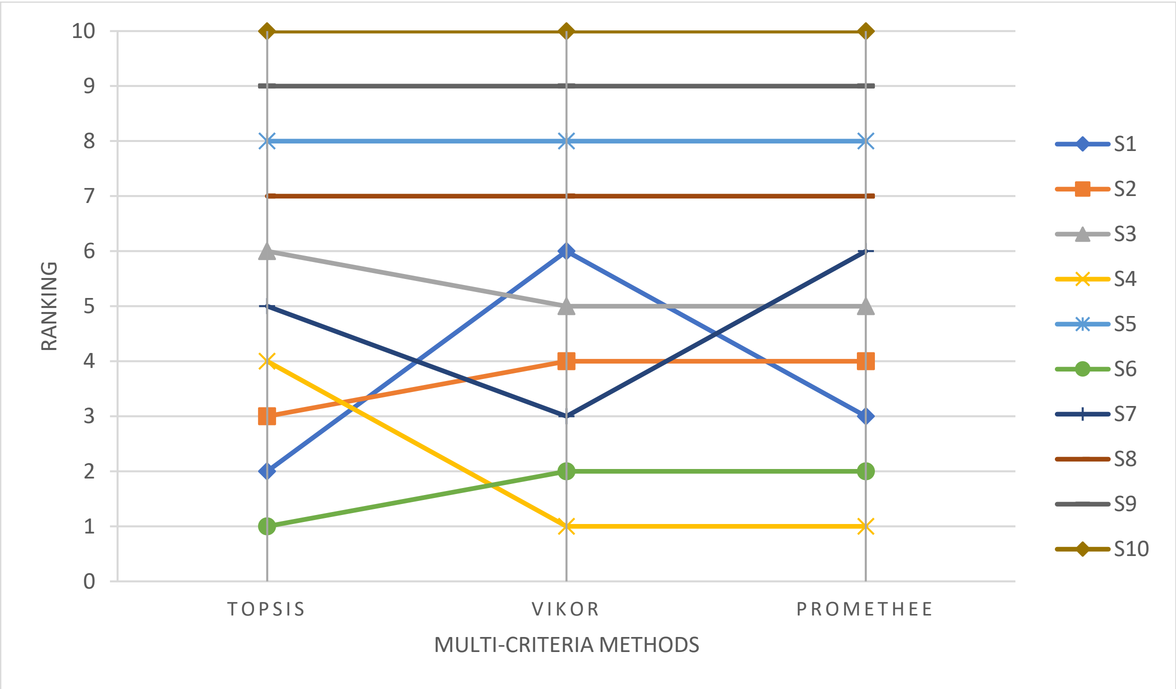


*Figure 36: Comparison of sustainability priority ranking results of different methods*

Figure 36 shows that the sustainability priority ranking results of olive oil life cycle is obtained by PROMRTHEE methods which are slightly different from the improved VIKOR method proposed in this study. However, both methods yield the result that the scenario with the best sustainable priority is scenario 4 and with the lowest are scenarios 9 and 10, which shows the rationality and effectiveness of the improved method. On the other side, TOPSIS method gives another ranking, more specifically in the best sustainable priority which is scenario 6 according to the results shown in Figure 36.

Thus, when several methods define the same best solution, the problem of the best scenario definition is practically solved. In our case, we have to answer the question of which is really the best solution among the best solutions obtained.

For this purpose, a new test has been developed by (Abbas & Chergui, 2017). It allows choosing the best solution among several good solutions. Using the mathematical formula (21), we compute the difference between two ratios, such that, the first one measures the percentage with which the action $A_k \in A$ is better than the action $A_l \in A$, the second one expresses the opposite.

$$A_k > A_l \Leftrightarrow \sum_{j}^{n} W_j \frac{a_{kj}}{a_{lj}} > \sum_{j}^{n} W_j \frac{a_{lj}}{a_{kj}} \quad (21)$$

We assume that $a_{kj}$and $a_{lj}$ are different from 0.

$$A_4 > A_6 \Leftrightarrow \sum_{j}^{n} W_j \frac{a_4}{a_6} > \sum_{j}^{n} W_j \frac{a_6}{a_4}$$

Applying equation (20) between the best solution (scenario 4) and the second solution (scenario 6) yields: $A_4$ =1,166939054 and $A_6$ =0,895561844 $\Leftrightarrow A_4 > A_6$. Thus, the ranking of the VIKOR method is validated by the robustness test.

However, the comparison analysis and the robustness test show that the proposed method is able to obtain a more rational and reliable sustainability ranking of olive oil life cycle in comparison with other existing ranking methods.

## IV.4. Conclusion

In this study, a modified approach based on 2-Tuple and extended VIKOR is proposed to enhance the sustainability of agriculture life cycle. It improves the accuracy of expert judgments to make sustainability analysis more accurate. Then, a real case of olive oil life cycle in Sfax-Tunisia is carried out to validate the feasibility and effectiveness of the proposed approach.

The comparison of the sensitivity analysis results with those of some other similar methods have confirmed that the proposed approach gives more reasonable sustainability priority ranking results. Based on the comparison and discussion, the main contributions of the proposed approach are as follows:

(1) The SADT is integrated to have a larger version using a top-down analysis of successive levels. This tool allows us to specify more and more finely the role of each element of the system, and to close the waste loop for each scenario. Our contribution is to build sustainable scenarios under the CE thinking.

(2) The 2-Tuple linguistic model is adopted to characterize the fuzziness and randomness of the linguistic expressions, such that experts can evaluate the scenario using linguistic terms easily. This adds the flexibility and applicability of sustainability to contradictory criteria.

(3) An improved synthetic dynamic weighting algorithm is proposed, which considers not only the personal status of the expert but also the agreement degree of the expert's comments. The multiplicity and uncertainty of expert knowledge information can be well managed.

(4) Furthermore, both subjective and objective weights of the sustainability criteria taken into consideration make the results more persuasive and comprehensive.

(5) The 2-Tuple extended VIKOR method introduced a sustainability priority index based on the particular measure of proximity to the ideal solution, which is an aggregation of all sustainability criteria and their importance, and a balance between total and individual satisfaction.

As previously mentioned, the feasibility and reasonability of the proposed method for assessing agriculture is verified. However, some limitations should be noted. Although the proposed methodology is employed to assess the olive oil life cycle, it can be expected to be used in other fields. Additionally, the potential relationships between the different criteria are neglected in this method, which may affect the actual scenario.

# Chapter V: Beyond Optimization: Improving the Best Case Scenario using the TRIZ Method

## V.1. Introduction

Sustainability in agricultural life cycle systems often involves addressing conflicting goals. For instance, protecting the environment may necessitate costly investments or changes to production practices, impacting economic viability. To address this challenge, the integration of optimization and inventive approaches becomes crucial in improving sustainability outcomes. By combining optimization techniques with inventive design, we can effectively reduce resource consumption, minimize waste and emissions, promote equitable and ethical practices, and resolve contradictions between various sustainability criteria.

This chapter aims to answer the scientific question of how to effectively combine MCDA and invention to enhance sustainability. Initially, we explore the use of MCDA tools to propose an optimal scenario. However, we recognize that the proposed optimal solution may still remain approximate due to the presence of contradictions, particularly in durability criteria. As we weigh the criteria, improvements in some aspects may lead to degradation in others, highlighting the need for an inventive approach.

To address these contradictions and provide sustainable and inventive solutions simultaneously, we propose the application of inventive design principles, specifically utilizing the TRIZ (Theory of Inventive Problem Solving) method. This chapter presents a comprehensive methodology, beginning with an introduction to the significance of employing an inventive approach to improve scenarios. Subsequently, we provide a literature review on the TRIZ method, encompassing relevant research and studies in the field.

The methodology is then detailed, outlining the step-by-step process of employing the TRIZ method to enhance scenarios. Each step is thoroughly explained, encompassing the tools, techniques, and examples that aid in understanding the process. Furthermore, we present a compelling case study, demonstrating the practical application of the methodology. The case study includes a detailed analysis of a scenario, the steps taken to improve it using the TRIZ method, and the resultant outcomes.

In conclusion, this chapter highlights the importance of combining MCDA and inventive approaches to improve sustainability. By addressing the scientific question at hand, we identify the limitations of optimal solutions generated by MCDA tools and propose inventive design, particularly through TRIZ, as a means to discover sustainable and inventive solutions.

## V.2. TRIZ method: Literature review

TRIZ, which stands for Theory of Inventive Problem Solving, is a methodology developed by Genrich Altshuller in the 1950s. It was created as a heuristic method to solve technical problems in a systematic and creative way. Altshuller analysed 400,000 cases and identified basic patterns that governed the process of generating new ideas and creating innovations. According to TRIZ, any problem that designers encounter may have already been resolved by other designers, and the fundamental idea of TRIZ is to provide access to a wide range of solutions proposed by former inventors. TRIZ involves the analysis of conflicts between design features, utilization of unused aspects of the design to serve value-adding functions, predictions that improve the ideal of the design and 40 general principles that can be used to solve most contradictions (Alʹtshuller, 1984). TRIZ promotes a focus on design feature conflicts at the design stage rather than the final modification, which compromises the quality of the product in other aspects (Boavida et al., 2020). TRIZ has been applied in various fields, including engineering design (Bersano et al., 2017), management (Spreafico, 2021), and sustainability (J. H. Zhou et al., 2022). TRIZ provides tools and techniques that help designers develop new ideas without numerous trials and errors. To solve a problem within TRIZ, the problem-solver must transform the real problem into a conceptual one and search for abstract solutions, which helps to diverge thinking and generate practical solutions. The TRIZ approach to solving a problem is displayed in Figure 37.

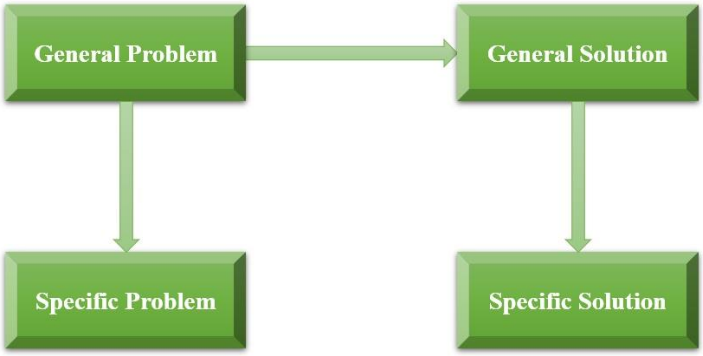


*Figure 37: TRIZ approach to solving an inventive problem*

### V.2.1. Notions of TRIZ

Contradictions refer to problems that arise when desired characteristics within a system conflict with each other. To improve the system, hidden contradictions within it must be identified and resolved. The most effective solutions come from solving technical problems that contain a contradiction. Paradoxical thinking is necessary to uncover these contradictions, but most people tend to avoid them because they can be challenging to resolve. The goal of TRIZ is to avoid compromises by proposing solutions to remove contradictions within a system. There are three types of contradictions: administrative, technical, and physical. In the following, we describe each types of contradictions.

- **An administrative contradiction** occurs when there is a desire to improve a system without showing the direction of the resolution. This kind of contradiction should be transformed into a technical contradiction to reduce ambiguity.
- **A technical contradiction** appears when the improvement of certain characteristics of a system leads to the deterioration of others in the same system. To resolve technical contradictions, TRIZ proposes applying the matrix of contradictions, which includes 39 features used in the design process and inventive principles.
- **A physical contradiction** arises when one element of the system should have two opposite values simultaneously. To resolve physical contradictions, TRIZ proposes several separation principles.

Contradiction comprises three components: elements, parameters, and values. In the following, we describe each component.

- **Elements:** They are the constituents of the system (Cavallucci et al., 2009, 2011). From a syntactical viewpoint, elements could be expressed by applying nouns, names, or groups of names. The nature of an element could be constantly changed based on the description which is given by it (Cavallucci et al., 2009).

- **Parameters:** These qualify elements by giving them a specificity, reflecting an explicit knowledge of the observed field (Zanni-Merk et al., 2009). It is possible to use adverbs, names, or complements to object to express the parameters. The form of their expression is different when represented by various experts (Cavallucci et al., 2009). There are two categories of parameters (Rousselot et al., 2012):
  - **Action parameters** have a negative effect on another parameter when their value is negative and a positive effect when their value is positive.
  - **Evaluation parameters** evaluate the positive and negative aspects of the designer's choice.

➢ **Values** are the adjectives used to describe a parameter.

Finally, **poly-contradiction** (See Table 23) is the relationship between all contradictions arising from the encounter between the parameters and it can be shown using a poly-contradiction template, which is a table that lists all related evaluation parameters under the action parameter.

*Table 23: Contradiction table*

| | **Action Parameter** | |
|---|---|---|
| | **(Va)** | **($Va^{-}$)** |
| **Evaluation Parameter (EP1)** | ☺ | ☹ |
| **Evaluation Parameter (EP2)** | ☹ | ☺ |

### V.2.2. Knowledge-based tools

Tools based on knowledge can provide valuable information to transform systems. One such group of tools includes inventive principles, 76 standard solutions, and effects. The 40 inventive principles were derived by analysing 40,000 patents across various fields and can help solve contradictions in systems. These principles are general solutions that allow designers to generate innovative ideas. The contradiction matrix is an effective tool of TRIZ that consists of 39 columns and rows. The matrix can guide designers to the inventive principles by identifying the technical parameters that need improvement and degradation. The process of applying the contradiction matrix includes three steps:

1) *Step 1:* The desired parameter should be translated into one of technical parameters existing in the rows.

2) *Step 2:* The harmful feature is transformed into one of the parameters of the vertical columns.

3) *Step 3:* The designers extract one or several inventive principles from the intersection of the parameters to solve the technical contradiction (Haines-Gadd, 2016).

The 76 standard solutions, developed by G. Altshuller and associates, help solve inventive problems based on the laws of evolution of technological systems. The standards are grouped into five classes and 18 groups, with each class offering different solutions for system improvement.

### V.2.3. TRIZ and Sustainability

In recent years, TRIZ has been increasingly used in sustainability-related contexts to develop more environmentally friendly products, processes, and systems. TRIZ's ability to identify contradictions and resolve them creatively makes it a powerful tool for sustainable innovation. TRIZ has been used to reduce waste, energy consumption, and material use, as well as to extend product life and optimize resource use. Several studies (Alvarez et al., 2022; Ben Moussa et al., 2019; Benmoussa, 2022; Bersano et al., 2017; Schaumann, 2022; Yang & Chen, 2011a, 2012) have investigated the use of TRIZ in eco-design, and they have found it to be effective in identifying more focused and conscious solutions compared to traditional approaches.

Conversely, designers face the critical demand for sustainability, which has been emphasized by legal standards, regulations, and the growing environmental consciousness of consumers. To address this challenge, several techniques have been developed to assist designers in evaluating the product's life cycle and providing recommendations for designing sustainably. TRIZ methodology, in particular, offers concepts and tools that can be employed to evaluate and innovate a technical system that meets sustainability requirements. A recent study (Yang & Chen, 2011b) explores the potential of TRIZ in ecological design by reorganizing TRIZ tools, such as Ideality, Resources, and the Laws of technical systems evolution, as eco-design guidelines for product innovation. These guidelines were tested on household appliances, and their effectiveness was evaluated by proposing them to students without any prior experience in TRIZ. The positive outcomes of the study have encouraged the authors to further develop this method.

In conclusion, TRIZ is a powerful methodology that has been increasingly applied in sustainability-related contexts to develop innovative and sustainable solutions. Its ability to identify and resolve contradictions creatively makes it a valuable tool for eco-design and sustainability-oriented innovation.

## V.3. Proposed methodology

The methodology proposed in this study aims to provide a sustainable and innovative life cycle for products by defining the problem area and providing a step-by-step guide to finding an innovate sustainable solution. Therefore, the present case study incorporates Multi-Criteria Decision Analysis (MCDA) in conjunction with Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (SLCA), along with the Theory of Inventive Problem Solving (TRIZ). The primary objective of this study is to examine the contradictions between the rankings of different olive oil life cycles, as established in the sustainability assessments conducted in the previous chapter (Chapter 4) and the ongoing chapter. By identifying these contradictions, our aim is to provide decision-makers with the most innovative and sustainable solutions for olive oil production practices. This comprehensive approach enables a holistic evaluation of the various dimensions of the life cycle, considering environmental, economic, and social aspects, thus offering a more robust and well-rounded perspective for decision-making in the industry.

The methodology consists of nine steps that will be explained in detail below, (See Figure 38):

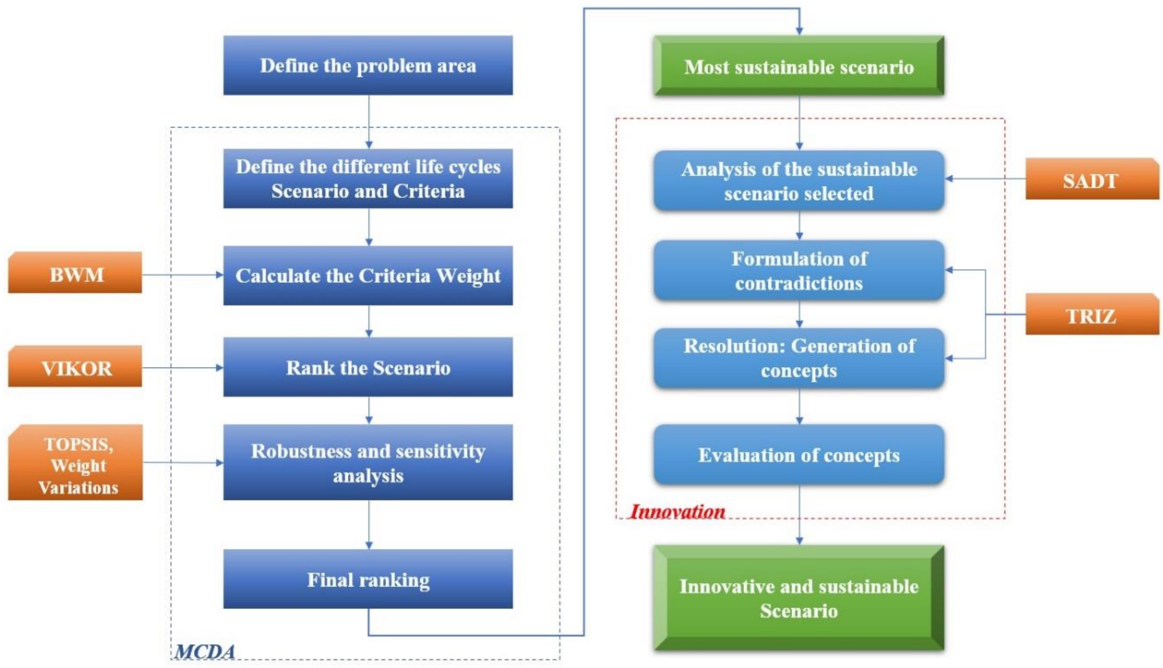


*Figure 38: Methodological framework*

- **<u>Step 1:</u>** The objective of this step is to define the problem area. This involves identifying the specific problem that needs to be addressed. For example, the problem could be reducing the environmental impact of a product or improving its durability. Defining the problem area provides a clear direction for the rest of the methodology.
- **<u>Step 2:</u>** The objective of this step is to define the different life cycles of the product that needs to be studied, and criteria to construct decision matrix. The life cycles could include manufacturing, transportation, use and disposal/recycling. Criteria to construct the decision matrix can include factors such as environmental impact, cost, and usability. These criteria will be used in later steps to evaluate the alternatives.
- **<u>Step 3:</u>** The objective of this step is to calculate the criteria weight using a weighting method. This step involves assigning weights to the different criteria based on their relative importance. The values of the weights of the sustainability evaluation criteria are determined using the BWM method. Those weights will be used in later steps to evaluate the alternatives. The BWM method consists of five steps, (Rezaei, 2015b):

  **Step 3.1:** Determine the best (e.g., most desirable, most important) and worst (least desirable, least important) criteria by the decision maker. No comparison is made in this step.

**Step 3.2:** Determine the preference of the best criterion over all others using a number between 1 and 9. The Best vector would be:

$$A_B = ( a_{B1,}\ a_{B2,}\ a_{BI,}\ a_{Bn} ) \qquad (22)$$

where $a_{BI,}$ indicates the preference of the best criterion *B* over criterion *I*. It is clear that $A_{BB}$=1.

**Step 3.3:** Determine the preference of all criteria over the worst criterion using a number between 1 and 9. The resulting Others to Worst vector would be:

$$A_W = ( a_{W1,}\ a_{W2,} a_{WI,}\ a_{Wn} ), \qquad (23)$$

where $a_{W1}$ , indicates the preference of criterion I over the worst criterion W. It is clear that $A_{Ww}$=1.

**Step 3.4:** Find the optimal weights ($W_1^*$,$W_2^*$, ......,$W_n^*$)

The problem can be transformed into the following problem:

Min ξ with the constraints:

$$|W_B - a_{BI}W_I| \leq \xi, \text{ pour tout } I \qquad (24)$$

$$|W_I - a_{IW}W_W| \leq \xi, \text{ pour tout } I \qquad (25)$$

$$\sum_I W_I = 1 \qquad (26)$$

$$W_I \geq 0, \text{ for all } I. \qquad (27)$$

Where:

$W_B$ : the best criterion B over *I*, $W_I$ : the worst criterion over W, $a_{BI}$ : the preference of the best criterion *B* over criterion *I*, $a_{IW}$ the preference of criterion *I* over the worst criterion *W*.

By solving the problem, the optimal weights ($W_1^*$,$W_2^*$, ......,$W_I^*$) and $\xi^*$ are obtained.

- **<u>Step 4:</u>** The objective of this step is to rank the alternatives using the Multiple Criteria Decision Making (MCDM) method. This step involves evaluating each alternative based on the criteria defined in the second step and using the weights defined in the third step. This step provides a ranking of the alternatives using VIKOR method based on their overall sustainability.

**Step 4.1:** Building the decision matrix, quantitative values of selected criteria (environmental, economic and social indicators) are expressed in matrix form.

**Step 4.2:** Determination of the best ($f_i^*$) and worst ($f_i^-$) values for each *Ci*. Therefore, equations (28) and (29) are used as follows:

If the criterion function is a benefit

$$f_{\mathrm{i}}^* = max f_{ij} \; ; f_{\mathrm{i}}^- = min f_{ij} \tag{28}$$

If the criterion function is a cost

$$f_{\mathrm{i}}^* = min f_{ij} \; ; f_{\mathrm{i}}^- = max f_{ij} \tag{29}$$

**Step 4.3:** In order to develop the distance of alternatives to the ideal solution, it is necessary to calculate the *Sj* indices (group utility values) in equation (28) and *Rj* (individual regrets) in equation (29).

The first $S_k$ represents the distance from an alternative to a positive ideal solution, while the second $R_k$ represents the distance from an alternative to a negative ideal solution.

$$S_j = \frac{\sum_{i=1}^{n} W_I^* \left(f_i^* - f_{i,j}\right)}{\left(f_i^* - f_i^-\right)} \tag{30}$$

$$R_j = max_i \left[ W_I^* \frac{\left(f_i^* - f_{i,j}^-\right)}{\left(f_i^* - f_i^-\right)} \right] \tag{31}$$

**Step 4.4:** Then the calculation of $Q_j$ in equation (32) represents the VIKOR synthetic index. The lowest value of $Q_J$ corresponds to the best scenario that is closest to the ideal value, ϑ represents the weight of the alternative with maximum utility and is normally equal to 0.5.

$$Q_J = \vartheta \frac{(S_j - S^*)}{(S^- - S^*)} + (1 - \vartheta) \frac{(R_j - R^*)}{(R^- - R^*)} \tag{32}$$

**Step 4.5:** When $\vartheta$=0,5 ➔ the two conditions must be met:

- Condition 1°: $(Q(A_2) - Q(A_1) \geq (1/(n-1))$ (33)

  Where: *n*: number of alternatives, *A1*: best alternative in the ranking list, *A2*: second best alternative in the ranking list.

- Condition 2: *A1* must also be the highest ranked by *S* and/or *R*.

After these two conditions, VIKOR can rank alternatives to quickly determine the best scenario accurately.

- **Step 5:** The objective of this step is to perform robustness and sensitivity analysis. This step involves evaluating the robustness of the alternatives to variations in the criteria and weights. Sensitivity analysis involves evaluating how changes in the criteria or weights affect the ranking of the alternatives. This step involves evaluating the robustness of the alternatives to variations in the criteria and weights, using the TOPSIS method to verify the robustness of the VIKOR calculation results and to analyse the consistency of the results.
- **Step 6:** Analysis of the most sustainable scenario selected: This step involves clearly describing the problem to be solved using modelling tools such as diagrams, schematics, or mind maps. It is important to identify the parties involved in the problem, environmental conditions, available resources, goals to be achieved and constraints to be respected. Our contribution is to integrate SADT in order to analysis all the loops of the initial situation. This tool could identify the different "materials flow" and "Return loops" in the most sustainable scenario. The next step is to propose new processes to exploit the return loops results while adding a new phase to the life cycle called the waste recovery management phase in order valorise all the identified waste during the life cycle. This step could help use to understand the different loops and give us an overview of the different contradiction that must be formulated in the most sustainable scenario (See Figure 39).

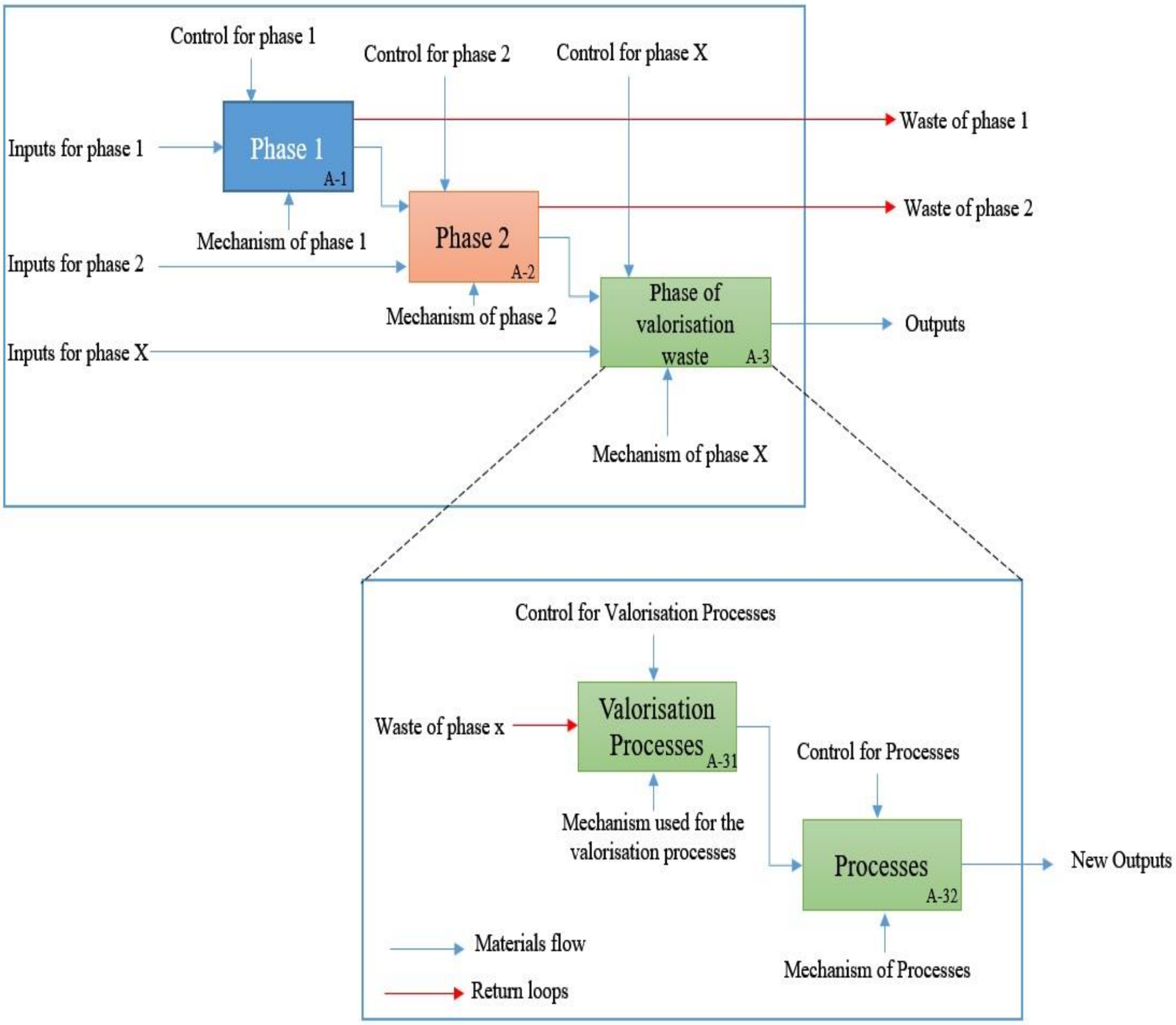


*Figure 39: SADT methodology*

- **Step 7:** Formulation of contradictions: TRIZ proposes that problems can be solved by identifying underlying contradictions. By identifying contradictions, we can begin to generate ideas to solve the problem.
- **Step 8:** Resolution: Generating Innovative Concepts: This critical step involves the application of TRIZ principles and tools to generate inventive solutions that effectively address the identified contradictions. However, it is essential to emphasize that in order to leverage TRIZ effectively, it is necessary to first model the problem using compatible criteria, parameters, and other relevant factors aligned with the 39 parameters of TRIZ. This modelling process allows for a comprehensive analysis, facilitating the identification of suitable inventive concepts that can successfully overcome the identified contradictions with precision and efficacy.

- **Step 9:** Evaluation of concepts: This step involves evaluating the ideas generated in the previous phase using criteria such as technical feasibility, cost, safety, sustainability, and environmental impact. Concepts that best meet the criteria are selected for further implementation. In conclusion, this methodology provides a systematic and comprehensive approach to finding sustainable solutions for product life cycles. By defining the problem area, identifying the criteria, and using MCDM and TRIZ, this methodology allows for a sustainable and innovative life cycle for products. The nine steps provide a clear and concise guide for addressing sustainability issues in product design and development.

## V.4. Case study

To illustrate our inventive decision-making methodology presented in Figure 38, for selecting the best sustainable and innovated scenario, we provide a second case study of olive oil supply chain using the life cycle sustainability assessment.

**Step 1:** The second case study of olive oil supply chain localised also in the region of Sfax-Tunisia. This case concerns agricultural practices, processing methods, and waste management practices in the olive oil industry.

**Step 2:** 8 scenarios have been identified through field studies with stakeholders such as farmers, mills, and government officials. These scenarios have been validated by experts from the Olive Institutes in Sfax. Each scenario includes a complete life cycle of olive oil (See Table 24), representing the most common situations in the local production chain, including the three main phases of the olive chain: agricultural cultivation, olive oil production, and waste management.

*Table 24: Description of scenarios*

| Phase | Practice | Scenarios (Density between 17 and 34 olive trees/ha) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 |
| Agriculture phase | **Agricultural practices** | Conventional | | | | Organic | | | |
| | **Production system** | 900 kg/ha | | 2160 kg/ha | | 1660 kg/ha | | 850 kg/ha | |
| | **Irrigation** | Dried | | With irrigation | | With irrigation | | Dried | |
| | **Soil management** | Mechanics with use of machines | | | | | | | |
| | **pruning** | Manual with saws | | | | | | | |
| | **Harvest** | Manual with workers | | | | | | | |
| | **Fertilization** | Distribution of manure and waste water from mills with fertiliser and on the ground | | | | With manure and wet pomace compost | With wet pomace compost and wastewater from the mills | With manure and wet pomace compost | With wet pomace compost and wastewater from the mills |
| | **Pesticides and herbicides** | Manual, twice a year, with insecticides (dimethoate) | | | | -- | | | |
| Extraction | **Extraction method** | Traditional system | 3-phase system | Traditional system | 3-phase system | 2-phase system | | | |
| Waste Management Phase | **Pomace processing** | Extraction of pomace oils | | | | -- | | | |
| | **Treatment of wet pomace** | -- | | | | With manure and wet pomace compost | With wet pomace compost and wastewater from the mills | With manure and wet pomace compost | With wet pomace compost and wastewater from the mills |
| | **Treatment of vegetable waters** | Application des eaux usées des moulins directe sur les champs | | | | | | Application des eaux usées sur les champs | |
| | **Treatment of pruning residues** | Crushing and dispersing on the fields | | Burning and ash scattering on the fields | | Crushing and dispersing on the fields | | Burning and ash scattering on the fields | |

**Step 3:** The BWM method was used to obtain the weight of each criterion by applying equations (24), (25), (26), and (27). Table 25 shows the weights of the criteria in our case study.

Table 25: Weight matrix of the three criteria

| Criteria | Sub-Criteria | Weight of Sub-Criteria | Weight of Criteria |
|---|---|---|---|
| AeCV | Global warm | 0,323 | 0,710 |
| | Eutrophication | 0,194 | |
| | Acidification | 0,194 | |
| AcCV | Operation cost (DT) | 0,097 | 0,194 |
| | Productivity (Kg) | 0,097 | |
| AsCV | Workers | 0,032 | 0,097 |
| | Work conditions | 0,065 | |

**Step 4:** The evaluation of each scenario from environmental, economic and social, criteria is based on the understanding and knowledge of multiple stakeholders acquired through statistics and our surveys.

- ***Life Cycle Assessment, (LCA):*** Environmental life cycle analysis is generally used to identify environmental impacts, in order to determine the assessment of sustainability. Decision-makers and experts have selected the methodologies that suit them, including the CML 2 characterization and the ReCiPe 2008 methodologies, (Salomone & Ioppolo, 2012b). Three environmental impact categories were obtained, as defined by the CML 2 baseline 2000 V2.04 characterization: Global warm, Eutrophication and Acidification. The results of this part were developed and analysed with the SimaPro 7.2 software (Salomone & Ioppolo, 2012b), Figure 39.

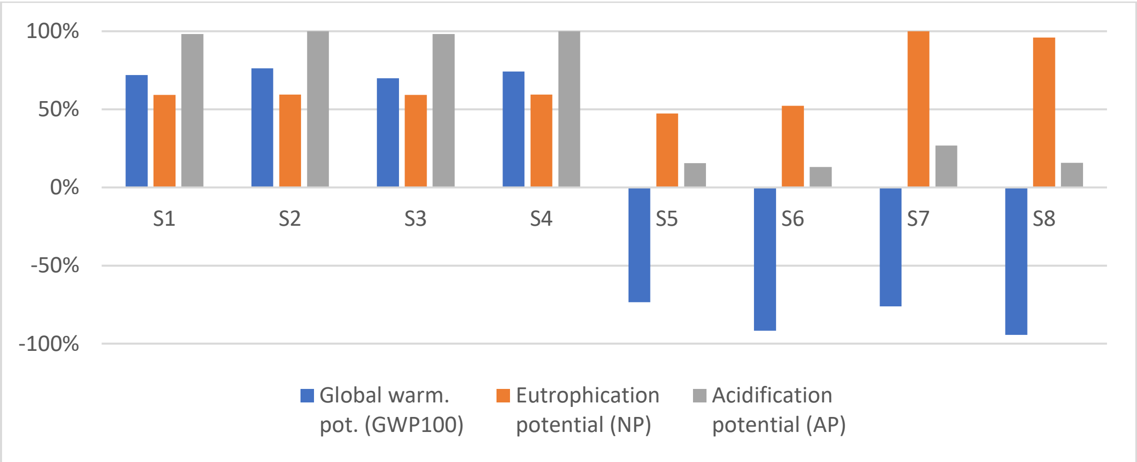


Figure 40: Environmental impact of each scenario

A comparison between the eight scenarios per functional unit is carried out (1000 kg of olives). The results obtained are presented in Figure 40 and show, in general, the conventional scenarios (Scenarios 1, 2, 3 and 4) presenting the highest environmental loads for each category of impact studied, while the scenarios (Scenarios 5, 6, 7 and 8) present negative environmental loads, therefore less polluting.

- ***Life Cycle Costing (LCC):*** In this study, decision-makers and experts selected economic criteria such as: operating cost and productivity. The results of this part have been developed with surveys and interviews with stakeholders. Figure 41 presents the economic impacts of each scenario, scenarios 5 and 6 present the highest economic burdens, this is due to the type of investment in the transformation phase (2-phase centrifugation system). This technique is considered a sustainable technique since it does not require a large amount of water, but it is still very expensive.

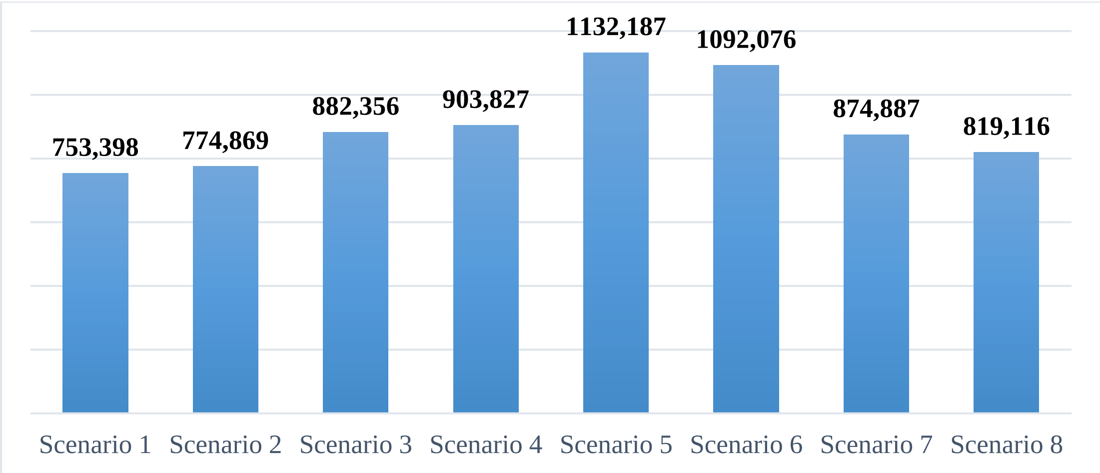


Figure 41: Economic impact of each scenario

- ***Social life cycle Assessment (S-LCA):*** In this study, decision makers and experts have selected social criteria such as: Workers (Human Rights) and Working conditions.

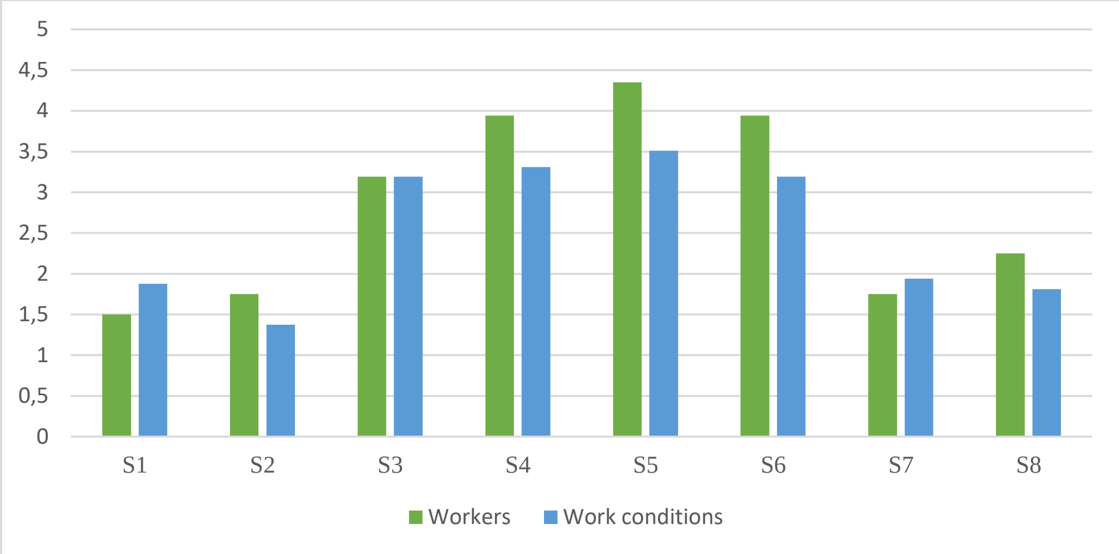


*Figure 42: Social impact of each scenario*

The results of this part have been developed with surveys and interviews with stakeholders. In our survey, a Likert scale has 5 points to express the degree of agreement or disagreement with a statement. Human rights and working conditions are less respected in scenarios S3, S4, S5 and S6, this is linked to productivity in these scenarios which is the greatest (See Figure 42). These scenarios require more physical effort.

*Table 26: The decision matrix of our investigation*

| Sous-critères | | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 |
|---|---|---|---|---|---|---|---|---|---|
| LCA | **Global warm** | 4,8E+02 | 5,1E+02 | 4,7E+02 | 5,0E+02 | -4,9E+02 | -6,1E+02 | -5,1E+02 | -6,3E+02 |
| | **Eutrophication** | 4,4E+01 | 4,5E+01 | 4,4E+01 | 4,5E+01 | 3,5E+01 | 3,9E+01 | 7,5E+01 | 7,2E+01 |
| | **Acidification** | 1,1E+01 | 1,1E+01 | 1,1E+01 | 1,1E+01 | 4,0E+00 | 1,4E+00 | 2,9E+00 | 1,7E+00 |
| LCC | **Operation cost (DT)** | 753,398 | 774,869 | 882,356 | 903,827 | 1232,18 | 1092,07 | 874,887 | 819,116 |
| | **Productivity (Kg)** | 900 | 900 | 2160 | 2160 | 1740 | 1660 | 850 | 850 |
| S-LCA | **Workers** | 1,5 | 1,75 | 3,19 | 3,94 | 4,35 | 3,94 | 1,75 | 2,25 |
| | **Working conditions** | 1,875 | 1,375 | 3,19 | 3,31 | 3,51 | 3,19 | 1,94 | 1,81 |

After obtaining the decision matrix, presented in table 26, the VIKOR method can be applied to evaluate the ranking of the 8 scenarios in order to obtain the best compromise solution. The results of the VIKOR calculation are illustrated in table 27.

*Table 27: VIKOR assessment results and sorting*

| | $S_j$ ***Eq(30)*** | $R_j$ ***Eq (31)*** | $Q_j$ ***Eq(32)*** | ***Classement*** |
|---|---|---|---|---|
| **S1** | 0,3297 | 0,1570 | 0,9631 | 6 |
| **S2** | 0,3324 | 0,1613 | 0,9856 | 7 |
| **S3** | 0,3242 | 0,1556 | 0,9457 | 5 |
| **S4** | 0,3391 | 0,1599 | 0,9944 | 8 |
| **S5** | 0,1583 | 0,0484 | 0,1672 | 2 |
| **S6** | 0,1064 | 0,0342 | 0,0000 | 1 |
| **S7** | 0,1995 | 0,0968 | 0,4461 | 4 |
| **S8** | 0,1584 | 0,0895 | 0,3292 | 3 |

Based on the results presented in Table 27, it can be observed that scenario 6 is ranked highest according to the $Q_j$ value (i.e., the minimum value) calculated using Equation (32). Since $\theta$=0.5, the two conditions of Step 5 were examined based on the ranking of the different scenarios. Condition 1: according to Equation (33) > Q(S6)-Q(S5) = 0.1672 > 1/(8-1) = 0.143. Condition 2: this alternative is ranked the highest by S and R. Both conditions are satisfactory, so the VIKOR method ranking is relevant.

**Step 5:** A sensitivity analysis was conducted by assigning different weight vectors to the criteria, for 4 cases: Equal importance: assigning an equal weight of 0.333 to each of the three criteria (case 1). One dominant with the rest equally important (cases 2, 3, and 4): this means a dominant weight is assigned to one criterion and an equal weight is assigned to the other 2 criteria. Taking case 2 as an example (See Table 28), a dominant weight of 0.40 is assigned to environmental impacts and a weight of 0.30 is assigned to each of the other two criteria (economic and social). According to the results presented in Table 28, scenario 6 is the most sustainable and scenario 4 is the worst in all four cases. Therefore, it can be concluded that the proposed method for calculating the weights of the criteria is valid in terms of sensitivity.

*Table 28: Results of the sensitivity analysis by modifying the weights of the criteria*

| Poids : | | | Cas : | Scénarii | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Env** | **Eco** | **Soc** | | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 |
| **0.33** | **0.33** | **0.33** | **Cas 1** | 5 | 4 | 2 | **8** | 7 | **1** | 6 | 3 |
| **0.40** | **0.30** | **0.30** | **Cas 2** | 5 | 4 | 2 | **8** | 7 | **1** | 6 | 3 |
| **0.30** | **0.40** | **0.30** | **Cas 3** | 6 | 5 | 2 | **8** | 3 | **1** | 7 | 4 |
| **0.30** | **0.30** | **0.40** | **Cas 4** | 3 | 2 | 6 | **8** | 7 | **1** | 4 | 5 |

The TOPSIS method was conducted in this study to verify the performance evaluation of the VIKOR analysis. The ranking coefficients, previously calculated by the TOPSIS method for the 8 scenarios are: (S1=0.159, S2=0.155, S3=0.174, S4=0.165, S5=0.829, S6=0.910, S7=0.775, and S8=0.819). Based on the results of the complete evaluation model, the sequence of olive oil life cycles, from best to worst, was derived as follows: Scenario 6 (best), Scenario 5, Scenario 8, Scenario 7, Scenario 3, Scenario 4, Scenario 1, Scenario 2 (worst). The order of the top four solutions obtained by both methods (TOPSIS and VIKOR) is similar. Therefore, it can be concluded that the proposed method for ranking alternatives is valid in terms of robustness.

**Step 6:** Scenario 6 is comparatively better than the other scenarios, particularly in terms of environmental, economic, and social performance. The SADT has been used to analyse complex systems and identify the root causes of problems (Appendix E). In this case study, SADT was used to analyse all the loops of scenario and identify contradictions in scenario 6. By providing a clear and structured representation of the system, SADT allowed the team to identify the various interactions and dependencies between different components, providing insight into the root causes of the problem. Furthermore, the identification of contradictions within the scenario using SADT allowed us to propose solutions that would resolve these conflicts and help to achieve the desired goals. The use of SADT in analysing the initial situation and identifying the different contradictions has proven to be an effective tool for various scientific and engineering fields.

**Step 7:** Many contradictions were identified in Scenario 6 (Most sustainable solution in the second case study, chapter 5) and Scenario 4 (Most sustainable solution in the first case study, chapter 4). These contradictions are summarized in the following tables:

- ***<u>Contradiction 1:</u>*** Using water to clean olives during the extraction phase but not using it to satisfy environmental impacts (See Table 29).

*Table 29: Contradiction 1*

| | | Cleaning olives | |
|---|---|---|---|
| **Contradiction 1** | | **Clean (Va)** | **Unclean (Va -)** |
| | **Use of water** | ☺ | ☹ |
| | **Environmental impact** | ☹ | ☺ |

- ***<u>Contradiction 2:</u>*** The pesticides and herbicides have to be used to satisfy productivity and not used to satisfy environmental impacts (See Table 30).

*Table 30: Contradiction 2*

| | | Agricultural practice | |
|---|---|---|---|
| **Contradiction 2** | | **Conventionnel (Va)** | **Organique (Va $^{-}$)** |
| | **Productivity** | ☺ | ☹ |
| | **Environmental impact** | ☹ | ☺ |

- ***<u>Contradiction 3:</u>*** The agricultural practices have to be conventionnel to satisfy productivity and organic to satisfy environmental impacts, (See Table 31).

*Table 31: Contradiction 3*

| | | Pesticides and herbicides | |
|---|---|---|---|
| **Contradiction 3** | | **Using (Va)** | **Not using (Va -)** |
| | **Productivity** | ☺ | ☹ |
| | **Environmental impact** | ☹ | ☺ |

- ***<u>Contradiction 4:</u>*** The Treatment of pruning residues has to be crush and dispersal on the fields to satisfy the environmental impacts and burning and ash scattering on the fields to satisfy Treatment cost, (See Table 32).

*Table 32: Contradiction 4*

| Contradiction 4 | | Treatment of pruning residues | |
|---|---|---|---|
| | | **Crush and dispersal on the fields (Va)** | **Burning and ash scattering on the fields ($Va^-$)** |
| | **Environmental impact** | ☺ | ☹ |
| | **Treatment cost** | ☹ | ☺ |

**Step 8:** In this step, the previously identified contradictions mentioned in step 7 will be resolved by generating inventive solutions:

❖ ***The possible inventive solution to the first contradiction:***

The first evaluation parameter, "Use of water" can be found in Parameter 26, "Amount of substance" in the TRIZ matrix. The second evaluation parameter, "Sustainability" can be found in Parameter 23, "Waste of substance" By combining these parameters in the TRIZ matrix, we arrived at four potential inventive principles: Local Quality (3), Universality (6), Prior Action (10) and Intermediary (24). In our case study, two principles could be used to solve this contradiction:

- The inventive principle 10, "Prior Action", the waste water that was used to cleaning action could be used to irrigate the olive trees, this system called "The closed-loop water system"
- The inventive principle 3, "Local Quality" could be interpreted by replacing water by other alternative such as steam and ultrasound. In this case, the parameter that was changed was the use of water in the extraction process.

The closed-loop water system was inspired from the circular economy principle could be proposed as a solution of how the parameter of water usage was changed to achieve the desired effect of reducing water usage and minimizing environmental impact. By capturing and recirculating water within the process or using alternative cleaning methods, the overall water usage can be reduced and wastewater discharge can be prevented.

The second solution could be to use another cleaning methods that do not require water. For example, some expert use mechanical or dry-cleaning methods to clean objects instead of using water. These methods can be effective at removing debris and contaminants from the objects without using water.

In summary, by implementing closed-loop water systems or alternative cleaning methods, olive oil producers can reduce their water usage and minimize the environmental impact of the extraction process. This approach can help satisfy both the cleaning requirements of the olives and the sustainability requirements of the industry.

- ***The possible innovative solution to the second contradiction***:

The first evaluation parameter, “Productivity” is the Parameter 35, in the TRIZ matrix. The second evaluation parameter, “Environmental impact” can be found in Parameter 30 “Harmful side effects”. By combining these parameters in the TRIZ matrix, we arrived at four potential inventive principles: Turn the Harm to One's Good (22), Change of Physical and Chemical Parameters (35), Other Way Round (13) and Intermediary (24).

In our context, the most compatible inventive principle is 35, “Transformation of properties”, which could be interpreted as changing the pesticides and herbicides with another substance that have less negative impact on the environment. This could be to shift to agroecological farming practices. Agroecology is a holistic approach to farming that focuses on using natural processes and ecological principles to promote soil health, biodiversity, and sustainability. By using agroecological methods, farmers can reduce their reliance on synthetic pesticides and herbicides while maintaining productivity. In our case study the Agroecological practices was inspired from Agroforestry approach. This solution is a beneficial approach where farm animals graze under trees for shelter and food, and their manure enriches the soil without the need to chemical pesticides and herbicides. Agroforestry is a win-win and part of many agroecological methods.

- ***The possible innovative solution to the third and forth contradiction:***

We follow the same process for the rest of contradictions to be resolved.

**Step 9:** The evaluation of proposed solution concepts is a critical step in the process of improving the sustainability of olive oil production (Yehya et al., 2021). During this step, experts in the field of olive oil production assess the feasibility of proposed solutions based on criteria such as technical feasibility, cost, safety, and sustainability. Using a Likert scale to express their judgments, experts will evaluate proposed solutions via a table (Row: criteria used and Column: Likert scale from 1 to 7). In our case expert appreciate the output of our study, as it ensures that proposed solutions are both effective and feasible in practice. Ultimately, the evaluation of proposed solutions will result in improvements to the sustainability of olive oil production, leading to a more sustainable and environmentally friendly process overall.

## V.5. New proposed inventive scenario

The new scenario incorporates the innovative solutions to the contradictions identified using TRIZ (See Figure 43).

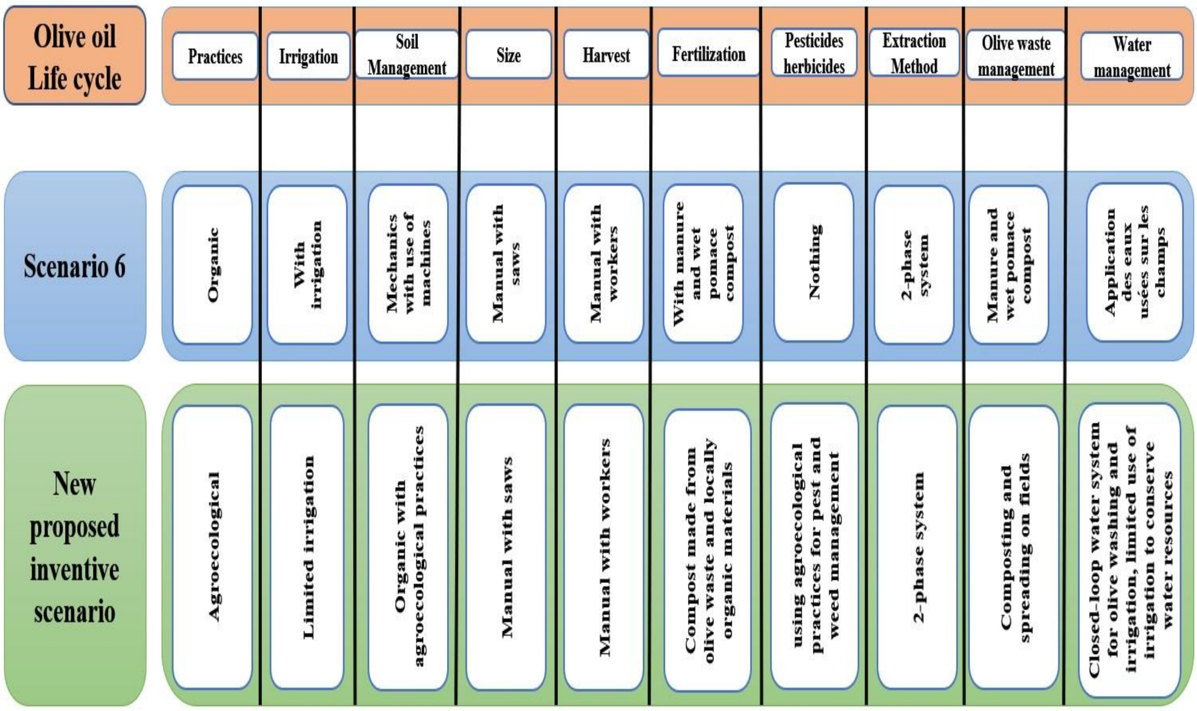


*Figure 43: Comparison between scenario 6 and the new proposed inventive scenario*

To address the contradiction of using water for olive washing but not for sustainability, the scenario includes a closed-loop water system for olive washing and limited use of irrigation to conserve water resources. This will reduce the overall water consumption and minimize the environmental impact of the process.

To address the contradiction of using pesticides and herbicides for productivity but not for sustainability, the scenario adopts agroecological farming practices. These practices prioritize soil health, biodiversity and sustainability, while also maintaining productivity levels. The scenario includes crop diversification, intercropping, crop rotation, cover cropping, and the use of natural pest control methods such as companion planting, biological controls and habitat manipulation. This approach minimizes the use of synthetic pesticides and herbicides, while promoting soil health and biodiversity.

Overall, the new scenario balances productivity and sustainability by incorporating innovative solutions to the contradictions identified using TRIZ.

## V.6. Conclusion

In conclusion, this chapter presented an innovative approach to improve decision-making processes using TRIZ methodology in combination with MCDA and LCSA methods. Through a comprehensive literature review, it was evident that there are limited studies that have investigated the integration of TRIZ with MCDA and LCSA methods in order to have a sustainable and innovative solution. Therefore, this proposed methodology offers a novel and valuable contribution to the field of decision-making. The case study presented in this chapter demonstrated the effectiveness of the proposed approach in the olive oil industry, where it successfully improved the decision-making process and resulted in a more sustainable and environmentally friendly solution. Overall, this chapter highlights the potential benefits of combining TRIZ with MCDA and LCSA methods and its importance in addressing complex and challenging decision-making problems.

# General Conclusion

This research work has focused on examining the sustainability and decision-making processes within the olive oil supply chain, with a particular emphasis on incorporating circular economy (CE) principles and employing multi-criteria decision analysis (MCDA) and life cycle sustainability assessment (LCSA) methodologies. The findings and contributions of each chapter have shed light on various aspects of the topic and have paved the way for a more comprehensive understanding of sustainable practices and informed decision-making in the agricultural sector.

Chapter 1 laid the foundation by highlighting the significance of sustainability and circular economy principles in the olive oil supply chain. It underscored the need for a sustainable supply chain model that maximizes resource utilization, minimizes waste, and creates value for stakeholders. By integrating circular economy approaches, a more resilient and sustainable system can be achieved.

Chapter 2 presented a thorough literature review on LCSA and MCDA, revealing the importance of utilizing multiple analytical methods and incorporating criteria such as life cycle costing (LCC) and social life cycle assessment (S-LCA) for a comprehensive sustainability assessment. It emphasized the complexities and uncertainties in decision-making within the agricultural sector, stressing the need for effective tools, including group decision-making methods and appropriate weighting and ranking techniques.

Chapter 3 introduced a novel approach to agricultural sustainability assessment, employing a multi-criteria, multi-phase, and multi-decision maker framework. The proposed methodology utilized tools such as the Structured Analysis and Design Technique (SADT) and the 2-tuple linguistic representation model, offering decision-makers a comprehensive framework for evaluating sustainability scenarios based on multiple criteria and expert opinions.

Chapter 4 further enhanced the proposed approach by integrating 2-Tuple and extended VIKOR methodologies. This modified approach improved the accuracy of expert judgments, leading to more accurate sustainability analysis. A real-life case study on the olive oil life cycle validated the feasibility and effectiveness of the proposed approach, providing reasonable sustainability priority ranking results.

Chapter 5 presented an innovative approach by integrating TRIZ methodology with MCDA and LCSA methods in the decision-making process. This integration aimed to combine an optimization phase with an innovation phase, resulting in the proposal of innovative and more sustainable solutions. The successful case study conducted in the olive oil industry demonstrated the benefits of this approach in addressing complex decision-making challenges and achieving superior sustainability outcomes. By bridging the gap between sustainability and inventive design, this chapter highlights the significance of integrating optimization and innovation phases to enhance decision-making processes and contribute to transformative advancements in sustainability. The findings emphasize the potential for improved decision-making and the generation of innovative solutions with enhanced sustainability performance. This work holds great relevance for researchers and practitioners seeking to enhance sustainability outcomes through a holistic and comprehensive approach.

Collectively, this research has contributed to the existing literature by emphasizing the importance of sustainability, circular economy principles, and informed decision-making in the olive oil supply chain. The findings underscore the need for comprehensive sustainability assessments, effective decision-making tools, and the integration of various methodologies to promote a more sustainable and resilient agriculture sector. By considering the principles of circular economy, employing appropriate analytical methods, and incorporating multi-criteria approaches, stakeholders can make more informed decisions that balance environmental, economic, and social considerations, leading to a sustainable future for the olive oil supply chain and beyond.

Despite the valuable insights and contributions of this research, it is important to acknowledge certain limitations. Firstly, the study focused specifically on the olive oil supply chain, which may limit the generalizability of the findings to other agricultural sectors. Different agricultural industries may have unique characteristics and sustainability challenges that require tailored approaches and methodologies. Also, the dynamic nature of sustainability challenges and the evolving nature of circular economy practices pose a challenge in terms of keeping up with the latest developments and incorporating them into decision-making frameworks. Ongoing research and continuous updates are necessary to adapt to emerging trends and address evolving sustainability concerns effectively.

This research lays the groundwork for future investigations and developments in the field of sustainability and decision-making within the olive oil supply chain. Several avenues for further exploration and improvement can be considered.

Firstly, future research could extend the scope beyond the olive oil industry and explore the applicability of the proposed methodologies and frameworks in other agricultural sectors. By expanding the analysis to different supply chains, a more comprehensive understanding of sustainability challenges and decision-making processes can be achieved, enabling cross-sectoral learning and knowledge exchange. Furthermore, incorporating advanced technologies such as blockchain, Internet of Things (IoT), and artificial intelligence (AI) can enhance data collection, traceability, and decision-making processes within the supply chain. Exploring the integration of these technologies into the proposed frameworks can provide more accurate and real-time information, enabling more informed decision-making and facilitating the implementation of circular economy principles. Lastly, engaging stakeholders from various sectors, including policymakers, producers, consumers, and environmental organizations, in the decision-making processes is crucial. Future research should explore effective participatory approaches and collaborative platforms that foster dialogue, knowledge sharing, and consensus building. This will ensure a broader perspective, diverse expertise, and collective decision-making, leading to more sustainable and inclusive outcomes.

In conclusion, this research provides a solid foundation for future investigations and advancements in sustainable practices and decision-making within the olive oil supply chain. By addressing the identified limitations and exploring the suggested perspectives, researchers and practitioners can further enhance sustainability outcomes, contribute to the broader field of agricultural sustainability, and pave the way for a more sustainable and resilient future.

# Appendix A

| Reference and code | | Waste Type | Phases | | | Country | System boundary |
|---|---|---|---|---|---|---|---|
| | | | Phase 1 | Phase 2 | Phase 3 | | |
| **1** | (Rivela et al., 2006) | Wood | X | | | Spain | Recycling<br>Combustion |
| **2** | (Miliute & Kazimieras Staniškis, 2009) | Plastic, Metal, Glass and paper | | | X | Lithuania | Incineration<br>Landfilling<br>Recycling |
| **3** | (Boldrin et al., 2011) | Garden waste | X | | | Denmark | Composting<br>Incineration |
| **4** | (Manfredi et al., 2011) | Plastic, Aluminium and Glass | | | X | Denmark | Incineration<br>Landfilling<br>Recycling |
| **5** | (Foolmaun & Ramjeeawon , 2012) | PET | | | X | Mauritius | Incineration Landfilling |
| **6** | (Salomone & Ioppolo, 2012a) | Oil Mill Wastewater (OMW) and Olive Pomace (OP) | | X | | Italy | Direct application to the soil<br>Composting |
| **7** | (Intini et al., 2012) | OMW and Wood | X | X | | Italy | Biomass production |
| **8** | (Foolmaun & Ramjeeawon , 2013) | PET | | | X | Mauritius | Incineration<br>Landfilling |
| **9** | (Cossu, Degl'innocenti, et al., 2013) | OP | | X | | Italy | Combustion<br>Generation of electric power<br>Composting |
| **10** | (Hjaila et al., 2013) | OP | | X | | Spain | Activated carbon production |
| **11** | (Xie et al., 2013) | Packaging waste | | | X | China | Incineration<br>Landfilling<br>Recycling |
| **12** | (El Hanandeh, 2013) | OP | | X | | Australia | Pyrolysis |
| **13** | (Ferreira et al., 2014) | Packaging waste | | | X | Portugal | Incineration<br>Landfilling<br>Recycling |
| **14** | (Ferrão et al., 2014) | Packaging waste | | | X | Portugal | Incineration<br>Landfilling<br>Recycling |
| **15** | (Hanandeh, 2015) | OMW and OP | X | X | | Australia | Pellets<br>heating Pyrolysis<br>Composting |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **16** | (Kylili et al., 2016) | OP | | X | | Cyprus | Pellets |
| **17** | (Oldfield et al., 2016) | Green (garden) waste | X | | | Ireland | Composting |
| **18** | (Battista et al., 2017) | OMW and OP | | X | | Italy | Direct application to the soil<br>Anaerobic digestion |
| **19** | | OMW and OP | | X | | Spain | Composting, Anaerobic digestion, Incineration, Hydrothermal carbonization |
| **20** | Guermazi et al., 2017 | OMW and OP | | X | | Tunisia | Composting<br>And<br>Cosmetic application |
| **21** | Ghani, et al., 2018 | Agricultural waste | X | | | Malaysia | Landfilling<br>and<br>Recycled |
| **22** | Diaz et al., 2018 | Agricultural waste | X | | | France | Composting |
| **23** | Parascanu et al., 2018 | OP | | X | | Spain | Combustion Gasification |
| **24** | Navarro et al., 2018 | Glass, Tin and PET | | | X | Spain | Recycling<br>Landfilling |
| **25** | Aryan et al., 2018 | PET and PE | | | X | India | Landfilling<br>Incineration |
| **26** | Hoeve et al., 2019 | Garden waste | X | | | Denmark | Composting |
| **27** | Landi et al., 2019 | Glass bottle | | | X | Italy | Recycling<br>Reuse |
| **28** | Batuecasa et al., 2019 | OMW and OP | | X | | Italy | Anaerobic digestion Direct application to soil. |
| **29** | Chen et al., 2019 | Plastic waste | | | X | China | Recycling<br>Incineration<br>Landfilling |
| **30** | Castellani et al., 2019 | OMW and OP | | X | | Italy | Composting |
| **31** | Inghels et al., 2019 | Garden waste | X | | | Netherlands Belgium | Composting, or for energy recovery |
| **32** | Duman et al., 2020 | OP | | X | | Turkey | Pellets and Composting |
| **33** | Fariñas et al., 2020 | OP | | X | | Spain | Anaerobic digestion<br>OP 2$^{nd}$ extraction |
| **34** | Valenti et al., 2020 | OP | | X | | Italy | Anaerobic digestion<br>Conventional treatment |
| **35** | Uceda-Rodríguez et al., 2020 | OP | | X | | Spain | landfill |
| **36** | Mohammadi et al., 2020 | OMW and OP | | X | | Sweden | Different hydrochar pellets producing |
| **37** | Martin et al., 2020 | PET bottle | | | X | Brazil | Incineration<br>Landfilling<br>Recycling |
| **38** | Mayer et al., 2021 | Organic waste | X | X | | Germany | Anaerobic digestion, HTC, Incineration |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **39** | Khounani et al., 2021 | Olive leaves | X | | | Iran | Two olive agro biorefinery scenarios |
| **40** | Fernandez-Lobato et al., 2021 | OP | X | X | | Spain | OP extraction |
| **41** | Yay et al., 2021 | OP | | X | | Turkey | Incineration<br>HTC Anaerobic Digestion |
| **42** | Cusenza et al., 2021 | agro-industrial biomass residues | X | X | | Italy | Pyrolysis |
| **43** | López-García et al., 2021 | OP | | X | | Spain | Ceramic Bricks |
| **44** | Pampuri et al., 2021 | OMW and Olive leaves | X | X | | Italy | Food Preparations with olive waste |
| **45** | Benalia et al., 2021 | OMW | | X | | Italy | Anaerobic codigestion, biomethane |
| **46** | Gamero et al., 2021 | OP | | X | | Spain | Gasification |
| **47** | Costa et al., 2022 | OP and forest residues | X | X | | Italy | Gasification, |
| **48** | Vilen et al., 2022 | Wood | X | | | Finland | Activated carbon |
| **49** | Zhu et al., 2022 | Agro-residues | X | X | | China | Comparing a typical technologies for biochar production |
| **50** | Fernández-Lobato et al., 2022 | OMW and OP | | X | | Spain | Biomass gasification |
| **51** | Ramos et al., 2022 | OP | | X | | Portugal | Thermochemical processes |
| **52** | Fernández-Lobato et al., 2022 | OP | | X | | Tunisia | 2nd extraction of OP |
| **53** | Ncube et al., 2022 | OP | | X | | Italy | Biogas |
| **54** | Amin et al., 2022 | Olive Wood trees | X | | | Italy | Activated Carbon |
| **55** | Amin et al., 2022 | Wasted Tree Leaves | X | | | Italy | Activated Carbon |
| **56** | Restucciaet al., 2022 | OMW and OP | | X | | Italy | Biogas, composting |

# Appendix B

| ID | Author name | Scope of the article | Limitation of this study |
|---|---|---|---|
| **3** | Myllyviita et al., 2012 | The purpose of this paper is to describe a process of assessing environmental impacts of two alternative raw materials and to present the problems related to it. A panel which includes experts in measuring the environmental impacts of biomass production was requested to identify and weight impact categories to assess environmental impacts of biomass production. The panelists identified new environmental impacts (such as biodiversity) not included to the standard LCA. | The main limitation of this study is that it focuses on only two alternative raw materials for biomass production and does not consider a broader range of factors that could impact environmental sustainability |
| **11** | Doderer and Kleynhans, 2014 | Following the LCA approach, 37 plausible lignocellulosic bioenergy systems were assessed against five financial-economic, three socio-economic and five environmental criteria. On translating the quantitative performance data into a standardized ‘common language’ of relative performance, an expert group attached weights to the considered criteria, using the analytical hierarchy process (AHP). | The limitation of this study is that it only considers the financial, socio-economic, and environmental criteria, which may not fully capture the complex interactions and trade-offs among various factors in the bioenergy systems. |
| **17** | Ren et al., 2015 | LCA, LCC, and S-LCA are combined to collect the corresponding criteria data on environmental, economic, and social aspects, respectively. The study develops a novel S-LCA method for quantifying the social criteria. The decision-makers/stakeholders can use linguistic terms to assess these criteria, and fuzzy theory is used to transform the linguistic variables into real numbers. Once the sustainability assessment criteria are determined, the study develops an MCDA method that combines the AHP and the VIKOR method to prioritize the alternatives. The AHP is used to determine the criteria weights that are a prerequisite when using VIKOR; the VIKOR method is then used to determine the sustainability sequence of the scenarios. | The main limitation of this study is that the S-LCA method developed to quantify the social criteria relies on the subjective judgments of stakeholders, which may introduce bias and uncertainty into the sustainability assessment. |
| **26** | Falcone et al., 2016 | This paper aims to make a sustainability assessment of different wine-growing scenarios located in Calabria (Southern Italy) that combines conflicting insights, i.e., environmental and | The limitation of this study is that it only considers the environmental and economic aspects of wine-growing scenarios and does not take into account |

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| | | economic ones, by applying LCA and LCC to identify the main hotspots and select the alternative scenarios closest to the ideal solution through the VIKOR multicriteria method. In particular, the latter allowed us to obtain synthetic indices for a two-dimensional sustainability assessment. | social and cultural factors that may affect sustainability. |
| **35** | Maia Angelo et al., 2017 | This paper aims at improving decision making in solid waste management by combining LCA and MCDA techniques harmonically, using management of food waste from households in the city of Rio de Janeiro as a case study. | The main limitation of this study is that it only focuses on the management of food waste from households in Rio de Janeiro and does not consider other sources of waste or alternative waste management options. |
| **36** | Milutinovic et al., 2017 | In this paper combination of LCA and multi-criteria analysis, was applied to assess environmental impact of different waste management scenarios with energy recovery in City of Nis as a case study. In the first step, the LCA is used to assess environmental impact of developed scenarios and to calculate values of impact categories (indicators). In the next step the AHP is used to rank developed scenarios according to the goal: selection of the scenario with minimum negative environmental impact according to the indicators. | The limitation of this study is that it only assesses the environmental impact of different waste management scenarios and does not consider the economic and social aspects of sustainability. |
| **39** | De Luca et al., 2018a | The present paper proposes an innovative and integrated approach, i.e., the LCSA, a methodology that is still under development within the conceptual framework of Life Cycle Thinking (Kl€opffer, 2008).LCA, LCC and S-LCA are integrated here by means of a multicriterial and participative method, the AHP. | The main limitation of this study is that the LCSA methodology proposed is still under development and may not yet fully capture all the aspects of sustainability. |
| **41** | De Luca et al., 2018c | This work evaluates different soil management practices in olive growing scenarios through the integration of life-cycle-based methodologies – LCA, LCC and S-LCA – with the AHP technique, which belongs to the framework of multicriteria decision analysis (MCDA). | The limitation of this study is that it only focuses on soil management practices in olive growing scenarios and does not consider other aspects of agricultural sustainability, such as water use and energy consumption. |
| **43** | Dekamin et al., 2018 | Water footprint (WF) is one of the best indicators developed with the aim of evaluating the virtual water contents of corps. Practitioners can take the benefit of LCA + WF in association with | The limitation of this study is that it only focuses on evaluating the virtual water contents of corps using LCA + WF and does not consider other sustainability |

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| | | management methods and optimization techniques, including Analytical Hierarchical Process (AHP) to obtain better results in their studies and provide their target populations with more practical solutions. | factors, such as social and economic impacts. |
| **57** | Nieder-Heitmann et al., 2019 | The LCSA parameters were normalized and weighed in a MCDA tool to determine the most sustainable solution for implementation by the South African sugar industry. | The main limitation of this study is that the LCSA parameters used to assess sustainability in the South African sugar industry may not be fully applicable to other agricultural systems or regions. |
| **58** | Nikkhah et al., 2019 | In this research, various impact categories were weighted using AHP, as amulti criteria decision making tool. Iranian tobacco production system was the example of agricultural system. | The study only focuses on the agricultural system in Iran and does not provide a generalizable approach to agricultural sustainability. |
| **60** | Rocchi et al., 2019 | The aim of this study was to assess the sustainability of three different poultry production systems, in order to evaluate their suitability to address human food need, as well as their environmental sustainability, economic feasibility and animal welfare. The three systems compared were: a conventional intensive indoor system, a free range system and a free range system combined with an olive orchard (where chickens grazed in an orchard instead of in an area used solely for the grazing). A model based on multicriteria decision analysis was developed, using environmental, social and economic criteria. Environmental criteria were estimated using a LCA, while economic and social criteria were both collected on farms and from the literature. | The study only compares three specific poultry production systems and may not be representative of all poultry production systems. Additionally, the LCA used to estimate environmental criteria only considers greenhouse gas emissions and does not account for other environmental impacts. |
| **61** | Schoubroeck et al., 2019 | This study aims for expert consensus concerning indicators needed and preferred for sustainability analysis of biobased chemicals in Europe. Experts are consulted by means of a Delphi method with stakeholders selected from three core groups: the private, public and academic sector. Best-Worst Scaling (BWS) is performed to gather data on the prioritization of the sustainability indicators per respondent. Afterwards, MCDA is used to develop a consensus ranking among the experts. | The study only focuses on biobased chemicals in Europe and may not be applicable to other regions or agricultural products. Additionally, the use of a Delphi method to gather expert consensus may not capture the full range of perspectives on sustainability. |

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| **70** | Bartzas et al., 2020 | In this study, a holistic methodology that integrates life cycle analysis (LCA), environmental risk assessment (ERA) along with on-site farm and regional surveys using the multi-criteria environment of the Analytical Hierarchy Process (AHP) is designed for the identification of the most sustainable agricultural management practices at regional level. | The study only focuses on agricultural management practices at a regional level and may not be applicable to other scales of analysis. |
| **71** | Florindo et al., 2020 | Thus, this study aims to develop an approach using sustainable LCA integrated to multicriteria methods of decision making and probabilistic weighting in order to evaluate the sustainability of four different alternatives of animal production | The study only evaluates four specific alternatives for animal production and may not be representative of all possible alternatives. |
| **74** | R.Lin et al., 2020b | In order to solve the decision-making problem under uncertainties in the selection process of biorefineries, a novel decision-making framework based on an improved interval goal programming was developed | The study focuses specifically on the selection process of biorefineries and may not be applicable to other agricultural sustainability problems. |
| **75** | Liu et al., 2020 | Aiming at promoting the sustainable development of sludge-to-energy and determining the decision making process for the most sustainable option among all the scenarios, a novel MCDA method based on Dempster-Shafer (DS) theory and fuzzy best-worst method (FBWM) was developed. | The study focuses specifically on the sustainable development of sludge-to-energy and may not be applicable to other agricultural sustainability problems. |
| **79** | Ren et al., 2020 | This chapter shows the feasibility of using life cycle aggregated sustainability index method developed by Ren (2018) to prioritize the alternative biofuel production pathways by aggregating all the criteria into a single sustainability index. | The study only applies the life cycle aggregated sustainability index method to the prioritization of alternative biofuel production pathways and may not be applicable to other agricultural products. |
| **81** | Zhou et al., 2020 | This study evaluated various sludge disposal and treatment technologies for their environmental, economic, and social sustainability and developed an assessment model using MCDA methods. A combined AHP and VIKOR approach was used for sequencing of the alternatives and evaluation of the most sustainable disposal system based on a set of sustainability indicators. | The study focuses specifically on sludge disposal and treatment technologies and may not be applicable to other agricultural sustainability problems. |

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| **97** | Fernandez-Tirado et al., 2021 | The aim of this study is to identify the best first-generation biodiesel alternative to replace Petro diesel in transport sector in the short term in Spain. LCA normalization and weighting can facilitate decision making in situations where trade-offs among impact category results do not allow choosing one preferable solution among the alternatives. | The study focuses specifically on the transport sector in Spain and may not be applicable to other agricultural products or regions. |
| **102** | Krol-Badziak et al., 2021 | This study aimed to evaluate the sustainability of no tillage, reduced tillage and conventional tillage in grain maize monoculture based on economic, environmental, and social aspects. Based on the outcomes of long-term field experiments conducted at the Agricultural Experimental Station in Grabow, LCA and fuzzy analytic hierarchy process (FAHP) were applied to evaluate tillage systems and calculate the criteria weights | The study only evaluates three specific tillage systems in grain maize monoculture and may not be representative of all tillage systems or agricultural products. Additionally, the use of fuzzy analytic hierarchy process may introduce subjectivity into the weighting of criteria. |
| **103** | Lim et al., 2021 | This study aims to develop a novel MCDA approach towards sustainable fertilization that incorporates both organic and chemical fertilizers with the consideration of economic, environmental, and health aspects. | The study only focuses on sustainable fertilization and does not address other aspects of agricultural sustainability such as water use or biodiversity conservation. Additionally, the study only evaluates two specific fertilizers and may not be representative of all fertilizer options. |
| **110** | (M. Liu et al., 2022) | The scope of the article is to develop a life cycle sustainability evaluation framework for the selection of ultra-low emission technologies in the iron and steel industry (ISI) in China. The study focuses specifically on sintering flue gas (SFG) treatment technologies. It incorporates environmental, economic, and technological dimensions in the evaluation process and uses life cycle assessment and life cycle costing as key components. The article also introduces a novel multi-criteria group decision-making framework that combines Bayesian and hesitant fuzzy set theories to evaluate the sustainability of the ultra-low emission technologies. | The findings and recommendations of this study may be specific to the context of the iron and steel industry in China. The applicability of the evaluation framework and the identified sustainable technology may vary in different geographical regions or industries. |
| **120** | (Ramesh et al., 2022) | The article focuses on the selection of sustainable lignocellulosic biomass for the production of | The applied methodology has some limitations, such as the expert inputs |

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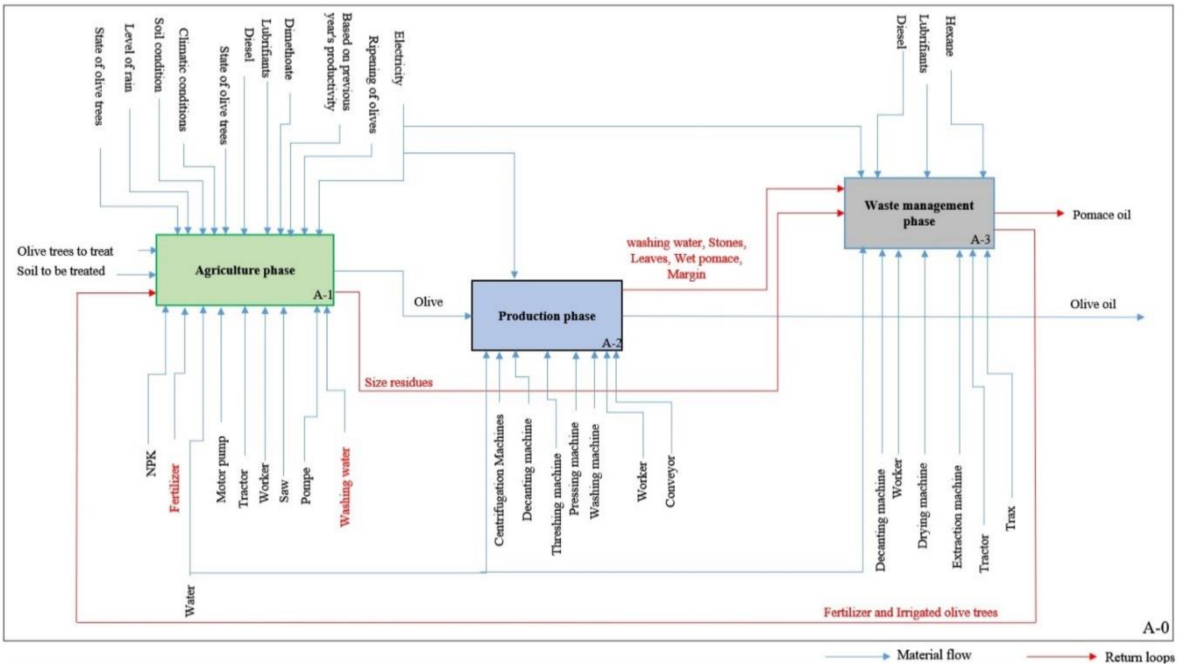
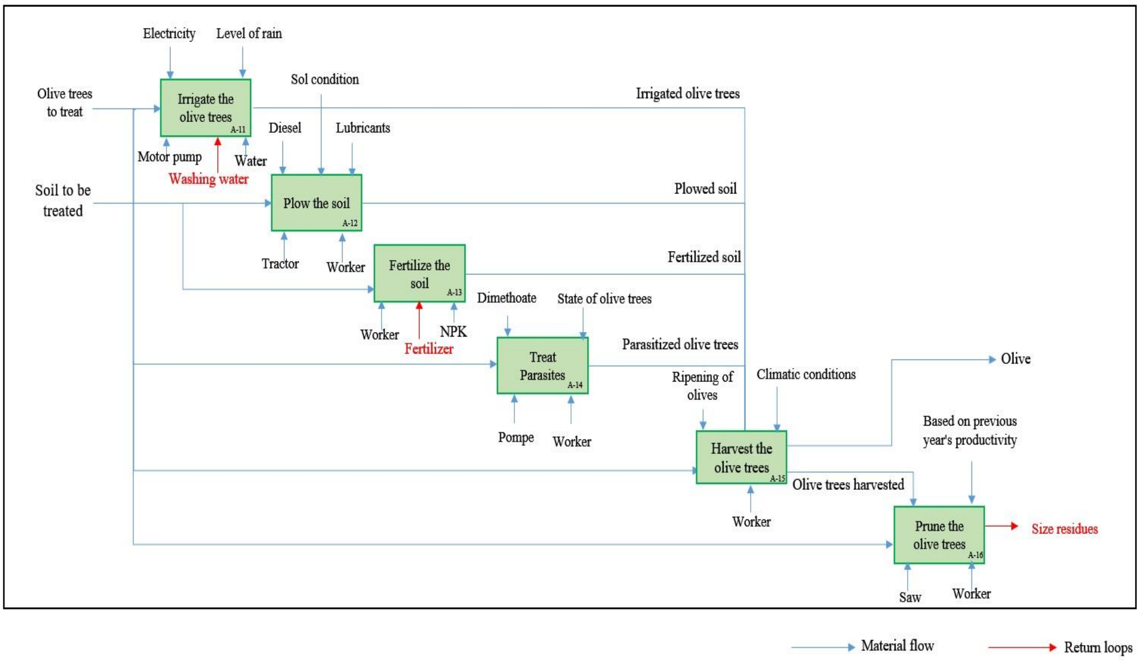
| | | second-generation ethanol in the Indian context. It identifies and prioritizes five lignocellulosic biomass sources (Sugarcane Bagasse, Rice straw, Wheat straw, Moringa, and Vetiver) using a Multi-Criteria Decision Making (MCDM) methodology. The study compares different MCDM approaches and develops a Python-based MCDM algorithm for evaluation. | (criteria short list and fuzzy scales), it may be biased due to constraints like reliability of biomass, economic and government norms etc., |
| **127** | (Heidari et al., 2022) | The article investigates the sustainability of different carbonaceous adsorbents (activated carbon, amine-modified activated carbon, and graphene) for capturing carbon dioxide (CO2). It considers the environmental, economic, and technical perspectives, and evaluates three end-of-life management options: incineration, reactivation, and landfilling. The study integrates Life Cycle Assessment (LCA), Life Cycle Cost (LCC) analysis, and CO2 adsorption capacity. | The study focuses on the sustainability of carbonaceous adsorbents from cradle to grave, but it may not account for all possible environmental and economic factors. The results are specific to the analyzed adsorbents and may not be generalizable to other materials or conditions. Sensitivity analysis indicates that variations in electricity and HCl can significantly affect the study's outputs, suggesting potential limitations in the robustness of the findings. |
| **133** | (Ben Abdallah et al., 2022) | The article focuses on assessing the life cycle sustainability of different olive farming systems in Tunisia, including traditional (conventional and organic) and innovative (intensive and highly-intensive) systems. It aims to evaluate the environmental, economic, and social impacts of these systems using a Life Cycle Sustainability Assessment framework. | The study acknowledges that the environmental and socio-economic impacts of olive farming systems have been poorly studied to date, indicating a lack of comprehensive research in this area. Additionally, while the study provides valuable insights into the sustainability of different farming systems, it is conducted in the specific context of Tunisia and may not be directly applicable to other regions or countries. |

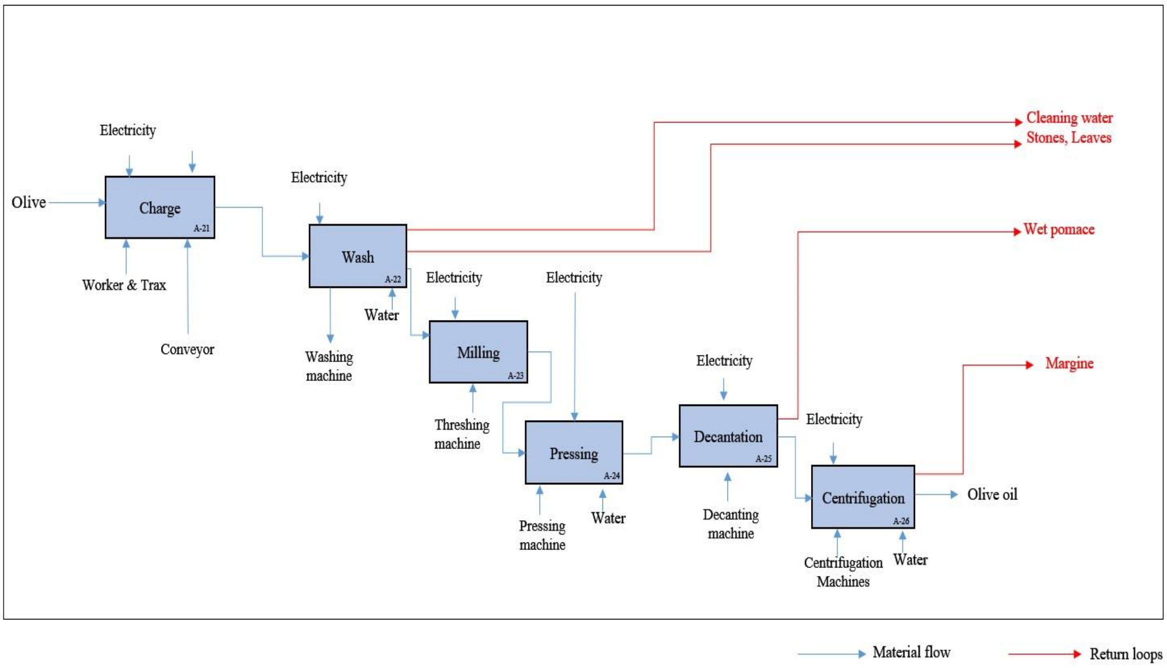
# Appendix C

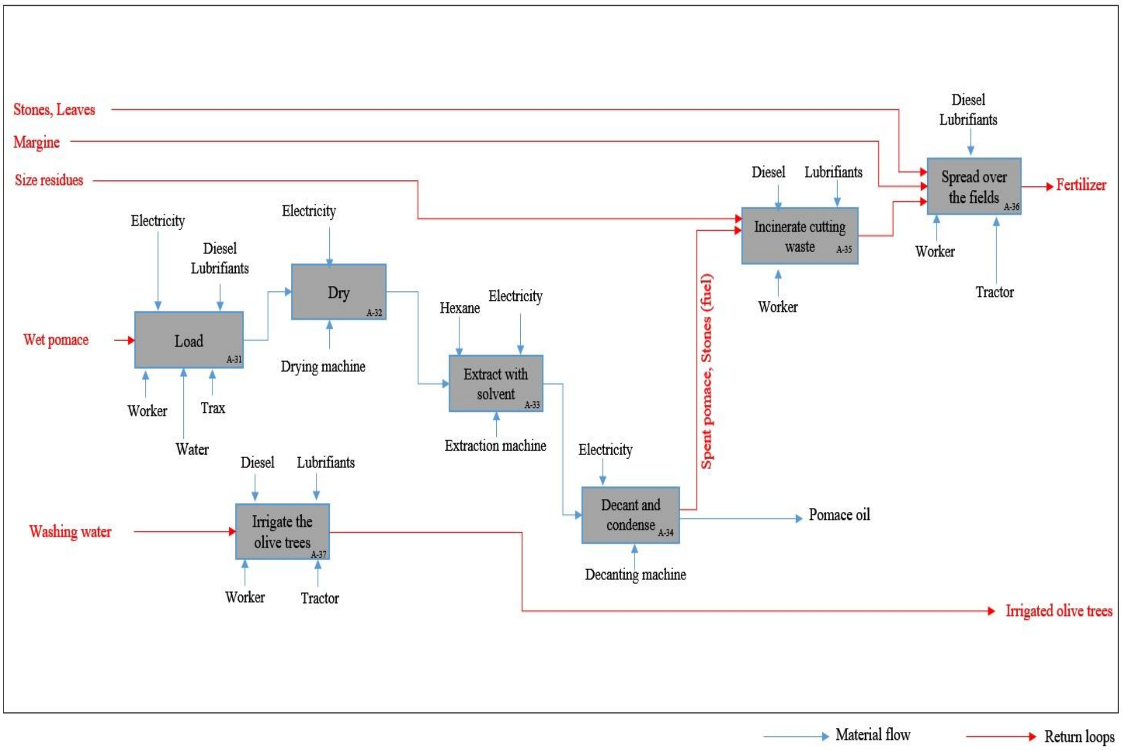


State of olive trees
Level of rain
Soil condition
Climatic conditions
State of olive trees
Diesel
Lubrifiants
Dimethoate
Based on previous year's productivity
Ripening of olives
Electricity
Diesel
Lubrifiants
Hexane
Olive trees to treat
Soil to be treated
Agriculture phase
A-1
Olive
Production phase
A-2
washing water, Stones, Leaves, Wet pomace, Margin
Waste management phase
A-3
Pomace oil
Olive oil
Size residues
NPK
Fertilizer
Motor pump
Tractor
Worker
Saw
Pompe
Washing water
Centrifugation Machines
Decanting machine
Threshing machine
Pressing machine
Washing machine
Worker
Conveyor
Decanting machine
Worker
Drying machine
Extraction machine
Tractor
Trax
Water
Fertilizer and Irrigated olive trees
A-0
Material flow
Return loops

Electricity
Level of rain
Olive trees to treat
Irrigate the olive trees
A-11
Sol condition
Irrigated olive trees
Diesel
Lubricants
Motor pump
Water
Washing water
Soil to be treated
Plow the soil
A-12
Plowed soil
Tractor
Worker
Fertilize the soil
A-13
Fertilized soil
Dimethoate
State of olive trees
Worker
NPK
Fertilizer
Treat Parasites
A-14
Parasitized olive trees
Ripening of olives
Climatic conditions
Olive
Pompe
Worker
Harvest the olive trees
A-15
Based on previous year's productivity
Olive trees harvested
Worker
Prune the olive trees
A-16
Size residues
Saw
Worker
Material flow
Return loops


Electricity
Olive
Charge
A-21
Worker & Trax
Conveyor
Electricity
Wash
A-22
Water
Washing machine
Electricity
Milling
A-23
Threshing machine
Electricity
Pressing
A-24
Pressing machine
Water
Electricity
Decantation
A-25
Decanting machine
Electricity
Centrifugation
A-26
Centrifugation Machines
Water
Olive oil
Cleaning water
Stones, Leaves
Wet pomace
Margine
Material flow
Return loops


Stones, Leaves
Margine
Size residues
Wet pomace
Washing water
Electricity
Diesel
Lubrifiants
Load
A-31
Worker
Trax
Water
Electricity
Dry
A-32
Drying machine
Hexane
Electricity
Extract with solvent
A-33
Extraction machine
Electricity
Decant and condense
A-34
Decanting machine
Pomace oil
Spent pomace, Stones (fuel)
Diesel
Lubrifiants
Incinerate cutting waste
A-35
Worker
Diesel
Lubrifiants
Spread over the fields
A-36
Worker
Tractor
Fertilizer
Diesel
Lubrifiants
Irrigate the olive trees
A-37
Worker
Tractor
Irrigated olive trees
Material flow
Return loops

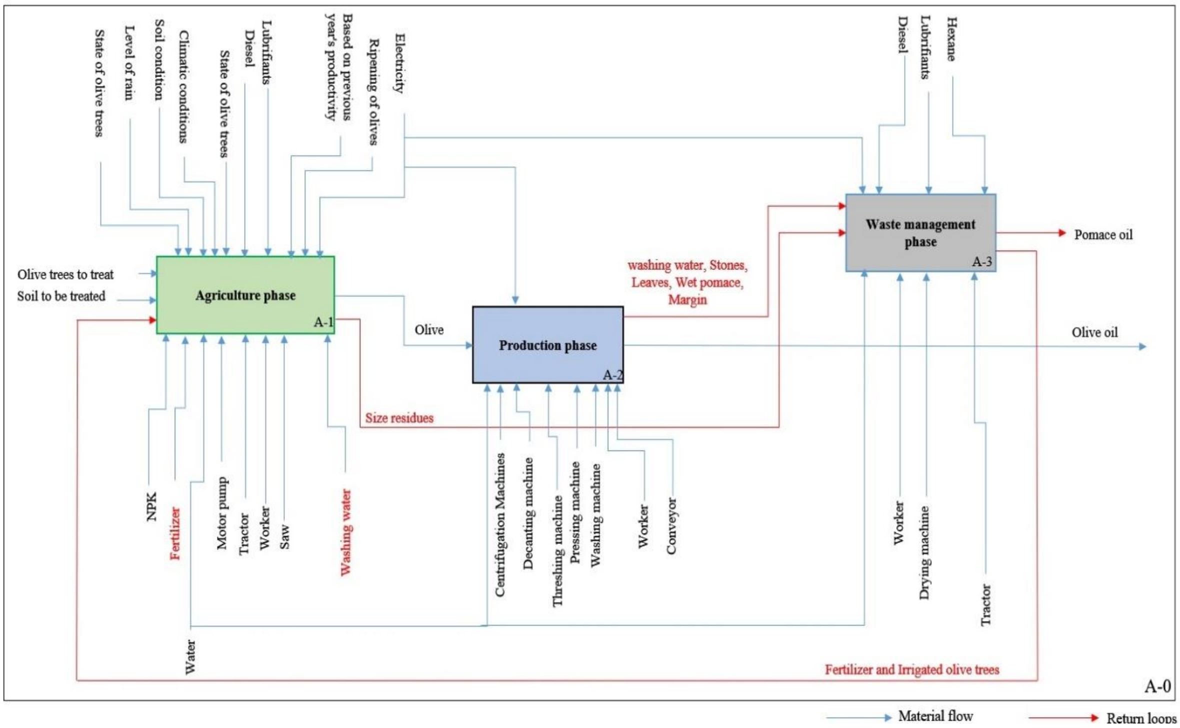
# Appendix D

| Expert: | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 |
|---|---|---|---|---|---|---|---|---|
| **Scenario 1:** | | | | | | | | |
| Exp 1 | L | L | H | M | VL | H | VL | H |
| Exp 2 | L | L | VH | L | M | VL | L | VH |
| Exp 3 | EH | L | EH | VH | VH | VH | VH | VH |
| Exp 4 | VL | M | M | M | H | VH | L | M |
| Exp 5 | H | L | L | H | L | M | L | M |
| Exp 6 | L | EL | H | L | VL | L | VL | VH |
| Exp 7 | M | M | H | L | M | M | L | L |
| Exp 8 | L | M | L | M | M | M | M | H |
| **Scenario 2:** | | | | | | | | |
| Exp 1 | VH | M | L | M | H | M | M | EH |
| Exp 2 | M | M | L | M | H | M | M | VH |
| Exp 3 | M | M | L | M | M | M | M | M |
| Exp 4 | VH | H | H | H | EH | H | M | H |
| Exp 5 | H | H | L | H | M | H | H | H |
| Exp 6 | M | M | M | H | EH | L | L | VH |
| Exp 7 | L | M | M | H | H | H | H | M |
| Exp 8 | L | M | VL | M | M | M | M | VH |
| **Scenario 3:** | | | | | | | | |
| Exp 1 | L | H | H | M | M | M | M | M |
| Exp 2 | L | H | M | H | M | M | M | H |
| Exp 3 | EL | H | EL | VL | VL | EL | VL | VL |
| Exp 4 | H | VH | H | H | VH | H | M | M |
| Exp 5 | VH | H | VL | H | M | M | H | H |
| Exp 6 | VH | VH | VH | H | M | H | H | H |
| Exp 7 | VH | H | VH | H | H | H | H | M |
| Exp 8 | L | M | L | M | M | M | M | M |
| **Scenario 4:** | | | | | | | | |
| Exp 1 | VH | H | VL | VH | H | M | M | EH |
| Exp 2 | H | H | M | H | M | L | M | VH |
| Exp 3 | VL | H | VL | L | L | VL | VL | VL |
| Exp 4 | EH | H | VH | H | VH | H | M | H |
| Exp 5 | M | M | VL | L | M | L | M | L |
| Exp 6 | H | H | H | VH | EH | EH | EH | EH |
| Exp 7 | H | M | M | H | H | H | H | VH |
| Exp 8 | H | M | L | H | H | M | M | L |
| **Scenario 5:** | | | | | | | | |
| Exp 1 | M | H | H | VH | M | M | M | L |
| Exp 2 | H | H | M | H | M | H | H | M |

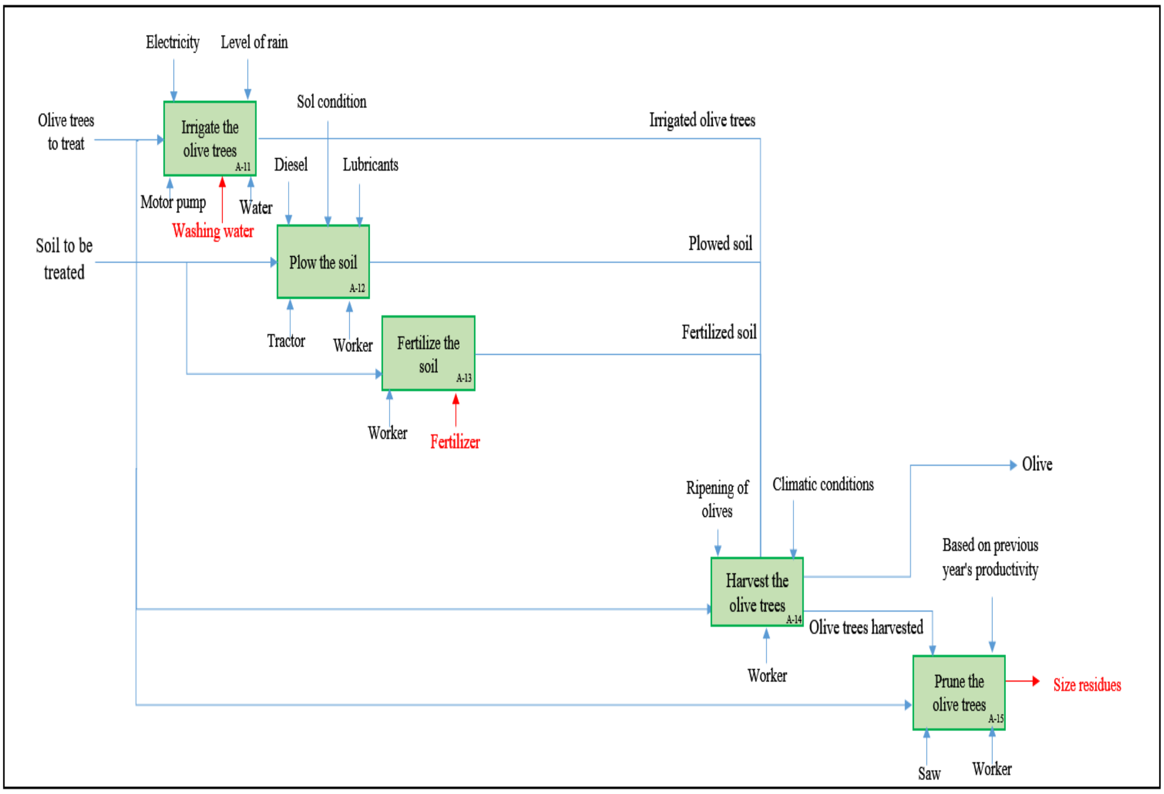
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Exp 3 | VL | H | EL | VL | EL | VL | VL | VL |
| Exp 4 | VH | VH | VH | VH | H | H | M | M |
| Exp 5 | M | H | M | H | H | M | H | H |
| Exp 6 | EH | EH | VH | EH | H | VH | VH | VH |
| Exp 7 | EH | VH | VH | H | VH | H | H | H |
| Exp 8 | H | M | H | M | M | M | M | L |
| **Scenario 6:** | | | | | | | | |
| Exp 1 | VH | VL | L | VL | VL | M | L | VH |
| Exp 2 | M | VL | VL | H | L | L | M | M |
| Exp 3 | EH | VL | EH | VH | VH | VH | VH | VH |
| Exp 4 | M | M | M | M | H | H | L | H |
| Exp 5 | EH | H | VL | VH | VH | H | VH | H |
| Exp 6 | VL | VL | VL | L | L | M | M | EH |
| Exp 7 | M | M | M | M | M | M | M | M |
| Exp 8 | EL | M | H | M | M | L | M | M |
| **Scenario 7:** | | | | | | | | |
| Exp 1 | VH | H | M | M | M | M | VH | EH |
| Exp 2 | L | H | VL | M | M | L | M | M |
| Exp 3 | H | H | H | H | M | H | H | H |
| Exp 4 | EH | VH | H | H | EH | M | M | H |
| Exp 5 | H | M | M | H | M | M | M | H |
| Exp 6 | VH | M | M | L | L | M | M | VH |
| Exp 7 | L | M | M | VH | H | VH | VH | VH |
| Exp 8 | M | M | L | H | H | H | M | M |
| **Scenario 8:** | | | | | | | | |
| Exp 1 | M | H | VH | H | EL | M | VH | M |
| Exp 2 | L | H | VL | L | M | L | M | VL |
| Exp 3 | VH | H | EH | VH | VH | VH | VH | VH |
| Exp 4 | EH | VH | VH | VH | VH | M | M | M |
| Exp 5 | VH | L | L | EH | VH | H | EH | EH |
| Exp 6 | VH | VH | M | EH | VH | M | M | M |
| Exp 7 | VH | H | H | H | H | H | H | M |
| Exp 8 | H | M | M | M | M | L | L | L |
| **Scenario 9:** | | | | | | | | |
| Exp 1 | H | H | VH | VH | VH | VH | VH | M |
| Exp 2 | VH | H | L | VH | VH | M | VH | M |
| Exp 3 | VH | H | VH | EH | VH | VH | VH | VH |
| Exp 4 | EH | VH | EH | VH | H | M | M | M |
| Exp 5 | VH | VH | M | H | H | VH | VH | H |
| Exp 6 | VH | VH | VH | VH | VH | VH | VH | M |
| Exp 7 | EH | VH | VH | H | VH | VH | H | M |
| Exp 8 | VH | H | H | VH | M | L | H | L |
| **Scenario 10:** | | | | | | | | |
| Exp 1 | EH | EH | EH | EH | EH | EH | EH | M |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Exp 2 | EH | EH | M | EH | EH | H | H | M |
| Exp 3 | VH | EH | VH | VH | H | VH | VH | VH |
| Exp 4 | EH | VH | EH | VH | H | H | H | H |
| Exp 5 | VH | VH | M | VH | H | H | VH | VH |
| Exp 6 | EH | EH | EH | EH | EH | EH | EH | L |
| Exp 7 | EH | EH | H | EH | VH | VH | VH | M |
| Exp 8 | EH | VH | VH | EH | VH | L | L | H |

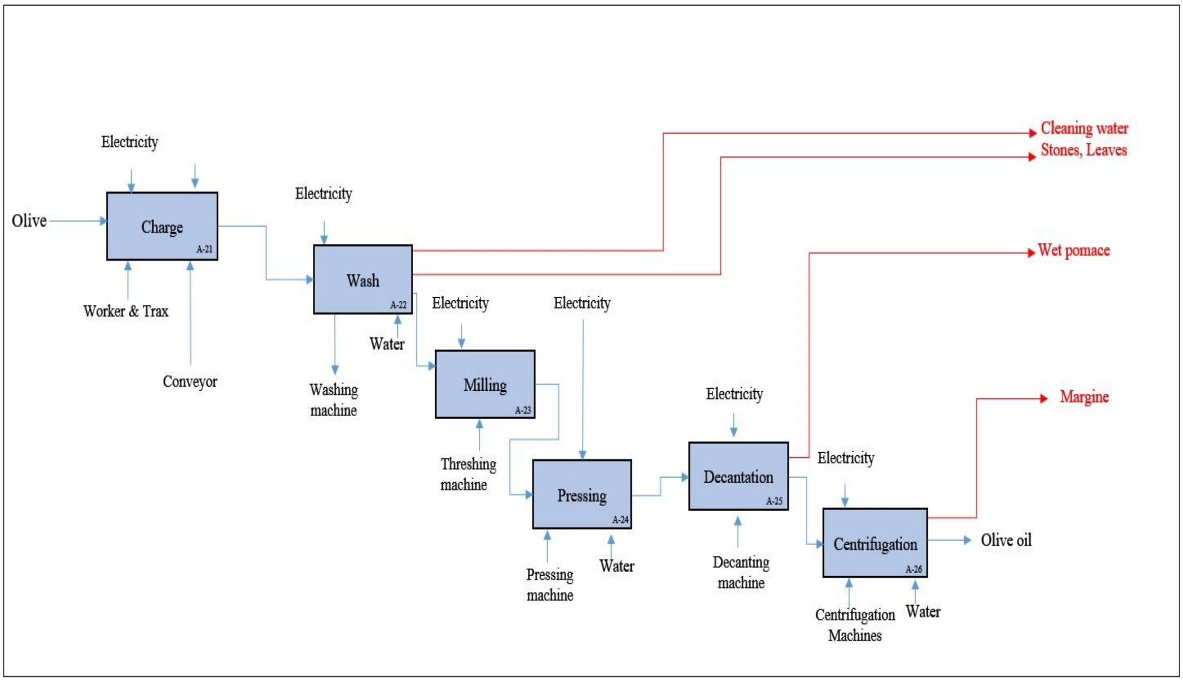
# Appendix E



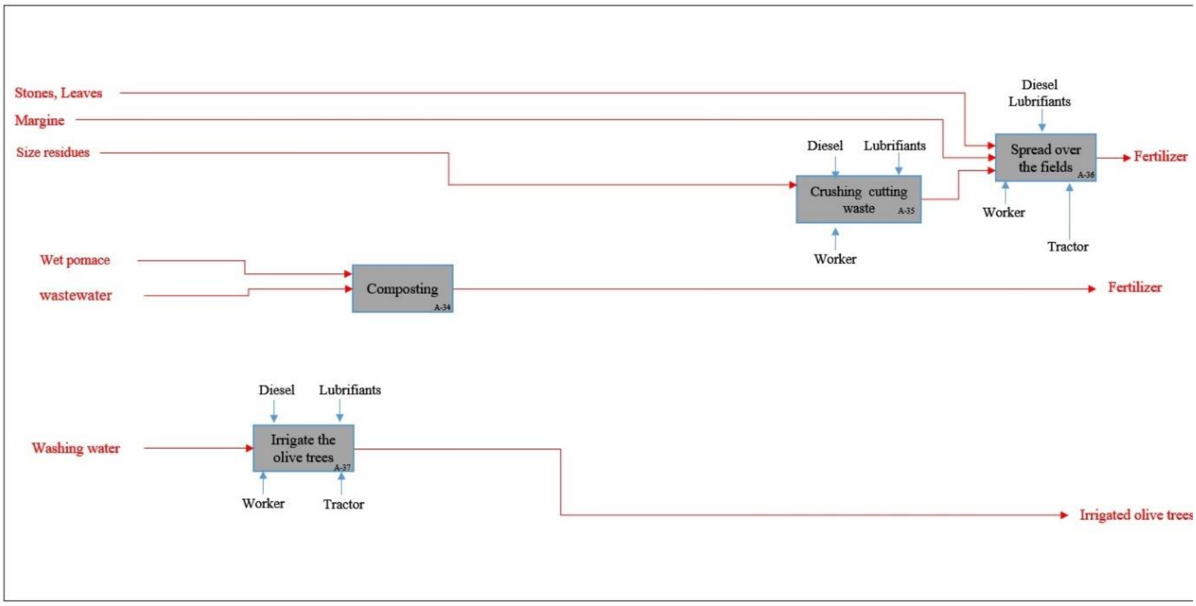
State of olive trees
Level of rain
Soil condition
Climatic conditions
State of olive trees
Diesel
Lubrifiants
Based on previous year's productivity
Ripening of olives
Electricity
Diesel
Lubrifiants
Hexane
Olive trees to treat
Soil to be treated
Agriculture phase
A-1
Olive
Production phase
A-2
washing water, Stones, Leaves, Wet pomace, Margin
Waste management phase
A-3
Pomace oil
Olive oil
Size residues
NPK
Fertilizer
Motor pump
Tractor
Worker
Saw
Washing water
Centrifugation Machines
Decanting machine
Threshing machine
Pressing machine
Washing machine
Worker
Conveyor
Worker
Drying machine
Tractor
Water
Fertilizer and Irrigated olive trees
A-0
Material flow
Return loops

Electricity
Level of rain
Olive trees to treat
Irrigate the olive trees
A-11
Sol condition
Irrigated olive trees
Diesel
Lubricants
Motor pump
Water
Washing water
Soil to be treated
Plow the soil
A-12
Plowed soil
Tractor
Worker
Fertilize the soil
A-13
Fertilized soil
Worker
Fertilizer
Ripening of olives
Climatic conditions
Olive
Based on previous year's productivity
Harvest the olive trees
A-14
Olive trees harvested
Worker
Prune the olive trees
A-15
Size residues
Saw
Worker



Electricity
Olive
Charge
A-21
Worker & Trax
Conveyor
Electricity
Wash
A-22
Washing machine
Water
Electricity
Milling
A-23
Threshing machine
Electricity
Pressing
A-24
Pressing machine
Water
Electricity
Decantation
A-25
Decanting machine
Electricity
Centrifugation
A-26
Centrifugation Machines
Water
Olive oil
Cleaning water
Stones, Leaves
Wet pomace
Margine

Stones, Leaves
Margine
Size residues
Diesel
Lubrifiants
Crushing cutting waste
A-35
Worker
Diesel
Lubrifiants
Spread over the fields
A-36
Worker
Tractor
Fertilizer
Wet pomace
wastewater
Composting
A-34
Fertilizer
Diesel
Lubrifiants
Washing water
Irrigate the olive trees
A-37
Worker
Tractor
Irrigated olive trees

# Dissemination

## Journal papers

- Keskes, M. A., Zouari, A., Lehyani, F., Houssin, R. (2022). *Circular economy implementation within manufacturing companies at Sfax-Tunisia: barriers and opportunities*. ***Environmental Engineering and Management Journal***, 21(3), 517-528. Available at: <http://89.44.47.69/index.php/EEMJ/article/view/4492>.
- Keskes M.A., Zouari A, Houssin R., Dhouib D., Renaud J. (2023). *A New Multi-Criteria, Multi-Phase and Multi-Decision Makers Approach to the Agricultural Sustainability Problem*. ***Journal of Environment Systems and Decisions*** (Second round of review).
- Keskes M.A., Zouari A, Houssin R., Dhouib D., Renaud J. (2023). *Towards Sustainable Olive Oil Production: A Systematic Review of Waste Management Strategies.* ***International Journal of Product Lifecycle Management***, (Under Review, 20%).

## Book chapter

- Keskes M.A., Zouari A, Houssin R., Dhouib D., Renaud J., (2022). *Priorisation à la production circulaire d'huile d'olive en Tunisie basée sur l'évaluation de la durabilité du cycle de vie et la prise de décision multicritère* », ***Optimization in agri-food supply chain: Recent studies in agrifood supply chain and animal Industry***.

## Conference papers

- Keskes M.A., Zouari A, Houssin R., Dhouib D., Renaud J., (2022). *An overview on olive oil waste valorization scenarios: Life Cycle Approach*, ***10th IFAC Conference on manufacturing modelling, management and control*** – , 22– 24, June 2022, Nantes-France.
- Keskes M.A., Houssin R., Zouari A, Dhouib D., Renaud J., (2022). *Integrating TRIZ and MCDM for Innovative and Sustainable Decision-Making: A Case Study in the Life Cycle of Olive Oil*, ***23rd International TRIZ Future Conference TFC-2023***, 12– 14, September 2023, Offenburg - Germany.

- Keskes M.A., Zouari A, Houssin R., Dhouib D., Renaud J., (2022). *Evaluation multicritère du cycle de vie dans une perspective de développement durable : Cas de l'huile d'olive*. ***Le 18ème colloque S.mart***, 4– 6, Avril 2023, Carry le Rouet-France.
- Keskes M.A., Zouari A, Houssin R., Dhouib D., Renaud J., (2022). *Proposal of a Multi-Criteria Decision Making for choosing the best waste valorisation scenarios based on life cycle sustainability assessment of olive supply*, ***10 th Doctoral Research Days ROAD'2***0, Sousse, Tunisia, January 2019

**Poster**

- Keskes M.A., Zouari A, Houssin R., Dhouib D., Renaud J. *Aide multicritère au choix des scénarii innovants sous la pensée de cycle de vie dans la chaine logistique oléicole*. ***Journée du département de mécanique***, le 2 June 2022 Strasbourg-France.

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Abdel-Basset, M., Gamal, A., & ELkomy, O. M. (2021). Hybrid Multi-Criteria Decision Making approach for the evaluation of sustainable photovoltaic farms locations. *Journal of Cleaner Production*, *328*. https://doi.org/10.1016/j.jclepro.2021.129526

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# Aide multicritère, multi-phases, multi-décideurs pour la sélection de meilleures stratégies innovantes durables: Cas de la chaîne logistique oléicole

Résumé

## 1. Introduction :

Pendant longtemps, la recherche agricole s'est concentrée sur des pratiques visant à améliorer la productivité des terres et des cultures. Au cours des dernières décennies, l'accent principal s'est déplacé vers des questions de durabilité, telles que la réduction des dommages environnementaux et de l'empreinte écologique de l'agriculture (Struik et al., 2014). La production agricole est l'un des plus grands secteurs industriels au monde, et elle est responsable d'une grande quantité d'émissions de gaz à effet de serre en raison de la consommation élevée d'énergie, ce qui aggrave le problème du réchauffement climatique (Roy et al., 2009). Par conséquent, les décideurs dans ce domaine sont devenus plus conscients et sensibles, ce qui a conduit les responsables politiques à donner la priorité à un nouvel ensemble de normes : une production agricole sûre, éthique et respectueuse de l'environnement (de Luca et al., 2017).

Parmi les principes du développement durable se trouve l'économie circulaire (CE) (Ahmed et al., 2022). Cette économie repose sur la transformation des déchets en ressources : le recyclage et la réduction des déchets en donnant une deuxième vie aux objets, aux déchets ou plus largement aux produits (Keskes, et al., 2022a). En appliquant les principes de l'économie circulaire, nous pouvons identifier les différents scénarios du cycle de vie d'un bien. En mettant en œuvre l'Analyse du Cycle de Vie Environnemental (E-LCA), l'Analyse des Coûts du Cycle de Vie (LCCA) et l'Analyse du Cycle de Vie Social (S-LCA), il est possible d'évaluer l'Analyse de la Durabilité du Cycle de Vie (LCSA) pour chaque scénario lié aux processus de la chaîne de production dans la chaîne de valeur agricole.

En général, dans le domaine agricole, il existe différentes phases importantes (phase agricole, phase de production, phase de gestion des déchets et transport entre les phases). En fait, toutes ces phases contribuent à caractériser l'ensemble du cycle de vie de tout produit (olive, raisin, ...). Chaque phase a son propre décideur et chaque décideur a sa propre méthode spécifique parmi plusieurs méthodes de production de produits agricoles. Chaque méthode a un impact spécifique sur l'environnement, l'économie et la société. Pour cette raison, les décideurs sont toujours confrontés à des choix conflictuels et difficiles. Par conséquent, nous sommes confrontés à plusieurs problèmes :

- Problème à plusieurs phases : Il y a différentes phases dans le cycle de vie de tout produit agricole.
- Problème à plusieurs critères : Différents critères différents et contradictoires doivent être étudiés.
- Problème à plusieurs décideurs : Les décideurs interviennent à différentes phases du cycle de vie du produit agricole.
- Problème circulaire et durable : La plus haute priorité est récemment accordée aux aspects environnementaux et durables du domaine agricole.

L'objectif de cette thèse est de soutenir les décideurs dans le choix des pratiques agricoles les plus durables, des méthodes d'extraction et de gestion des déchets de manière à ce que l'ensemble du cycle de vie du produit devienne circulaire et durable. Pour atteindre cet objectif, nous proposons un nouveau cadre multicritère pour aider les décideurs à comparer et à classer différents scénarios de cycle de vie.

## 2. Revue de literature

Les méthodes d'évaluation de la durabilité ont été appliquées dans différents domaines agricoles et ont donné de bons résultats. Parmi ces méthodes, nous avons l'analyse de la durabilité du cycle de vie, qui nous permet d'évaluer l'impact environnemental, économique et social associé à toutes les phases de la vie d'un produit, depuis l'extraction des matières premières, la fabrication, le transport, l'utilisation et l'élimination (Batuecas et al., 2019).

De plus, l'analyse multicritère de la décision (MCDA) peut également être utilisée pour identifier et comparer différentes stratégies de durabilité en évaluant leurs performances et leurs impacts (Jenkins et Keisler, 2022 ; Igor Linkov et al., 2023). Étant donné que les critères environnementaux, économiques et sociaux sont partiellement ou complètement contradictoires et de nature très diversifiée, et exprimés dans des unités différentes, la

MCDA est la méthode appropriée pour évaluer la durabilité des problèmes agricoles (Delesposte et al., 2021).

Pour mener à bien les méthodologies MCDA, différentes étapes doivent être suivies. L'une des étapes cruciales consiste à attribuer des poids aux critères d'évaluation ; c'est pourquoi le choix d'une méthode de pondération appropriée est important (Cinelli et al., 2022). Les méthodes de pondération peuvent être obtenues en intégrant des méthodes MCDA telles que l'AHP (Darko et al., 2019), la méthode du meilleur pire (Rezaei, 2015), ou par le biais de calculs mathématiques, connus sous le nom de poids objectifs (Amari et al., 2023), ou en fonction des préférences des experts, appelés poids subjectifs (Divino Miranda de Oliveira et al., 2023), ou en utilisant les deux (Raudeli et al., 2023). En combinant les poids subjectifs et objectifs, nous garantissons l'exactitude de la pondération des critères (Amari et al., 2023). Cette approche prend en compte divers facteurs, surmonte les biais potentiels et reconnaît que les jugements des décideurs peuvent être influencés par leurs connaissances et leur expérience, ce qui peut avoir un impact sur le processus de prise de décision (Liu et al., 2013).

Une autre étape cruciale consiste à choisir les méthodes de classement adéquates (Cinelli et al., 2022 ; Linkov et al., 2021). Des approches importantes comme la méthode de l'Analyse Hiérarchique (AHP), la Technique de Performance par Similarité à la Solution Idéale (TOPSIS) et VIKOR sont couramment utilisées (Li & Hu, 2022 ; Razi et Ali, 2019). Des techniques MCDM hybrides combinant ces méthodes de classement avec d'autres méthodes de pondération ont été développées pour améliorer leur efficacité. Par exemple, un cadre proposé par Singh & Gupta (2020), Razi et Ali (2019), et Hamurcu & Eren (2023) combine TOPSIS floue et AHP pour évaluer les problèmes de durabilité, assurant la précision en convertissant les valeurs floues en valeurs nettes. Une autre étude menée par Ossei-Bremang & Kemausuor (2021) intègre l'AHP floue et le TOPSIS flou pour évaluer la sélection de la ressource biomasse la plus durable en fonction de facteurs politiques, économiques, environnementaux et sociaux. Ces techniques tiennent compte de la vague linguistique et de l'ambiguïté, permettant la détermination des poids et le classement des emplacements alternatifs.

Après le travail de Herrera et Martínez (2000), qui présente pour la première fois la représentation linguistique à deux tuples, de nombreux chercheurs ont essayé de combiner les modèles linguistiques avec les méthodes MCDA. Par exemple, une méthode avancée d'Analyse des Modes de Défaillance et de leurs Effets combine les variables linguistiques à deux tuples (ITLV) avec TOPSIS pour classer les priorités de risque. Les ITLV gèrent efficacement les informations incertaines, et TOPSIS prend en compte de manière exhaustive tous les facteurs de risque (Liu et al., 2020). De plus, une méthodologie inspirée de la méthode PROMETHEE II a été proposée pour analyser les problèmes de prise de décision sous le cadre linguistique à deux tuples (Singh and Gupta, 2019). De même, (Liu et al., 2013) combinent le modèle linguistique à deux tuples avec la méthode VIKOR pour la sélection de matériaux sous information incertaine et incomplète. L'extension de la méthode VIKOR avec le modèle à deux tuples offre d'importants avantages en matière d'analyse décisionnelle. Le modèle linguistique à deux tuples permet aux experts d'exprimer leurs préférences en utilisant des termes linguistiques (Herrera and Martínez 2000). De plus, il intègre des nombres flous pour représenter l'incertitude, permettant une modélisation plus complète et flexible des critères de décision (Herrera and Martínez 2005). La méthode VIKOR permet également aux décideurs de prendre des décisions plus intuitives et robustes, en tenant compte à la fois des facteurs quantitatifs et qualitatifs (Siksnelyte-Butkiene et al., 2020). Cette approche combinée améliore non seulement la précision et l'expressivité de l'analyse décisionnelle, mais offre également une efficacité informatique et un cadre pratique pour les problèmes de décision complexes. Pour choisir la méthode de combinaison la plus adaptée à une étude de cas donnée, l'article de Cinelli et al. (2022), ainsi que le livre théorique et appliqué sur la MCDA de Linkov et al. (2023), ont développé une méthodologie et un logiciel pour aider les décideurs et les analystes à sélectionner la méthode MCDA la plus adaptée à un type donné de problème de prise de décision.

Pour parvenir à un consensus, il est nécessaire de trouver une fonction d'agrégation d'un groupe d'experts pour regrouper leurs évaluations dans une matrice (Rani et al., 2022). C'est pourquoi plusieurs auteurs utilisent la prise de décision multicritère en groupe (MCGDM) pour résoudre les conflits et les contradictions dans les opinions des experts. Hsi-Mei Hsu & Chen-Tung Chen (1996) ont présenté pour la première fois une méthode novatrice d'agrégation des opinions des experts en utilisant l'indice de consensus et la position de chaque expert. Ils ont suggéré la détermination de l'indice de consensus de chaque expert par rapport aux scores des autres experts à l'aide de la méthode de mesure de similarité.

De plus, pour obtenir des résultats cohérents dans le processus de sollicitation des experts, il est nécessaire d'utiliser une méthode appropriée pour attribuer des poids aux experts. Cela peut avoir un impact significatif sur la précision des résultats d'évaluation. La méthode d'agrégation de similarité (SAM) est une approche largement utilisée et efficace pour pondérer les opinions des experts en vue de l'agrégation des opinions. Elle tient compte à la fois du poids objectif des experts et de la cohérence relative de leurs opinions (Jianxing et al., 2021a). Cependant, la méthode SAM peut encore être affectée par l'incertitude des opinions des experts lors du processus de sollicitation. Pour remédier à ce problème, Yazdi et al. (2020) ont introduit une nouvelle méthode qui tient compte des niveaux de confiance des experts. Ils ont appliqué cette méthode pour évaluer les incendies et les explosions dans un réservoir de stockage d'hydrocarbures. Ziemba et al. (2020) proposent un nouveau cadre méthodologique pour l'agrégation des opinions des experts dans la méthode TOPSIS floue, en tenant compte du degré d'accord de leurs opinions à l'aide de la SAM et du classement des experts. De plus, ils ont utilisé cette méthode dans le domaine de la gestion des ressources humaines.

De plus, une nouvelle technique proposée par Jianxing et al. (2021a) utilise la méthode SAM pour agréger les opinions des experts. Cette technique est largement utilisée pour déterminer le degré de consensus relatif pour mesurer le poids de chaque expert dans un cas d'évaluation spécifique. Ainsi, la SAM traditionnelle est modifiée pour être adaptée à la théorie du modèle nuage. De plus, cette méthode a été utilisée pour l'évaluation des risques liés aux pipelines sous-marins. De manière similaire, Guo et al. (2021) étudient la SAM comme méthode d'agrégation des opinions floues en tenant compte du degré de consensus. Cependant, la SAM ne prend pas en compte l'impact des différences individuelles sur la cohérence, ce qui introduit un certain degré d'incertitude. Par conséquent, dans leur travail, ils proposent une SAM améliorée basée sur le modèle de réseau bayésien flou (FBN) pour mieux traiter divers types d'incertitude. Cette méthodologie rend les résultats de prédiction de l'accident de réservoir de stockage plus précis et fiables. À notre connaissance, il n'existe pas d'études existantes dans la littérature qui combinent la SAM avec un modèle à deux tuples. Par conséquent, notre contribution est unique en utilisant le modèle à deux tuples pour considérer et faciliter l'expression des préférences des experts, tout en utilisant la méthode SAM pour agréger leurs opinions.

En raison du développement et de la complexité croissante du cycle de vie de la production d'huile d'olive, il est nécessaire d'étudier la question de la durabilité de ce produit à l'aide de nouvelles méthodes multicritères. Cela nous permettra de réaliser une analyse plus complète et systématique de la durabilité du cycle de vie de la production d'huile d'olive. Parallèlement, l'analyse traditionnelle de la décision multicritère présente de nombreuses lacunes, notamment la méthode d'analyse multicritère de groupe pour l'évaluation de la durabilité nécessite davantage de recherches en ce qui concerne l'incertitude de l'évaluation des experts.

## 3. Une nouvelle approche multi-critères, multi-phases et multi-décideurs pour le problème de la durabilité agricole

Dans cette section, une nouvelle approche multicritères, multiphases, multidécideurs et durable est proposée, basée sur le modèle à deux tuples. L'approche proposée est divisée en six étapes critiques différentes, comme illustré dans la Figure 1.

La méthode proposée offre plusieurs avantages, qui sont mis en évidence ci-dessous :

- La première étape de la méthode consiste à élaborer des scénarios durables en utilisant l'approche de l'économie circulaire (CE). L'outil SADT est intégré pour optimiser les boucles de retour des déchets pour chaque scénario.
- L'objectif principal de l'utilisation du modèle linguistique à deux tuples est de représenter de manière quantitative des informations incertaines et imprécises. Le modèle linguistique à deux tuples est une forme de logique floue, qui est un cadre mathématique pour traiter l'incertitude et l'imprécision.
- Un algorithme de pondération dynamique synthétique amélioré est proposé pour gérer la multiplicité et l'incertitude de différents types de connaissances, en tenant compte du niveau de confiance des opinions des experts en fonction de leur expérience et de la phase de leur implication.
- Une méthode de pondération intégrée est utilisée pour calculer à la fois les poids subjectifs et objectifs des critères, ce qui permet d'obtenir des poids plus raisonnables pour l'évaluation globale.

- Le modèle à deux tuples est étendu à la méthode VIKOR pour évaluer la durabilité des scénarios, offrant une solution de compromis pour prendre en compte plusieurs scénarios dans un cadre multicritères.

Dans la section suivante, nous décrivons en détail les six étapes de la méthode proposée.

### 3.1. Identifier l'équipe de prise de décision, le scénario et les critères (Étape 1) :

#### 3.1.1. Constituer l'équipe de prise de décision.

Pour tenir compte de la complexité et de l'incertitude inhérentes aux systèmes agricoles, il est important de constituer une équipe d'experts comprenant plusieurs décideurs possédant une expertise en agriculture. Cela contribue à améliorer l'objectivité et la précision des résultats de l'évaluation, car les connaissances et les perspectives de plusieurs experts sont prises en compte. La constitution de l'équipe d'experts doit respecter les trois principes suivants :

- Compétence des experts : L'équipe de décideurs doit être impliquée dans les phases de l'agriculture, de l'extraction et de la récupération des déchets. De plus, ils doivent être familiarisés avec le domaine de l'agriculture et être en mesure de fournir des jugements raisonnables et réels (Cai et al. 2013).
- Nombre d'experts : Pour garantir la crédibilité et la rationalité des résultats de l'évaluation, il est important d'avoir un nombre approprié d'experts dans l'équipe. Des études antérieures suggèrent qu'une équipe composée de 3 à 10 experts est généralement choisie pour fournir des évaluations fiables de la durabilité agricole basée sur les connaissances expertes. Le choix d'un nombre adéquat d'experts est crucial pour obtenir des résultats précis et crédibles (Yazdi et al. 2020).
- Diversification des profils d'experts : Une équipe hétérogène de décideurs devrait être constituée en tenant compte de leurs différents niveaux de connaissances et de leurs antécédents afin d'éviter une convergence extrême des jugements. Les experts doivent avoir différentes positions, connaissances, compétences, expériences et spécialisations dans différentes phases du cycle de vie, ainsi que des points de vue divergents sur la même question, afin d'améliorer l'objectivité et l'exhaustivité des évaluations.

### 3.1.2. Identifier le scénario et les critères

Nous incluons la revue de la littérature (articles de recherche, (Keskes et al. 2022b)) et des études sur le terrain (entretiens semi-structurés) nécessaires pour construire une compréhension complète du cycle de vie d'un produit. L'objectif de cette phase est d'extraire les scénarios appropriés et les critères de l'étude. Pour les scénarios, un outil SADT a été intégré pour obtenir une version plus large grâce à une analyse descendante des niveaux successifs. Cet outil nous permet de spécifier avec une plus grande précision le rôle de chaque élément du système et de fermer la boucle des déchets pour chaque scénario. Notre contribution consiste à construire un scénario durable et un ensemble de critères tout en respectant le concept de l'économie circulaire.

## 3.2. Collecte et conversion de l'évaluation linguistique (Étape 2) :

Pendant l'évaluation de la durabilité, le décideur exprime sa décision en termes linguistiques qualitatifs pour fournir des données d'évaluation sensibles et réelles. Dans ce processus, les experts évaluent chaque scénario séquentiellement pour chaque critère grâce à une enquête menée auprès d'un décideur. Pour une question d'évaluation précise, on suppose qu'il y a m scénarios, où *i = 1, 2, ..., m*, tandis qu'il y a n critères où *j = 1, 2, ..., n*, et *l* décideurs où *k = 1, 2, ..., l* sélectionnés pour l'évaluation. $\tilde{y}_{ij}^{k} = (y_{ij}^{k}, c_{ij}^{k})$ représente les résultats de l'évaluation du $k^{ème}$ expert (*Ek*) pour le i-ème scénario *($SC_i$)* concernant le j-ème critère (*Crj*). Le symbole $y_{ij}^{k}$ signifie le commentaire linguistique du scénario $Sc_i$ dans l'ensemble des termes d'évaluation *T*, et peut être transformé en un modèle d'évaluation standard correspondant à un modèle à deux tuples. La matrice d'évaluation $Y^K$ peut être conçue en créant les valeurs de termes linguistiques de chaque décideur. Le symbole $C_{ij}^{k}$ est une valeur numérique représentant la traduction symbolique $E_k$ de son propre commentaire linguistique $y_{ij}^{k}$, avec une plage de [0,1].

## 4.3. Détermination des poids des experts et agrégation des jugements (Étape 3) :

Dans cette phase, le poids de l'évaluation de chaque décideur est déterminé à l'aide de l'algorithme de pondération dynamique synthétique proposé. Les poids obtenus sont utilisés pour combiner les modèles d'évaluation à deux tuples grâce à un opérateur d'agrégation, ce qui donne comme résultat la matrice d'évaluation synthétique à deux tuples. L'algorithme de pondération dynamique synthétique prend en compte deux aspects : la situation personnelle de chaque membre de l'équipe de prise de décision et leurs observations pour le cas d'évaluation spécifique. La situation personnelle d'un décideur représente son niveau d'expertise et d'expérience, tandis que ses observations sont utilisées pour mesurer son poids dans le cas spécifique en les comparant aux autres en fonction des principes démocratiques. Les poids individuels des experts liés à leurs identités sont constants pour tous les cas d'évaluation. Le degré de consensus relatif des commentaires est ensuite agrégé pour obtenir une matrice de décision unifiée, ce qui est fait en quatre étapes comme décrit dans la section suivante.

### 3.3.1. Acquisition des poids individuels des experts.

Les décideurs sont sélectionnés dans différentes phases du cycle de vie d'un produit, avec différentes expériences, compétences et points de vue. Dans cette étude, quatre critères sont sélectionnés pour déterminer l'autorité ou le poids de chaque expert : la position professionnelle, le temps de service, le niveau d'éducation et l'âge (Jianxing et al. 2021a). En fonction de la situation individuelle de chaque expert et des critères de jugement répertoriés dans le Tableau 1, le score individuel $S_{iwe}^{k}$de chaque expert est obtenu. Ensuite, le poids individuel $W_{iwe}^{k}$ de chaque expert $E_k$ est calculé comme suit :

$$w_{iwe}^{k} = \frac{S_{inf}^{k}}{\sum_{k=1}^{l} S_{iwe}^{k}} \quad (1)$$

Tableau 1 Critères de pondération et scores des experts, (Jianxing et al. 2021b).

| Paramètres et Classification | Pontuation |
|---|---|
| ***Position professionnelle*** *:* | |
| Académicien senior (Chercheur) | 5 |
| Académicien junior | 4 |
| Ingénieur | 3 |
| Technicien | 2 |
| Ouvrier | 1 |
| ***Ancienneté de service :*** | |
| > 30 years | 5 |
| 20–30 | 4 |
| 10–20 | 3 |
| 6–9 | 2 |

| | |
|---|---|
| < 6 years | 1 |
| *Niveau d'éducation :* | |
| Doctorat | 5 |
| Master | 4 |
| Licence | 3 |
| BTS | 2 |
| Niveau scolaire | 1 |
| *Âge:* | |
| > 50 | 4 |
| 40–50 | 3 |
| 30–39 | 2 |
| < 30 | 1 |

### 3.3.2. Calcul du degré de consensus relatif :

Le jugement de chaque expert affecte également l'importance des commentaires, car les jugements les plus fréquents sont considérés comme les plus crédibles. Dans le même temps, les jugements extrêmes sont autorisés. Néanmoins, les jugements populaires reçoivent un degré de confiance plus élevé en vertu de la loi de la majorité. Par conséquent, un poids plus important est accordé aux jugements qui sont en accord avec l'opinion de la majorité, ce qui est soutenu par le degré de concordance relative des commentaires (Guo et al. 2021). La méthode d'agrégation de similarité (SAM) est une approche utile pour combiner les opinions des experts et déterminer le degré de concordance relative de chaque expert dans un cas d'évaluation particulier (Jianxing et al. 2021a). Cette méthode a été modifiée dans le cadre de cette étude pour intégrer la théorie des 2-tuples. Le processus de calcul pour le SAM basé sur le modèle des 2-tuples est décrit ci-dessous : Tout d'abord, la distance entre l'évaluation en 2-tuple de n'importe quelle paire d'experts est calculée. (Pei-de 2009) a défini une distance linguistique comme suit :

$$\tilde{y}_1=(y_k,\ c_k)$$

$$\tilde{y}_2=(y_v,\ c_v)$$

$$d\ (\tilde{y}_1, \tilde{y}_2)= \Delta[(|\Delta^{-1}(\tilde{y}_1 - \tilde{y}_2)|)]$$

$$d(\tilde{y}_1, \tilde{y}_2) = \Delta[(|\Delta^{-1}(y_k, c_k) - \Delta^{-1}(y_v, c_v)|)] \quad (2)$$

$d$ $(\tilde{y}_1, \tilde{y}_2)$: est la distance linguistique entre deux 2-tuples $(\tilde{y}_1, \tilde{y}_2)$.

Ensuite, la distance moyenne $Ad^k$ entre un expert et tous les autres experts est obtenue..

$$Ad^k = \frac{1}{l-1} \sum_{\substack{v=1 \\ v \neq k}}^{l} d(k, v) \qquad (3)$$

Troisièmement, l'accord moyen $AA^k$des experts est déterminé en prenant le réciproque de $Ad^k$.

$$AA^k = \frac{1}{Ad^k} \quad (4)$$

Enfin, le degré de concordance relatif $RA^k$de chaque expert est calculé selon la méthode de normalisation.

$$RA^k = \frac{AA^k}{\sum_{k=1}^{l} AA^k} \quad (5)$$

**3.3.3. Obtention du poids synthétique dynamique de chaque expert** :

L'algorithme de poids dynamique synthétique présenté dans cette étude améliore le SAM traditionnel en incorporant la théorie des 2-tuples et en tenant compte des niveaux de confiance des experts dans leurs commentaires. Cela conduit à des résultats agrégés plus fiables et plus précis. Par conséquent, le poids synthétique dynamique $w_{ij}^k$ de chaque expert est déterminé en tenant compte de la situation personnelle et du degré d'accord, en utilisant la formule suivante :

$$w_{ij}^k = \alpha w_{iwe}^k + \beta RA_{ij}^k \text{ (6)}$$

où α et β sont les facteurs de relaxation qui reflètent l'importance relative des trois indices de poids. Ces paramètres peuvent être déterminés par les décideurs, et ils satisfont généralement α, β∈ [0,1] et α+ β =1.

**3.3.4. Agrégation de l'évaluation à 2-tuples :**

À cette étape, l'agrégation des opinions des experts est réalisée pour construire une matrice de décision linguistique collective à 2-tuples. Ainsi, chaque évaluation $\tilde{y}_{ij}^{k}$est transformée en un nouveau $B_{ij}^{k}$ pondéré par l'opérateur de multiplication scalaire comme suit :

$$B_{ij}^{k} = w_{ij}^{k} * \tilde{y}_{ij}^{k}$$

$$\tilde{y}_{ij}^{k} = \Delta\left[ {}^{1}/_{l} * \sum_{k=1}^{l} \Delta^{-1} \tilde{y}_{ij}^{k} \right], j=1, 2, \ldots, n \quad (7)$$

Pour tous les critères et les scénarios, l'évaluation synthétique à 2-tuples peut être calculée en utilisant l'opérateur d'agrégation, et une matrice d'évaluation synthétique à 2-tuples Ỹ sera obtenue, exprimée comme suit :

$$\tilde{Y} = \begin{bmatrix} \tilde{y}_{11} & \tilde{y}_{12} & \cdots & \tilde{y}_{1n} \\ \tilde{y}_{21} & \tilde{y}_{22} & \cdots & \tilde{y}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{y}_{m1} & \tilde{y}_{m2} & \cdots & \tilde{y}_{mn} \end{bmatrix} \quad (8)$$

**3.4. Calcul des pondérations des critères, (Étape 4) :**

En quatrième lieu, les poids des critères peuvent être attribués directement par le décideur ; cela suppose que le décideur est capable de pondérer les critères de manière appropriée, au moins lorsque le nombre de critères n'est pas trop élevé (Cicciù et al. 2022). De plus, ces poids peuvent être déterminés par l'intégration d'autres méthodes multicritères, telles que l'AHP (Darko et al. 2019), et l'hybridation de l'AHP et de la logique floue (Rajasekhar et al. 2019), la méthode Best Worst (Rezaei 2015), la méthode de programmation linéaire logarithmique floue à deux étapes (Ren 2018), etc. Pour cette étude, nous déterminerons les poids subjectifs et les poids objectifs des critères. L'approche subjective détermine les poids uniquement en fonction de la prise en compte ou des jugements des DMs, tandis que l'approche objective sélectionne les poids par le biais de calculs mathématiques, qui négligent l'information de jugement subjective des DMs (Paramanik et al. 2022). Comme chaque approche, subjective ou objective, présente ses avantages et ses inconvénients, une méthode intégrée ou combinée semble plus souhaitable pour la détermination des poids des critères (Liu et al. 2013).

**3.4.1. Détermination des poids subjectifs des critères :**

Sur la base des poids agrégés des critères ($w_j$, $\alpha_{wj}$), $j = 1, 2, \ldots, n$, les poids subjectifs normalisés $w_j^s$ peuvent être obtenus à l'aide de l'équation suivante :

$$w_j^s = \frac{\Delta^{-1}(w_j, \alpha_{wj})}{\sum_{j=1}^{n} \Delta^{-1}(w_j, \alpha_{wj})}, \; j = 1, 2, \ldots, n \quad (9)$$

### 3.4.2. Détermination des poids objectifs des critères :

Dans cette thèse, les informations de décision sont exprimées par des 2-tuples, tels que $z_{ij}^k = (y_{ij}^k, c_{ij}^k)$ représentant que la performance d'un scénario sur un critère se situe entre deux 2-tuples $(y_{ij}^k, c_{ij}^k)$. Inspirés par les travaux de (Liu et al. 2013), le concept de variance statistique est utilisé pour déterminer les poids objectifs des critères.

Ainsi, les poids objectifs des critères $w_j^0$ peuvent être calculés à l'aide de l'équation suivante :

$$w_j^0 = \frac{\Delta^{-1}(\sigma_j^2)}{\sum_{j=1}^{n} \Delta^{-1}(\sigma_j^2)}, \; j = 1, 2, \ldots, n. \quad (10)$$

Ou,

$$\sigma_J^2 = \Delta(\tfrac{1}{m}\textstyle\sum_{i=1}^{m}(\Delta^{-1} \, d\big(z_{ij}^k, \bar{X}_j\big)^2) \; , j = 1, 2, \ldots, n.$$

$$and \Rightarrow d\,(z_{ij}^k, \bar{X}_j) = \Delta\big[\big(\big|\Delta^{-1}(y_{ij}^k - \bar{X}_j\big|\big)\big]$$

$$\bar{X}_j = \Delta\left[\frac{1}{m}\sum_{i=1}^{m} \Delta^{-1}(\, y_{ij}^k, c_{ij}^k)\right], j = 1, 2, \ldots, n$$

### 3.4.3. Méthode combinée pour la détermination des poids des critères

À cette étape, les poids finaux des critères sont calculés en combinant les poids subjectifs et objectifs des critères à l'aide de l'équation suivante :

$$w_j^c = \boldsymbol{\alpha_S} * w_j^s + \boldsymbol{\alpha_O} * w_j^0 \quad (11)$$

### 3.5. Extension du VIKOR pour le classement des scénarios, (Étape 5) :

Selon le travail de (Siksnelyte-Butkiene et al. 2020), la méthode VIKOR offre de nombreux avantages qui en font un choix idéal. Tout d'abord, elle fournit une solution de compromis unique qui équilibre efficacement les critères conflictuels, garantissant ainsi un résultat équitable et bien équilibré. Deuxièmement, elle prend en considération à la fois les meilleures et les pires issues possibles pour chaque alternative, assurant ainsi une évaluation approfondie. De plus, elle reconnaît l'importance relative des critères, ce qui permet une évaluation complète. Ce qui distingue VIKOR, c'est sa capacité à traiter à la fois les critères quantitatifs et qualitatifs, ce qui lui permet de prendre en compte une large gamme de facteurs. De plus, les décideurs sont habilités à affiner l'importance des critères, ce qui permet des ajustements personnalisés. Sur la base de ces avantages exceptionnels, nous avons sélectionné la méthode VIKOR pour classer les différents scénarios du cycle de vie.

### 3.5.1. Identification des solutions idéales positives et négatives.

Au cours de cette étape, nous établissons les solutions idéales positives et négatives de la matrice de décision linguistique en 2-tuples. La solution idéale positive est définie à l'aide de l'équation 12, tandis que la solution idéale négative est définie à l'aide de l'équation 13 pour la solution de coût :

$$(y_{ij}^{+}, c_{ij}^{+}) = \begin{Bmatrix} \underset{i}{\mathrm{Max}}\{(y_{ij}, c_{ij})\} & \text{efficiency index} \\ \underset{i}{\mathrm{Min}}\{(y_{ij}, c_{ij})\} & \text{cost index} \end{Bmatrix} \quad (12)$$

$$(y_{ij}^{-}, c_{ij}^{-}) = \begin{Bmatrix} \underset{i}{\mathrm{Min}}\{(y_{ij}, c_{ij})\} & \text{efficiency index} \\ \underset{i}{\mathrm{Max}}\{(y_{ij}, c_{ij})\} & \text{cost index} \end{Bmatrix} \quad (13)$$

### 3.5.2. Distances linguistiques en 2-tuples.

Conformément aux équations (12) et (13), nous calculons les distances linguistiques normalisées en 2-tuples.

$$\bar{d}(y_{ij}, c_{ij}) = \Delta\left(\frac{\Delta^{-1} d((y_{ij}^{+}, c_{ij}^{+}), (y_{ij}, c_{ij})}{\Delta^{-1} d\ ((y_{ij}^{+}, c_{ij}^{+}), (y_{ij}^{-}, c_{ij}^{-})}\right) \quad (14)$$

Où :

$$d\left((y_{ij}^{+}, c_{ij}^{+}), (y_{ij}, c_{ij})\right) = \Delta\left(\left|\Delta^{-1}(y_{ij}^{+}, c_{ij}^{+}) - \Delta^{-1}(y_{ij}, c_{ij})\right|\right)$$

$$d\left((y_{ij}^{+}, c_{ij}^{+}), (y_{ij}^{-}, c_{ij}^{-})\right) = \Delta\left(\left|\Delta^{-1}(y_{ij}^{+}, c_{ij}^{+}) - \Delta^{-1}(y_{ij}^{-}, c_{ij}^{-})\right|\right)$$

### 3.5.3. Calcul des 2-tuples *Si*, *Ri*, et Q*i*

Selon la méthode VIKOR, nous calculons la valeur d'utilité de groupe $(S_i, c_i)$ et la valeur de regret individuel (($R_i, c_i$) :

$$(S_i, c_i) = \Delta\left(\sum_{j=1}^{n} w_j^c * \Delta^{-1}\bar{d}\big(y_{ij}, c_{ij}\big)\right) \quad (15)$$

$$(R_i, c_i) = \Delta\left(\underset{i}{\text{Max}}\left(w_j^c * \Delta^{-1}\bar{d}\big(y_{ij}, c_{ij}\big)\right)\right) \quad (16)$$

La solution idéale pour le calcul des valeurs d'utilité de groupe $(S_i, c_i)$ et des regrets individuels $(R_i, c_i)$ est donnée comme suit :

$$\begin{cases} (S^*, c^*) = \underset{i1 \le i \le m}{\text{Min}}\{(S_i, c_i)\} \\ (S^-, c^-) = \underset{i1 \le i \le m}{\text{Max}}\{(S_i, c_i)\} \end{cases} \quad (17)$$

$$\begin{cases} (R^*, c^*) = \underset{i1 \le i \le m}{\text{Min}}\{(R_i, c_i)\} \\ (R^-, c^-) = \underset{i1 \le i \le m}{\text{Max}}\{(R_i, c_i)\} \end{cases} (18)$$

Nous calculons la valeur d'évaluation linguistique en 2-tuples globale $(Q_i, c_i)$ de chaque alternative comme suit :

$$(Q_i, c_i) = \Delta\left(\vartheta \frac{\Delta^{-1}(S_i, c_i) - \Delta^{-1}(S^*, c^*)}{\Delta^{-1}(S^-, c^-) - \Delta^{-1}(S^*, c^*)} + (1 - \vartheta)\frac{\Delta^{-1}(R_i, c_i) - \Delta^{-1}(R^*, c^*)}{\Delta^{-1}(R^-, c^-) - \Delta^{-1}(R^*, c^*)}\right) \quad (19)$$

lorsque $\vartheta$=0,5 => Deux conditions doivent être satisfaites :

- ✓ Condition 1 : (($Q(A_2)$ – Q($A_1$) ≥ (1/ ($n$-1)) (20)
- ✓ Condition 2 : $A_1$ est le meilleur scénario dans la liste classée, il doit également être classé en tête par *S* (utilité) et/ou *R* (regret).

Où : *n* = nombre de scénarios, $A_1$ = meilleur scénario dans la liste classée, $A_2$ = deuxième meilleur scénario dans la liste classée.

Après ces deux conditions, VIKOR peut classer les scénarios pour déterminer le meilleur scénario avec une grande précision (Lahanea and Kant, 2021). Les valeurs d'évaluation linguistique en 2-tuples $S_i$, $R_i$ et Qi sont utilisées pour trier les alternatives par ordre croissant, respectivement, de manière à obtenir les séquences des différents scénarios.

### 3.6. Analyse de sensibilité et de robustesse, (Étape 6) :

À cette étape, une analyse de sensibilité et de robustesse a été réalisée afin d'analyser la crédibilité des résultats de l'étude. Le premier test est le test d'analyse de sensibilité, où nous avons utilisé la "variation des poids de changement". Cet outil nous permet de modifier les poids des critères et de découvrir l'effet de cette perturbation sur nos résultats. Nous recalculons les poids pour l'analyse de sensibilité jusqu'à ce que les résultats soient valides (classement stable). Le deuxième test est l'analyse de robustesse, où nous avons utilisé deux méthodes différentes, "TOPSIS" et "PROMETHEE", pour comparer les résultats de classement avec le classement obtenu par la méthode VIKOR étendue. Ces méthodes ont été choisies en raison de leurs avantages uniques en matière de prise de décision multicritère. TOPSIS fournit un système de classement clair et un calcul efficace, permettant une approche directe et rationnelle. Il prend en compte toutes les informations fournies sans nécessiter d'indépendance et fournit rapidement des résultats. En revanche, PROMETHEE excelle dans le traitement de situations complexes avec des alternatives difficiles, en accommodant à la fois des informations qualitatives et quantitatives. Il peut intégrer des données incertaines et floues, permettant aux décideurs de faire face à l'ambiguïté et à l'incertitude. Les deux méthodes apportent des avantages précieux au domaine, répondant à différents contextes et exigences de décision. De plus, le travail de Cinelli et al. (2022) suggère que, sur la base de données qualitatives et du modèle en 2-tuples, TOPSIS et PROMETHEE peuvent être utilisés efficacement. Ces tests nous donnent le classement final pour notre étude.

## 4. Application de la méthodologie :

Étude de cas Dans cette section, une étude de cas spécifique est présentée pour résoudre les problèmes de prise de décision, de critères multiples, de phases multiples, de multiples décideurs et de circularité, en vue de sélectionner le scénario de production d'huile d'olive le plus durable en se basant sur le cycle de vie. Cette étude aborde les pratiques agricoles, la méthode d'extraction et la gestion de la récupération des déchets. Notre étude vise à évaluer la durabilité des systèmes de culture de l'olivier existants dans la région de Sfax en Tunisie à partir de 10 scénarios identifiés. Cette agriculture occupe une place importante dans l'économie de la Tunisie et plus spécifiquement de la région de Sfax.

#### 4.1.1. Identification des Scénarios et des Critères :

Dans cette section, nous présentons une étude de cas spécifique visant à relever les défis de la prise de décision impliquant de multiples critères, phases, décideurs et processus circulaires. L'objectif est de sélectionner le scénario le plus durable pour la production d'huile d'olive en se basant sur le cycle de vie du produit. Cette étude englobe divers aspects, notamment les pratiques agricoles, les méthodes d'extraction et la gestion de la récupération des déchets. Notre évaluation se concentre sur la durabilité des systèmes existants de culture de l'olivier dans la région de Sfax, en Tunisie, en tenant compte de dix scénarios identifiés. La culture de l'olivier occupe une place importante dans l'économie de la Tunisie, en particulier dans la région de Sfax.

### 4.1. Identifying the Decision-Making Team, Scenarios, and Criteria:

#### 4.1.1. Establishing the Decision-Making Team:

Dans le cadre de cette étude, nous évaluons la durabilité de la production d'huile d'olive. Pour ce faire, nous avons réuni une équipe de huit experts originaires de Tunisie. Ces experts avaient pour mission de fournir des avis sur dix scénarios, en prenant en compte des facteurs tels que les conditions environnementales, la situation économique, les aspects sociaux et les taux de circularité au sein du processus de production d'huile d'olive. Tous les membres de l'équipe possèdent des antécédents professionnels pertinents dans le domaine de l'agriculture, des processus d'extraction et de la valorisation des déchets liés à la production d'huile d'olive. Ils apportent une expérience substantielle en génie agricole et sur le plan académique.

#### 4.1.2. Identification des Scénarios et des Critères :

Nous avons identifié dix scénarios basés sur la littérature scientifique et des études de terrain menées avec des décideurs. Ces scénarios ont été validés par des experts de l'Institut de l'Olivier de Sfax. Chaque scénario englobe l'ensemble du cycle de vie de la production d'huile d'olive, couvrant les phases de culture des oliviers, de production d'huile d'olive et de gestion des déchets. Nous avons utilisé la Technique d'Analyse et de Conception Structurée (SADT) pour obtenir une compréhension globale de chaque scénario, ce qui nous a permis de définir précisément le rôle de chaque élément et de boucler les circuits de déchets. Notre contribution réside dans la création de scénarios durables tout en respectant le concept d'Économie Circulaire (EC).

Cette étude prend en compte des objectifs environnementaux, économiques et sociaux. Il est important de noter que le choix des critères peut varier en fonction du contexte spécifique de l'étude et de ses objectifs. La durabilité est un concept complexe, et différents acteurs peuvent accorder plus d'importance à certains aspects en fonction de leurs intérêts et de leurs priorités. Dans notre étude, nous nous sommes concentrés sur les critères les plus pertinents pour nos objectifs de recherche et en adéquation avec le contexte à l'étude. Nous avons introduit un critère innovant pour calculer les taux de récupération des déchets pour chaque scénario. Ces multiples critères ont ensuite été traités à l'aide de méthodes de prise de décision multicritères (MCDM). Dans cette étude de cas, nous avons adopté une hiérarchie étendue à deux niveaux (Critères et Sous-critères), comme le montre le Tableau 2, pour évaluer la production d'huile d'olive.

Table 2: List of Criteria

| Critères | Sous-critère | Description |
|---|---|---|
| **Critères environnementaux** | Utilisation des ressources en eau | Quantité d'eau utilisée dans un scénario. |
| | Utilisation des ressources abiotiques | Quantité de ressources abiotiques (carburant, etc.) utilisée dans un scénario.. |
| | Pollution | Cet indicateur inclut la pollution de l'air, de l'eau et du sol. |
| **Critères financiers** | Performance financière | Elle est définie comme la rentabilité financière d'un scénario. |
| | Coûts opérationnels | Tous les coûts nécessaires pour réaliser un scénario. |
| **Critères sociaux** | Conditions de travail | Cette question inclut la pénibilité, le travail des enfants et la discrimination (race, sexe ou autre). |
| | Sécurité au travail | Cette question inclut le taux de fréquence et le taux de gravité des accidents du travail dans un scénario. |

| Critères de l'économie circulaire | Taux de circularité | Il s'agit du taux de valorisation des déchets d'un scénario. |
|---|---|---|

### 4.2. Collection and Conversion of Linguistic Assessments

Dans l'évaluation de la durabilité agricole, déterminer avec précision le scénario le plus durable peut être difficile en raison de la complexité du système d'évaluation, des contradictions inhérentes, et parfois du manque de connaissances ou de données sur certains aspects du problème. Pour relever ces défis, cette étude utilise une échelle d'évaluation linguistique composée de sept niveaux, représentés comme suit : $T$ = *{'EL,' 'VL,' 'L,' 'RL,' 'M,' 'H,' 'VH,' 'EH'}*, (Tableau 3). Ces termes linguistiques offrent un moyen plus flexible et intuitif d'exprimer le niveau de durabilité atteint par chaque scénario.

Table 3: 2-Tuple Standard assessment

| Termes linguistiques: | Symboles | Valeur sémantique |
|---|---|---|
| Extrêmement bas | EL | 0 |
| Très bas | VL | 0,17 |
| Bas | L | 0,33 |
| Moyen | M | 0,5 |
| Élevé | H | 0,67 |
| Très élevé | VH | 0,83 |
| Extrêmement élevé | EH | 1 |

Chaque expert $E_k$ de l'équipe est invité à fournir une évaluation précise $\tilde{y}_{ij}^{k} = (y_{ij}^{k}, c_{ij}^{k})$ pour chaque scénario en suivant les différents critères, tels que répertoriés dans l'Annexe C. Dans cette annexe, les huit lignes correspondantes des éléments de la cellule 'Sc1-C1' représentent les évaluations fournies respectivement par les experts Ex1 à Ex8.

### 4.3. Détermination des poids des experts et agrégation des jugements

#### 4.3.1. Acquisition des poids individuels des experts :

La position personnelle de chaque expert au sein de l'équipe est représentée dans le Tableau 4. Chacun se voit attribuer un score spécifique $S_{iwe}$ en fonction de ses données (Position professionnelle, Ancienneté de service, Niveau éducatif et Âge), qui sont toutes répertoriées dans le Tableau 4. L'étape suivante consiste à calculer le poids individuel à l'aide de l'équation (1), comme présenté dans le tableau 4.

Tableau 4 : Informations personnelles des expert

| No. | Professional position | Service time | Educational level | Age | Score ($S_{iwe}$) | Weight ($W_{iwe}$) |
|---|---|---|---|---|---|---|
| Exp 1 | 4 | 1 | 5 | 1 | 11 | 0,11 |
| Exp 2 | 5 | 2 | 5 | 2 | 14 | 0,14 |
| Exp 3 | 2 | 3 | 4 | 2 | 11 | 0,11 |
| Exp 4 | 5 | 1 | 5 | 4 | 15 | 0,15 |
| Exp 5 | 3 | 3 | 4 | 1 | 11 | 0,11 |
| Exp 6 | 1 | 3 | 3 | 3 | 10 | 0,10 |
| Exp 7 | 4 | 1 | 5 | 2 | 12 | 0,12 |
| Exp 8 | 5 | 3 | 5 | 3 | 16 | 0,16 |

### 4.3.2. Calcul du degré de concordance relatif :

Le degré de concordance relatif d'un commentaire d'évaluation pour chaque scénario par rapport à chaque critère est déterminé en utilisant les équations (2) à (5).

Tableau 5 : Processus de calcul du degré relatif de concordance pour SC1 sous le critère C1.

| | Exp 1 | Exp 2 | Exp 3 | Exp 4 | Exp 5 | Exp 6 | Exp 7 | Exp 8 |
|---|---|---|---|---|---|---|---|---|
| Exp 1 | 0 | 0 | 0,67 | 0,16 | 0,34 | 0 | 0,17 | 0 |
| Exp 2 | 0 | 0 | 0,67 | 0,16 | 0,34 | 0 | 0,17 | 0 |
| Exp 3 | 0,67 | 0,67 | 0 | 0,83 | 0,33 | 0,67 | 0,5 | 0,67 |
| Exp 4 | 0,16 | 0,16 | 0,83 | 0 | 0,5 | 0,16 | 0,33 | 0,16 |
| Exp 5 | 0,34 | 0,34 | 0,33 | 0,5 | 0 | 0,34 | 0,17 | 0,34 |
| Exp 6 | 0 | 0 | 0,67 | 0,16 | 0,34 | 0 | 0,17 | 0 |
| Exp 7 | 0,17 | 0,17 | 0,5 | 0,33 | 0,17 | 0,17 | 0 | 0,17 |
| Exp 8 | 0 | 0 | 0,67 | 0,16 | 0,34 | 0 | 0,17 | 0 |
| Ad | 0,191 | 0,191 | 0,620 | 0,329 | 0,337 | 0,191 | 0,240 | 0,191 |
| AA | 5,224 | 5,224 | 1,613 | 3,043 | 2,966 | 5,224 | 4,167 | 5,224 |
| RA | 0,160 | 0,160 | 0,049 | 0,093 | 0,091 | 0,160 | 0,127 | 0,160 |

$\text{Ad}^1 = \frac{0 + 0 + 0.67 + 0.16 + 0.34 + 0 + 0.17 + 0}{8-1} = 0,191$

$\text{AA}^1 = \frac{1}{\text{AA}^1} = \frac{1}{0,191} = 5,224$

$\text{RA}^1 = \frac{5,224}{5,224 + 5,224 + 1,613 + 3,043 + 2,966 + 5,224 + 4,167 + 5,224} = 0,160$

En considérant les commentaires pour le SC1 de C1 par exemple, sept valeurs d'évaluation sont obtenues des experts comme suit : {‘L’, ‘L’, ‘EH’, ‘VL’ ‘H’, ‘L’, ‘M’ et ‘L’}, qui peuvent être transformées en un modèle 2-Tuple {0,33 ; 0,33 ; 1 ; 0,17 ; 0,67 ; 0,33 ; 0,5 ; 0,33}. Bien que les évaluations fournies par les experts puissent être incohérentes, le SAM modifié proposé prend en compte les opinions tant de la majorité que de la minorité grâce au degré de concordance relatif. Par conséquent, le processus de calcul suivant, tel qu'indiqué dans le Tableau 5, doit être répété pour tous les scénarios et les critères. La convention selon laquelle la minorité doit suivre la majorité est également prise en compte.

### 4.3.3. Obtention du poids dynamique synthétique de chaque expert :

Le vecteur de poids dynamique synthétique, $w_{11}$= (0,1349 ; 0,1477 ; 0,1333 ; 0,1499 ; 0,1070 ; 0,1186 ; 0,1125 ; 0,1523) est calculé à l'aide de l'équation (6). Ici, les facteurs de relaxation $\alpha$ = 0,5 et $\beta$ = 0,5 sont adoptés. De manière similaire, le vecteur de poids dynamique synthétique $w_{ij}^{k}$de chaque commentaire est calculé en fonction de la valeur d'évaluation et du niveau de confiance des cas d'évaluation.

### 4.3.4. Agrégation des évaluations 2-Tuple

Pour parvenir à une décision de groupe, les évaluations individuelles des experts sous forme de 2-Tuples doivent être agrégées en une seule valeur à l'aide de l'équation (7). Il est important de prendre en compte à la fois le poids de chaque évaluation et leur ordre de comparaison numérique. Ce processus est nécessaire pour parvenir à une évaluation globale qui intègre la contribution de tous les experts dans le processus décisionnel. Les évaluations les plus grandes et les plus petites sont considérées comme ayant des valeurs de référence relativement faibles, elles se voient donc attribuer des poids plus faibles. Ensuite, en répétant les procédures précédentes, une matrice d'évaluation synthétique $\tilde{Y}$ est formée comme indiqué dans le Tableau 6.

Tableau 6 : Matrice d'évaluation synthétique en 2-Tuple

| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 |
|---|---|---|---|---|---|---|---|---|
| **Sc 1** | 0,05869163 | 0,04820473 | 0,06489767 | 0,06033906 | 0,05668121 | 0,06862256 | 0,04875914 | 0,08747944 |
| **Sc 2** | 0,06995024 | 0,07285383 | 0,05091757 | 0,06809189 | 0,08214511 | 0,06463861 | 0,06404074 | 0,09632028 |
| **Sc 3** | 0,06824222 | 0,09277225 | 0,04715783 | 0,06949282 | 0,0696809 | 0,06347239 | 0,06647151 | 0,06900519 |
| **Sc 4** | 0,08402016 | 0,08302332 | 0,04536018 | 0,07924162 | 0,07719927 | 0,05786483 | 0,0704938 | 0,08646426 |
| **Sc 5** | 0,08722484 | 0,10011246 | 0,05913225 | 0,08858024 | 0,07448376 | 0,06158754 | 0,0719962 | 0,06183907 |
| **Sc 6** | 0,06617781 | 0,04650585 | 0,04820941 | 0,07089683 | 0,06216239 | 0,06780897 | 0,07161658 | 0,08350922 |
| **Sc 7** | 0,08328598 | 0,07064838 | 0,06106337 | 0,07253452 | 0,08273748 | 0,07146797 | 0,06848162 | 0,08922241 |
| **Sc 8** | 0,09177391 | 0,07023009 | 0,07527869 | 0,09533878 | 0,07190623 | 0,07034872 | 0,08665663 | 0,06640696 |
| **Sc 9** | 0,11550832 | 0,09623493 | 0,0912335 | 0,09036612 | 0,09012446 | 0,09450007 | 0,09352101 | 0,06434637 |
| **Sc 10** | 0,12197361 | 0,11811867 | 0,09599828 | 0,09554578 | 0,09515484 | 0,09814439 | 0,11238459 | 0,07771352 |

### 4.4. Calcul des poids des critères de durabilité

Les poids des critères subjectifs et objectifs sont calculés en utilisant les équations (9)-(11), comme indiqué dans le Tableau 7.

Tableau 7 : Pondération des critères par les méthodes de pondération subjectives, objectives et combinées

| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 |
|---|---|---|---|---|---|---|---|---|
| $w_j^0$ | 0,13636364 | 0,10227273 | 0,13636364 | 0,14772727 | 0,13636364 | 0,09659091 | 0,10227273 | 0,14204545 |
| $w_j^s$ | 0,1591412 | 0,146994397 | 0,086688618 | 0,13191714 | 0,123073095 | 0,105777704 | 0,126868673 | 0,119539202 |
| $w_j^c$ | 0,147752403 | 0,124633562 | 0,111526127 | 0,139822206 | 0,129718366 | 0,101184307 | 0,1145707 | 0,130792328 |

### 4.5. Classement de la priorité de durabilité de chaque scénario

Sur la base de la pondération des critères fournie dans le Tableau 7, le classement de chaque scénario est déterminé par la combinaison du modèle en 2-tuples et de la méthode VIKOR étendue. Les équations (12) et (13) sont utilisées pour déterminer la solution idéale en 2-tuples positive et négative de chaque critère. Chaque évaluation en 2-tuples est comparée à la solution idéale positive et négative pour mesurer leur distance en utilisant les équations (2) de (Liu et al. 2013). Ensuite, sur la base des poids intégrés des critères, l'utilité de groupe maximale Si et le regret individuel minimal Ri de chaque scénario sont calculés à l'aide des équations (15) et (16), et les résultats sont résumés dans le Tableau 8. Ensuite, la solution idéale pour le calcul des valeurs d'utilité de groupe $(S_i, c_i)$ et des regrets individuels $(R_i, c_i)$ est identifiée à l'aide des équations (17) et (18). Enfin, l'indice de priorité $Q_i$ est calculé à l'aide de l'équation (19) avec un paramètre $\vartheta$ réglé à 0,5, et le classement par ordre croissant est répertorié dans le Tableau 8.

Tableau 8 : Résultats et classement des scénarios du cycle de vie.

| | **$S_i$** | **$R_i$** | **$Q_i$** | **Ranking** |
|---|---|---|---|---|
| **Sc 1** | 0,24636715 | 0,13982221 | 0,450 | 6 |
| **Sc 2** | 0,32380253 | 0,10903214 | 0,324 | 4 |
| **Sc 3** | 0,40366907 | 0,10361018 | 0,361 | 5 |
| **Sc 4** | 0,33314552 | 0,06917906 | 0,078 | 1 |
| **Sc 5** | 0,45992166 | 0,13079233 | 0,585 | 8 |
| **Sc 6** | 0,25486089 | 0,0978924 | 0,190 | 2 |
| **Sc 7** | 0,40987525 | 0,09138837 | 0,289 | 3 |
| **Sc 8** | 0,44964662 | 0,11346566 | 0,465 | 7 |
| **Sc 9** | 0,74747971 | 0,13265709 | 0,857 | 9 |
| **Sco 10** | 0,79996365 | 0,1477524 | 1,000 | 10 |

Ainsi, lorsque $\vartheta$=0,5, deux conditions représentées dans l'équation (20) doivent être satisfaites :

- Condition 1 : *(Q(Sc2) – Q(Sc1) ≥ (1/ (n-1)) = 0,190 - 0,078 ≥ (1/ (10-1)) =0,112 ≥ 0,111* ➔ Cette condition est vérifiée.
- Condition 2 : $Sc_4$ est le meilleur scénario dans la liste classée ($Q_i$), et $Sc_4$ est également classé le plus haut par ($R_i$). ➔ Cette condition est vérifiée.

Après ces deux conditions, VIKOR est adapté pour classer le scénario $Sc_4$ comme le cycle de vie le plus durable de la production d'huile d'olive avec une grande précision. (Tous les résultats de cette étude sont disponibles dans l'Annexe D).

## 5. Validation et discussion

### 5.1. Analyse des résultats

Dans cette thèse, un cycle de vie durable de l'olive pour l'agriculture en Tunisie est proposé afin d'atteindre des objectifs de circularité et ainsi d'assurer une production durable d'huile d'olive. Le cycle de vie proposé (Scénario 4) implique la culture conventionnelle de l'olive avec irrigation.

Ce type de configuration offre une productivité maximale en utilisant un système d'irrigation, une fertilisation (distribution de fumier avec NPK sur le sol, application des eaux usées du moulin à huile directement sur les champs, et broyage et dispersion des résidus de taille sur les champs) et l'utilisation de pesticides et d'herbicides pour produire les cultures agricoles. Pour la deuxième phase du cycle de vie de l'olive, le système à deux phases continues a été proposé comme la solution la plus durable. Ce type de système produit une huile d'olive de très bonne qualité et au goût meilleur (riche en antioxydants naturels, en polyphénols, etc.) tout en préservant l'environnement et en assurant le bien-être social, cependant, cette méthode d'extraction reste très coûteuse économiquement. Pour la dernière phase, notre méthode propose comme scénario le plus durable de valoriser les déchets de l'huile d'olive : "Application directe sur le sol" pour les eaux usées du moulin à huile et "Digestion anaérobie" pour la pulpe d'olive. De nombreuses études ont été publiées sur les effets de l'épandage des eaux usées du moulin à huile sur les sols cultivés. Les expériences agronomiques menées avec des doses conformes aux règles de fertilisation ont toutes montré l'effet favorable des eaux usées du moulin à huile sur la fertilité du sol. En effet, d'une part, elles ne contiennent pas de métaux lourds ni de micro-organismes pathogènes, et d'autre part, elles sont riches en éléments nutritifs minéraux (N, P, K). De plus, étant donné qu'elles sont constituées de matière organique, elles représentent un excellent substrat pour le développement de la microflore, qui améliore les propriétés physico-chimiques du sol. De même, le système d'extraction choisi dans les deuxième phases produit une petite quantité d'eaux usées du moulin à huile par rapport à d'autres méthodes de traitement de l'olive. Par conséquent, cette méthode de valorisation (récupération) pourrait être une solution durable pour ce type de déchet. D'autres travaux se concentrent sur les effets positifs de la digestion anaérobie sur la durabilité. En effet, cette méthode a été caractérisée par un impact environnemental moindre par rapport à d'autres méthodes de récupération des résidus solides. Ainsi, la valorisation des déchets de l'huile d'olive par digestion anaérobie produit du biogaz et un résidu organique. Le biogaz peut être utilisé pour l'énergie et le résidu organique peut être appliqué comme amendement du sol. Afin d'évaluer les retours et la satisfaction de notre processus et de ses résultats, nous avons réalisé le scénario 4 avec les décideurs (DM). Cette étape a permis aux DM d'évaluer la pertinence, l'utilité et la fiabilité des informations fournies. En impliquant activement les DM dans le processus d'évaluation, nous avons cherché à nous assurer que la méthode correspond à leurs préoccupations et capture plus efficacement leurs perspectives du monde réel. Leurs commentaires ont joué un rôle crucial pour évaluer le niveau de satisfaction à l'égard du processus et de ses résultats. Revenant à notre étude de cas, nous avons reçu des retours positifs de diverses parties prenantes, notamment des experts, des agriculteurs et de l'Institut de l'olivier du gouvernement. Lors de réunions visant à discuter de l'exactitude et de la validité de nos résultats, l'Institut de l'olivier a exprimé son appréciation pour nos commentaires. De plus, ils ont encouragé les agriculteurs à mettre en œuvre le scénario proposé sur le terrain lors de la prochaine session. De nombreux agriculteurs ont également montré leur confiance dans l'efficacité du scénario et ont exprimé leur impatience de commencer à le mettre en œuvre dans leurs champs. Il convient de noter que bien que la majorité des experts aient exprimé leur soutien, certains ont soulevé des préoccupations et des désaccords valables, que nous nous engageons à aborder pour assurer une évaluation complète de nos conclusions.

### 5.2. Analyse de sensibilité

#### 5.2.1. Paramètre de contrôle "$\vartheta$"

L'importance relative de l'utilité de groupe maximale ‘Si’ et du regret individuel minimal ‘Ri’ des résultats de l'évaluation est gérée par $\vartheta$ pour générer l'indice de classement de durabilité, comme exprimé dans l'équation (18). Le choix de la valeur de $\vartheta$ est [0,1]. En prenant $\vartheta$ = 0,1, 0,3, 0,5, 0,7 et 0,9 respectivement pour le cas 1, le cas 2, le cas 3, le cas 4 et le cas 5. Les résultats obtenus de l'indice de classement de durabilité avec les différents cas sont montrés dans la Figure 4.

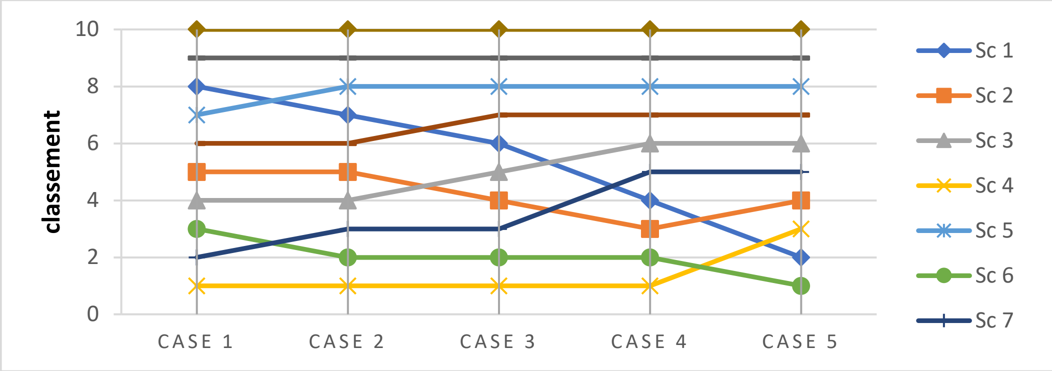


Figure 4 : Analyse de sensibilité du paramètre de contrôle "ϑ".

Il ressort de la Figure 3 que lorsque la valeur du paramètre de contrôle ϑ change, il y a quelques différences dans la variation de l'indice de priorité de durabilité, Qi, de chaque scénario. On peut voir dans la Figure 4 que les classements des scénarios les plus durables et les moins durables ne changent pas dans de nombreux cas (pour l'alternative la plus durable : Sc 4 en jaune : Cas 1, Cas 2, Cas 3 et Cas 4. Pour l'alternative de scénario la moins favorable Sc 10 en marron : Cas 1, Cas 2, Cas e3, Cas 4 et Cas 5). Par conséquent, dans la plupart des cas avec le changement de la valeur du paramètre de contrôle ϑ, nous pouvons constater qu'il n'y a aucun impact sur les meilleurs et les pires résultats.

### 5.2.2. Coefficients de proportion $\alpha_S$ *et* $\alpha_O$

À l'étape 4 de la méthodologie, les poids des critères sont déterminés par une combinaison de la méthode de pondération directe (poids subjectif) et de la méthode des 2-Tuples (poids objectif). Les coefficients de proportion S et O des poids subjectifs et objectifs jouent un rôle crucial dans la détermination des poids intégrés et du classement des scénarios. Ces coefficients prennent des valeurs entre 0 et 1, avec une somme égale à 1. Une analyse de sensibilité est effectuée en faisant varier les valeurs de S= 0,1, 0,3, 0,5, 0,7 et 0,9 respectivement. Tous les résultats de cette étape sont présentés dans la Figure 5.

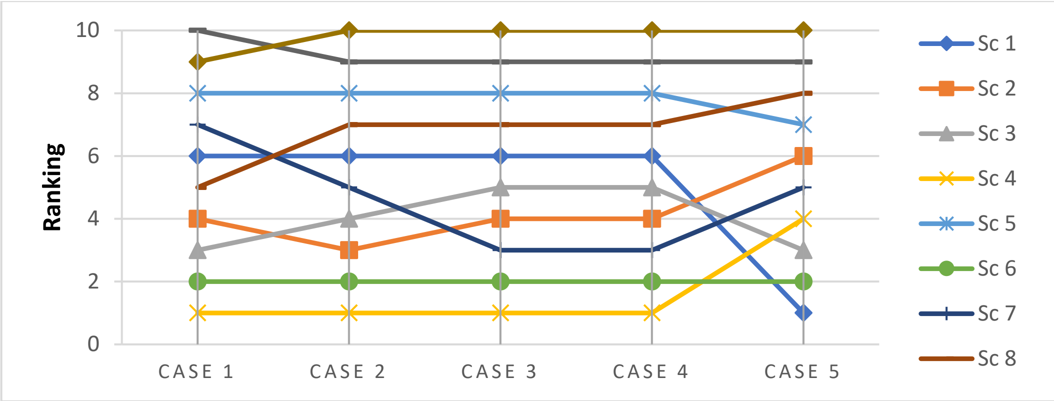


Figure 5 : Analyse de sensibilité du coefficient de proportion $\boldsymbol{\alpha_S}$.

À mesure que la valeur de S augmente de 0,1 à 0,9, l'impact du poids subjectif sur les poids intégrés des critères augmente progressivement, tandis que celui du poids objectif diminue. Cela entraîne quelques fluctuations dans le classement de durabilité des scénarios, comme le montre la Figure 5. En comparaison, les meilleures et les pires solutions durables restent presque stables dans les différents cas, comme le scénario 4 a toujours les meilleurs résultats de durabilité, plus spécifiquement dans : Cas 1, Cas 2, Cas 3 et Cas 4. De plus, les scénarios 10 et 9 ont toujours les priorités de durabilité les plus faibles dans : Cas 2, Cas 3, Cas 4 et Cas 5. Nous notons également que les classements de durabilité ne changent pas dans les Cas 3 et 4. Par conséquent, la tendance générale des résultats d'évaluation reste stable et le classement de durabilité reste élevé. La sensibilité des coefficients de proportion aux résultats de classement de durabilité est également faible. Cependant, afin de différencier le classement de durabilité des différents scénarios agricoles, il est essentiel de trouver un équilibre raisonnable entre l'importance relative des poids subjectifs et objectifs.

### 5.2.3. Facteurs de relaxation α et β

Le poids dynamique synthétique $w_{ij}^k$ d'une évaluation d'expert est utilisé pour agréger les commentaires des 2-Tuples. Il est calculé à l'aide du poids individuel de l'expert et du degré de concordance relatif. L'importance relative de ces deux facteurs est mesurée par les facteurs de relaxation α et β, comme exprimé dans l'équation (6). Les facteurs de relaxation satisfont à $\alpha$ et $\beta \in [0,1]$ *et* $\alpha + \beta = 1$. Leur sensibilité est analysée en sélectionnant 5 cas (S= 0,1, 0,3, 0,5, 0,7 et 0,9 respectivement pour le cas 1, le cas 2, le cas e3, le cas 4 et le cas5) avec diverses valeurs des deux facteurs de relaxation dans leur plage et en calculant le classement de priorité de durabilité. Les résultats sont présentés dans la Figure 6.

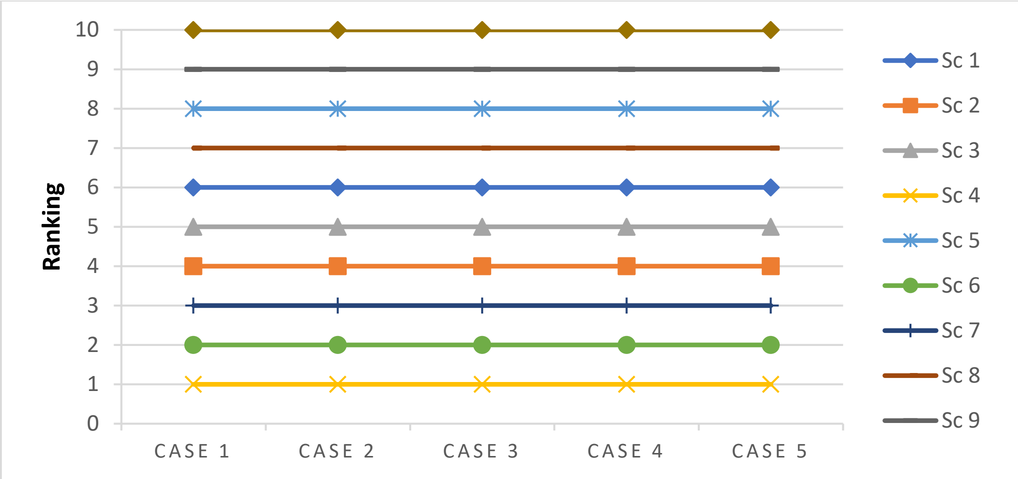


Figure 6 : Analyse de sensibilité des facteurs de relaxation (α et β) du poids dynamique synthétique des experts.

Comme le montre la Figure 6, lorsque les facteurs de relaxation changent, ils présentent une stabilité pendant les 5 cas. Ainsi, le résultat de classement ne varie pas. En général, la sensibilité du paramètre de contrôle $\vartheta$ est faible, et bien que l'indice de priorité de durabilité change avec $\vartheta$, le classement des meilleurs et des pires résultats ne varie pas. Les changements dans les coefficients de proportion $\boldsymbol{\alpha_S}$ et $\boldsymbol{\alpha_O}$ont des impacts sur les résultats de calcul de la priorité de durabilité, en particulier pour les scénarios agricoles de classement intermédiaire. En revanche, les facteurs de relaxation montrent une stabilité significative. En comparaison, les scénarios à priorité maximale et minimale ont une influence minimale sur la tendance globale du classement, ce qui indique que la méthode proposée est très robuste.

### 5.3. Analyse comparative

Afin de démontrer la robustesse de la méthode VIKOR, une comparaison avec deux autres méthodes, à savoir les méthodes TOPSIS et PROMETHEE, a été réalisée avec les mêmes données d'évaluation fournies par les experts. Les résultats obtenus ont ensuite été comparés à ceux obtenus par la méthode proposée et présentés dans la Figure 7.

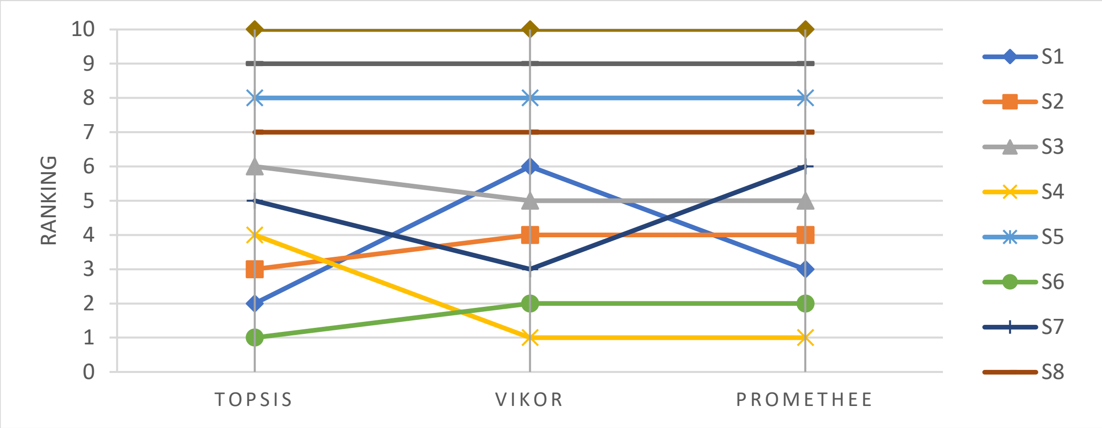


Figure 7 : Comparaison des résultats de classement de priorité de durabilité de différentes méthodes

La Figure 7 montre que les résultats de classement de priorité de durabilité du cycle de vie de l'huile d'olive sont obtenus par les méthodes PROMETHEE, qui sont légèrement différents de la méthode VIKOR améliorée proposée dans cette étude. Cependant, les deux méthodes conduisent au résultat que le scénario avec la meilleure priorité durable est le scénario 4 et avec la plus faible sont les scénarios 9 et 10, ce qui montre la rationalité et l'efficacité de la méthode améliorée. D'un autre côté, la méthode TOPSIS donne un autre classement, plus spécifiquement pour la meilleure priorité durable qui est le scénario 6 selon les résultats présentés dans la figure 7. Ainsi, lorsque plusieurs méthodes définissent la même meilleure solution, le problème de la meilleure définition de scénario est pratiquement résolu. Dans notre cas, nous devons répondre à la question de quelle est vraiment la meilleure solution parmi les meilleures solutions obtenues. À cette fin, un nouveau test a été développé par (Abbas and Chergui 2017). Il permet de choisir la meilleure solution parmi plusieurs bonnes solutions. En utilisant la formule mathématique (21), nous calculons la différence entre deux ratios, de telle sorte que le premier mesure le pourcentage avec lequel l'action Ak ∈ A est meilleure que l'action Al ∈ A, et le deuxième exprime l'inverse.

$$A_k > A_l \Leftrightarrow \sum_{j}^{n} W_j \frac{a_{kj}}{a_{lj}} > \sum_{j}^{n} W_j \frac{a_{lj}}{a_{kj}} \quad (21)$$

Nous supposons que $A_k$ et $A_l$ sont différents de 0.

$$A_4 > A_6 \Leftrightarrow \sum_{j}^{n} W_j \frac{a_4}{a_6} > \sum_{j}^{n} W_j \frac{a_6}{a_4}$$

En appliquant l'équation (20) entre la meilleure solution (scénario 4) et la deuxième solution (scénario 6), on obtient : $A_4$=1,166939054 et $A_6$=0,895561844 ⇔ $A_4 > A_6$. Ainsi, le classement de la méthode VIKOR est validé par le test de robustesse. Cependant, l'analyse comparative et le test de robustesse montrent que la méthode proposée est capable d'obtenir un classement de durabilité plus rationnel et fiable du cycle de vie de l'huile d'olive en comparaison avec d'autres méthodes de classement existantes.

## 6. Integrating TRIZ and MCDM for Innovative and Sustainable Decision-Making: A Case Study in the Life Cycle of Olive Oil

La deuxième méthodologie proposée dans cette étude vise à fournir un cycle de vie durable et innovant pour les produits en définissant le domaine du problème et en proposant un guide étape par étape pour trouver une solution durable, (Figure 1).

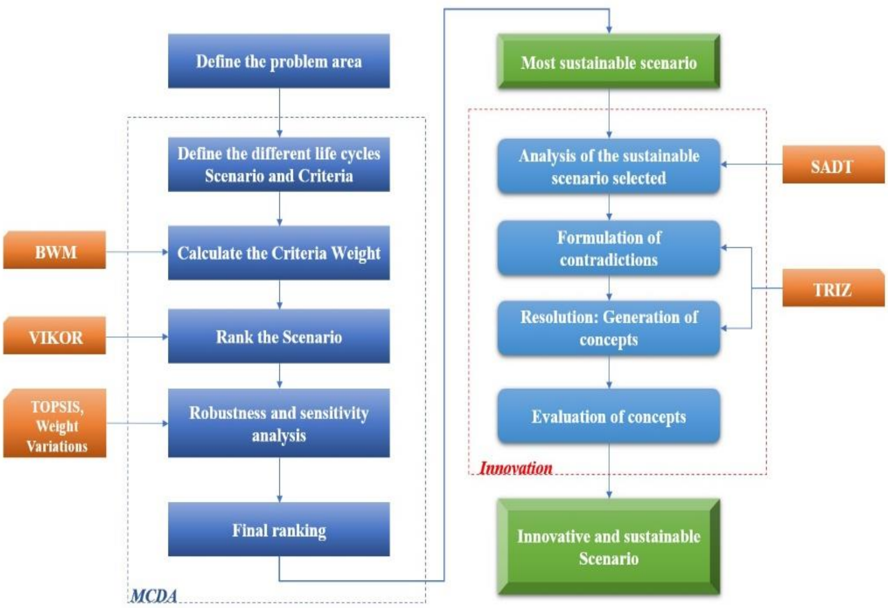


Fig. 1. Cadre méthodologique

La méthodologie comprend différentes étapes qui seront expliquées en détail ci-dessous :

• **Étape 1 :** L'objectif de cette étape est de définir le domaine du problème. Cela implique d'identifier le problème spécifique qui doit être résolu. Par exemple, le problème pourrait être la réduction de l'impact environnemental d'un produit ou l'amélioration de sa durabilité.

• **Étape 2 :** L'objectif de cette étape est de définir les différents cycles de vie du produit qui doivent être étudiés, ainsi que les critères pour construire une matrice de décision. Les cycles de vie peuvent inclure la fabrication, le transport, l'utilisation et l'élimination. Les critères pour construire la matrice de décision peuvent inclure des facteurs tels que l'impact environnemental, le coût et la convivialité. Ces critères seront utilisés dans les étapes ultérieures pour évaluer la durabilité des alternatives.

• **Étape 3 :** Dans le cadre d'un processus multicritère, plusieurs sous-étapes doivent être prises en considération. Tout d'abord, il est nécessaire de calculer les poids des critères à l'aide de la méthode du Best Worst Method(BWM). Ensuite, la méthode VIKOR peut être utilisée pour classer les différents cycles de vie des produits en utilisant trois indices : l'indice $S_j$ (valeurs d'utilité du groupe), l'indice $R_j$ (regrets individuels) et l'indice VIKOR synthétique représenté par le calcul de $Q_j$, [8]. La plus faible valeur de $Q_j$ correspond au meilleur scénario le plus proche de la valeur idéale. Enfin, il est essentiel d'analyser la robustesse et la sensibilité des résultats. L'analyse de sensibilité permet d'évaluer l'impact des changements de critères ou de poids sur le classement des alternatives. L'analyse de la robustesse, en revanche, consiste à évaluer la capacité des alternatives à résister aux variations de critères et de poids, en utilisant la méthode TOPSIS pour vérifier la robustesse des résultats de calcul de VIKOR et analyser la cohérence des résultats obtenus.

• **Étape 4 :** Analyse du scénario le plus durable sélectionné : Cette étape consiste à décrire clairement les flux, les entrées, les sorties et les ressources rares (eau, énergie, énergies fossiles, ...) de chaque scénario en utilisant la technique d'analyse et de conception structurée (SADT). Notre contribution consiste à intégrer SADT afin d'analyser toutes les boucles de la situation initiale pour comprendre le cycle de vie de notre système [9].

• **Étape 5 :** Formulation des contradictions : Ici, nous avons identifié les paramètres TRIZ qui représentent les contradictions au sein du cycle de vie de tout produit. En identifiant ces contradictions, nous pouvons commencer à générer des idées pour résoudre le problème.

• **Étape 6 :** Résolution : génération de concepts : Cette étape consiste à appliquer les principes et les outils TRIZ pour générer des solutions innovantes aux contradictions identifiées.

• **Étape 7** : Évaluation des concepts de solution : Cette étape consiste à évaluer les idées générées dans la phase précédente en utilisant des critères tels que la faisabilité technique, le coût, la sécurité, la durabilité et l'impact environnemental, [10].

En conclusion, cette méthodologie offre une approche systématique et complète pour trouver des solutions durables pour tous les cycles de vie des produits en combinant des méthodes d'optimisation et TRIZ. En définissant le domaine du problème, en identifiant les critères et en utilisant MCDM et TRIZ, cette méthodologie permet de créer des cycles de vie durables et innovants pour les produits. Le processus en sept étapes fournit un guide clair et concis pour aborder les préoccupations en matière de durabilité dans la conception et le développement de produits.

## 7. Conclusion

Ce travail de recherche s'est concentré sur l'examen des processus de durabilité et de prise de décision au sein de la chaîne d'approvisionnement de l'huile d'olive, en mettant particulièrement l'accent sur l'incorporation des principes de l'économie circulaire (EC), ainsi que sur l'utilisation de la méthode d'analyse multicritère (MCDA) et de l'évaluation de la durabilité du cycle de vie (LCSA). Les résultats et les contributions, ont éclairé divers aspects du sujet et ont ouvert la voie à une compréhension plus complète des pratiques durables et de la prise de décision éclairée dans le secteur agricole. Dans l'ensemble, cette recherche a contribué à la littérature existante en mettant l'accent sur l'importance de la durabilité, des principes de l'économie circulaire et de la prise de décision éclairée dans la chaîne d'approvisionnement de l'huile d'olive. Les résultats soulignent la nécessité d'évaluations globales de la durabilité, d'outils de prise de décision efficaces et de l'intégration de diverses méthodologies pour promouvoir un secteur agricole plus durable et résilient. En tenant compte des principes de l'économie circulaire, en utilisant des méthodes analytiques appropriées et en intégrant des approches multicritères, les parties prenantes peuvent prendre des décisions plus éclairées qui équilibrent les considérations environnementales, économiques et sociales, conduisant à un avenir durable pour la chaîne d'approvisionnement de l'huile d'olive et au-delà. Malgré les précieuses informations et contributions de cette recherche, il est important de reconnaître certaines limites. Tout d'abord, l'étude s'est concentrée spécifiquement sur la chaîne d'approvisionnement de l'huile d'olive, ce qui pourrait limiter la généralisation des résultats à d'autres secteurs agricoles. Différentes industries agricoles peuvent présenter des caractéristiques uniques et des défis en matière de durabilité qui nécessitent des approches et des méthodologies adaptées. De plus, la nature dynamique des défis en matière de durabilité et l'évolution des pratiques de l'économie circulaire posent un défi en termes de suivi des derniers développements et de leur incorporation dans les cadres de prise de décision. Des recherches en cours et des mises à jour continues sont nécessaires pour s'adapter aux tendances émergentes et aborder efficacement les préoccupations évolutives en matière de durabilité. Cette recherche pose les bases pour des enquêtes futures et des développements dans le domaine de la durabilité et de la prise de décision au sein de la chaîne d'approvisionnement de l'huile d'olive. Plusieurs pistes d'exploration et d'amélioration peuvent être envisagées. Tout d'abord, les futures recherches pourraient étendre la portée au-delà de l'industrie de l'huile d'olive et explorer l'applicabilité des méthodologies et des cadres proposés dans d'autres secteurs agricoles. En élargissant l'analyse à différentes chaînes d'approvisionnement, une compréhension plus complète des défis en matière de durabilité et des processus de prise de décision peut être atteinte, favorisant l'apprentissage intersectoriel et l'échange de connaissances. De plus, l'incorporation de technologies avancées telles que la blockchain, l'Internet des objets (IoT) et l'intelligence artificielle (IA) peut améliorer la collecte de données, la traçabilité et les processus de prise de décision au sein de la chaîne d'approvisionnement. L'exploration de l'intégration de ces technologies dans les cadres proposés peut fournir des informations plus précises et en temps réel, permettant une prise de décision plus éclairée et facilitant la mise en œuvre des principes de l'économie circulaire. Enfin, il est essentiel d'impliquer les parties prenantes de différents secteurs, notamment les décideurs politiques, les producteurs, les consommateurs et les organisations environnementales, dans les processus de prise de décision. Les futures recherches devraient explorer des approches participatives efficaces et des plates-formes de collaboration qui favorisent le dialogue, le partage des connaissances et la construction de consensus. Cela garantira une perspective plus large, une expertise diversifiée et une prise de décision collective, conduisant à des résultats plus durables et inclusifs. En conclusion, cette recherche fournit une base solide pour les enquêtes futures et les avancées dans les pratiques durables et la prise de décision au sein de la chaîne d'approvisionnement de l'huile d'olive. En abordant les limites identifiées et en explorant les perspectives suggérées, les chercheurs et les praticiens peuvent renforcer davantage les résultats en matière de durabilité, contribuer au domaine plus large de la durabilité agricole et ouvrir la voie à un avenir plus durable et plus résilient.

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# TITRE de la thèse

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## Résumé

Prendre des décisions dans le secteur de l'agriculture est un processus complexe et exigeant, surtout en visant la durabilité. Les décideurs doivent concilier réduction des impacts environnementaux et sociaux sans sacrifier les profits. Cette thèse vise à aider les décideurs à choisir les pratiques agricoles, l'extraction et la gestion des déchets pour rendre le cycle de vie circulaire et durable. Notre nouveau cadre multicritère propose plusieurs contributions : scénarios durables intégrant une économie circulaire, modèle 2-Tuple pour gérer l'incertitude, algorithme de pondération synthétique dynamique pour agréger les opinions des décideurs, extension de VIKOR avec le modèle 2-Tuple pour classer la durabilité des scénarios. Une étude de cas sur l'huile d'olive à Sfax-Tunisie illustre notre approche. Les résultats montrent l'efficacité de notre méthode pour résoudre les problèmes de durabilité agricole. L'intégration de TRIZ avec l'analyse multicritère vise à améliore les processus de prise de décision. Les résultats apportent des méthodologies pour d'autres industries, promouvant un avenir plus durable.



**Mots clés :**
Durabilité, Multicritères, Multi phases, Analyse de décision, Agriculture, Méthode d'agrégation de similarité, Économie circulaire, Identification de contradictions, Résolution de contradictions.



## Résumé en anglais

Making decisions in the agriculture sector is a complex and demanding process, especially when aiming for sustainability. Decision-makers must reconcile reducing environmental and social impacts without sacrificing profits. This thesis aims to assist decision-makers in selecting agricultural practices, extraction methods, and waste management to make the product's lifecycle more circular and sustainable. Our new multicriteria framework offers several key contributions: sustainable scenarios incorporating a circular economy, the use of the 2-Tuple model to manage uncertainty, a dynamic synthetic weighting algorithm to aggregate decision-makers' opinions, and an extension of VIKOR using the 2-Tuple model to assess scenario sustainability. A case study on olive oil in Sfax, Tunisia, illustrates our approach. The results demonstrate the effectiveness of our method in addressing agricultural sustainability issues. Integrating TRIZ with multicriteria analysis is intended to enhance decision-making processes. These results provide methodologies applicable to other industries, promoting a more sustainable future.



**Keywords :**
Sustainability, Multi-criteria, Multi-phases, Multi-decision-makers, decision analysis, Agriculture, Similarity aggregation method, Circular economy, Contradiction identification, Contradiction solving.