Mechanisms to promote Circular Economy in agricultural sector - Life Cycle Assessment of olive oil production in Portugal

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Table of contents

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Abstract

Nowadays a crucial goal for the world is to search for a more sustainable future in all sectors of our lives. The solution for reducing environmental impacts is introducing the concept of Circular Economy. The agricultural sector is no exception, and the olive oil industry has a great importance in the European economics. It is crucial to understand and manage the impacts associated with this sector, as well as identify and apply the good practices in order to change the economic model from linear to circular.

This work presents the Life Cycle Assessment of the olive oil production in region Alentejo, Portugal. It compares two different scenarios - conventional production and production with the implementation of good practices identified in the sector. The proposed solution in Good Practices Scenario includes energetic valorisation of olive stones, through direct combustion to produce electricity in the vapour cycle. The results show that the electricity production from olive stones is possible and this solution can be implemented in the olive oil mill. However, overall, the environmental impacts associated with it are slightly higher than in the conventional method. Regarding cost analysis, the proposed solution requires high investment, with a payback period of 7 years and 5 months and a Return On Investment (ROI) of 33.5% at year 10. However, it creates a possibility of generating income and at the same time re-using by-products of olive oil production. Finally, the suggestions and possible further actions were proposed for this case study.

Keywords: Olive oil, Life Cycle Assessment, Circular Economy, Agriculture, Biomass, Energy

Resumo

Actualmente, é objetivo a nível mundial procurar soluções para um futuro sustentável em todos os sectores. A solução para reduzir os impactos ambientais passa pela introdução do conceito Economia Circular. O sector agrícola não é exceção e a indústria do azeite tem um papel de grande relevo na economia europeia. É então importante compreender e gerir os impactos associados a este sector, tal como identificar e usar as boas práticas, de forma a mudar o modelo económico de linear para circular.

Este trabalho consiste na Análise do Ciclo de Vida da produção de azeite na região do Alentejo, Portugal. Compara dois cenários diferentes – produção convencional e produção com a implementação das boas práticas identificadas no sector. A solução proposta no Cenário de Boas Práticas inclui a valorização energética do caroço da azeitona, através da sua combustão direta tendo por objectivo produzir eletricidade no ciclo de vapor. Os resultados revelam que a produção de eletricidade a partir do caroço da azeitona é possível e que esta solução pode ser implementada num lagar de azeite resultando, contudo, num maior impacto ambiental associado, maior do que no método convencional. Relativamente à análise de custos, a solução proposta requer grande investimento, com um período de retorno de 7 anos e 5 meses e um retorno sobre o investimento (ROI) de 33,5% no ano 10. Todavia, existe a possibilidade de gerar receita e, ao mesmo tempo, reutilizar os resíduos da produção do azeite. Finalmente, foram propostas algumas sugestões e ações futuras para este caso.

Palavras-chave: Azeite, Análise do Ciclo de Vida, Economia Circular, Agricultura, Biomassa, Energia

List of figures

List of tables

List of equations

1 Introduction

Each year globally around 65 billion tons of resources are extracted, and only 7% of this amount is recycled. This is where the linear extract-transform-use-reject economy has led the world. According to the European Commission (EU), Europe is highly dependent on imports of resources and unstable supplies or prices volatility can have a high negative impact on the economy.

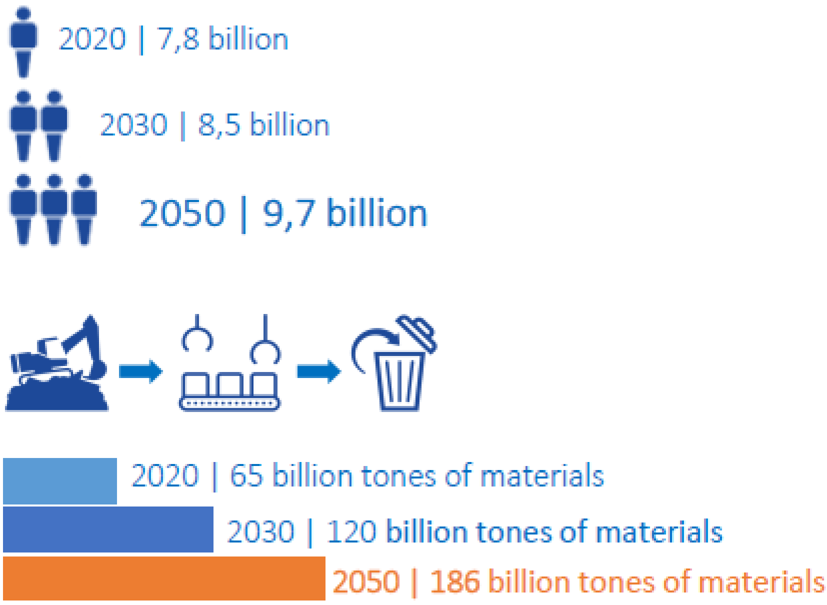

Figure 1 Linear economy projection [1]

According to the Figure 1, in 2030 there will be 8.5 billion people on the planet, and over half (56%) will belong to middle-class consumers, and around 60% will be living in the major urbanised centres. Generally, the recent trends are: growing global Gross Domestic Product (GDP), better living conditions, wealthier society, less people in extreme poverty and population growth. Simultaneously with the increasing population, the extraction of materials will increase and in 2030 it will almost double the amount projected for 2020. This scenario follows the linear operating system, which includes the extraction of resources, which later are being processed and transformed into products. Products are sold, and when their lifecycle is over, they are rejected. If the society will still follow this path, altogether with a higher population and consumption, greenhouse gases (GHG) emissions, air pollutions and the amount of waste produced will increase too.

Nowadays a crucial goal for the whole world is to search for a more sustainable future in all sectors of our lives. The global objectives are to reduce the environmental impact, energy consumption, and costs associated with each sector. The solution for reducing the environmental footprint is introducing the concept of circular economy. This way it would be possible to preserve the resources, which are already in use in the economy while keeping them at their highest economic value for a longer time. Consequently, the need to extract so many raw materials would not be so high, which would lead to reduced waste production and smaller environmental impact. It is said that if the circular economy model would be implemented, it could bring to European Union gains of € 1.8 billion, 1-3 million job positions, and 2-4% of the decrease in total annual greenhouse gas emissions.

The Portuguese economy is facing the same challenges. It has a slow metabolism, which means that there is a tendency to accumulate materials - more raw materials are extracted and imported than final goods exported. Material productivity is evolving more slowly than for example Ireland or Spain, which are countries that had the same level of productivity in 2005. Until 2015, the European Union improved by 30%, Portugal by 23% and Spain by 134%. When it comes to environmental aspects, in last 13 years, the GHG emissions decreased due to better prevention and control technologies, as well as less polluting fuels and improvements in the energy efficiency of the processes. Regarding waste production, the construction sector dominates and is responsible for the greatest share of waste production from all sectors (40%). [1]

Nowadays, production and consumption of food are becoming more and more globalised and industrialized. In all the developed countries, agricultural practices have been intensified in order to increase the effectiveness of production. That is why agri-food is considered one of the sectors with great impact on human capital employment, nutritional security, but also on environmental sustainability because of the big inputs of the resources. [2]

Olive oil, according to the International Olive Oil Council, is a typical Mediterranean product that has great importance in the economics of the European Union, in both production and consumption stages. Moreover, in many countries the olive oil industry causes different environmental impacts in terms of depletion of the resources, land degradation, waste generation and air emissions. These impacts vary from one country to another, depending on the practices and techniques applies in olive trees cultivation and olive oil production. Depending on these different practices and techniques, the production of olive oil is associated with several effects on the environment. It is crucial to understand and manage the environmental impacts related to the production of olive oil, with an in-depth analysis of the good practices and techniques that can be applied in this industrial sector. Consequently, tools such as Life Cycle Assessment are becoming increasingly important for this type of industry. [3]

2 Literature review

2.1 Agricultural sector in Portugal

The purpose of the agriculture sector is to fulfil multiple roles – contributing to the population's supply with food, supporting employment, preserving precious landscapes of the country and assisting rural areas. [4]

As in all industrialised countries, in Portugal over the years, the importance of agriculture in the overall economy has decreased, but it is still relatively high comparing to the average values for the European Union. Nowadays Portuguese agriculture is facing two main challenges, and there is a need to find the balance between them. Those challenges are food safety and environmental safety. [5]

In Portugal, 40% of total territory belongs to Utilized Agricultural Area (UAA), and Alentejo region represents almost half of it. Alentejo is located in the southern part of Portugal, and it is the biggest province of the country, occupying 1/3 of the national territory. On the north side, it borders with the river Tagus, on the west side with the Atlantic Ocean, on the east side with Spanish border and on the south side with the region Algarve. The province itself is composed of 46 municipalities and divided into four smaller parts: Alto Alentejo, Alentejo Central, Baixo Alentejo and Alentejo Litoral. [6]

The region of Alentejo is a big area, mostly rural with a low demographic density. It is the main agricultural region of Portugal. The most produced crops there are cereals, olives and grapes. Alentejo is also being called the "bread basket" of Portugal – it produces around 75% of the country's wheat, and almost all the bigger towns of Alentejo rely on agriculture, livestock and forestry. [7] The olive oil production sector has an important role in this region, and it represents 30% of the national production. There are three types of olive plantations: traditional (low density), intensive (high density) or super intensive (very high density). Alentejo also fulfils the minimum requirements for producing authentic quality wines and its production accounts for 42% in the whole country. Another important role in Alentejo's agriculture plays the breeding of cattle – pigs, bovines, goats and ovines stand for 50% of the total national breeding of cattle. [6]

Although a large part of Alentejo is classified as arable land, poor soils are dominating in most of this region, and they are incapable of significant agriculture production without extensive irrigation schemes. Alentejo has a sub-humid Mediterranean type of climate, with very hot and dry summers and most rainfall occurring between October and March. Droughts are common phenomena in this region and water is usually deficient. To mitigate the impacts of droughts, it is required to manage the water rationally and pro-actively. [8] When it comes to groundwater use for agricultural irrigation, Portugal is one of the top ten OECD countries. The sector of agriculture is responsible for over ¾ of the total groundwater withdrawals. [9]

High level of degradation of water, soil and biodiversity of Alentejo region were diagnosed in several scientific studies, and the situation is getting worse every year. This may lead to the desertification of this part of the country, which is a serious environmental issue. This phenomenon has an especially great impact in developing countries, where the existence of agriculture can cause problems like famine or sub-nutrition. [10]

As it is shown in this chapter, there are some inefficiencies existing in Portuguese agriculture and a few aspects could be improved in order to increase the efficiency of this sector. Changing the current linear economy system to a circular economy is a potential solution for these problems.

2.2 Olives and olive oil production in Portugal

The olive tree is perfectly adapted to the Mediterranean climate, and the presence of this climate defines the limits of the olive tree expansion worldwide. Portugal is responsible for 2-3% of the global olive oil production. In last years olive production fluctuates and usually, one year of good production is followed by another with lower production as can be seen in Figure 2.

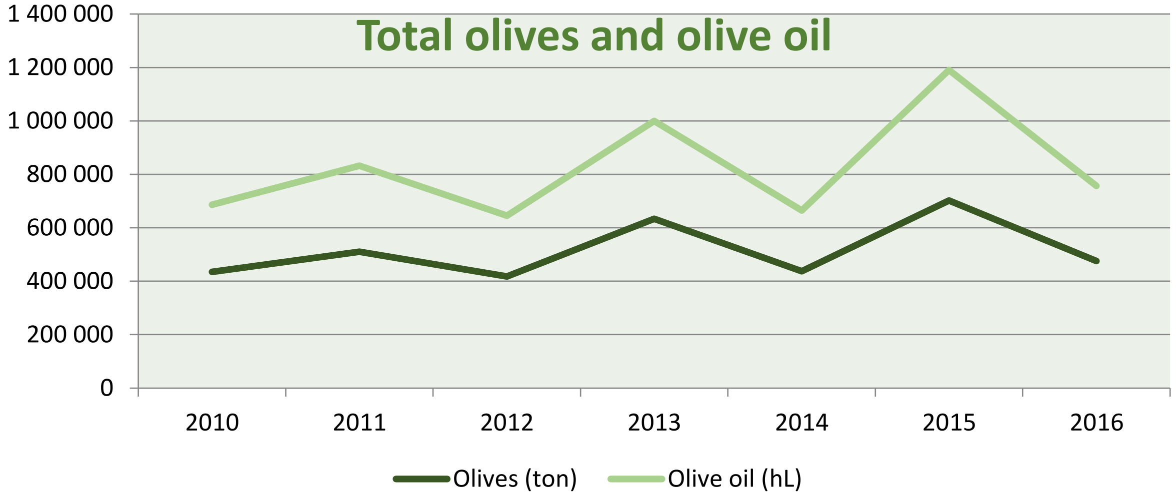

Figure 2 Production of olives and olive oil in Portugal from 2010 to 2016 [11]

However, even with this oscillation, in recent years there has been seen a gradual increase in the total amount of olive and olive oil in Portugal. This phenomenon could be partly explained by the increase of olive grove area in the country.

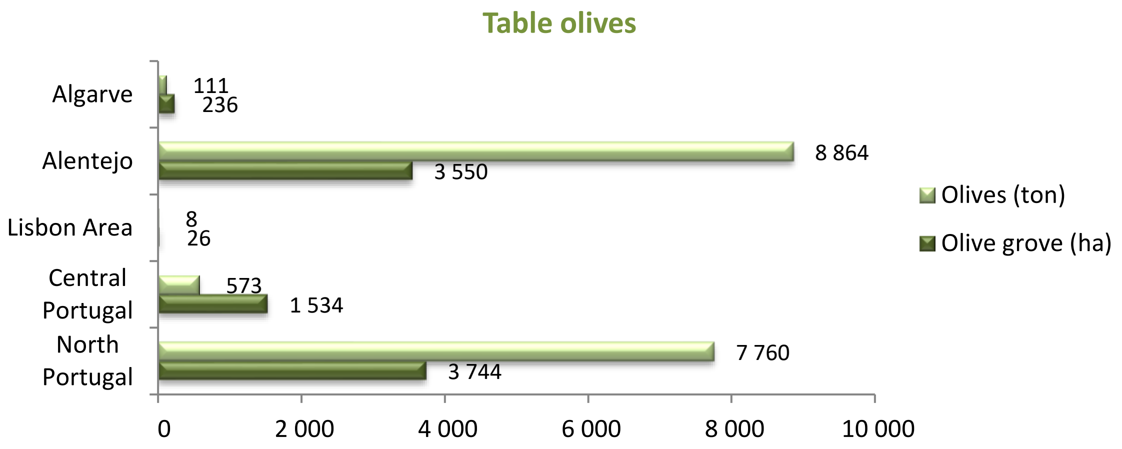

Figure 3 Provenance of table olives in Portugal [11]

Table olives are produced from north to south of Portugal but are more relevant in terms of area in the Alentejo and in the North, areas where obviously also their total production is larger (Figure 3). In 2016, in Alentejo, the olive productivity was 2.49 ton/ha, and in the North region was 2 ton/ha.

In the case of olive oil, the Alentejo differs widely from the other regions, either in the area (approximately 550,000 ha), or in the total tons of olives, and clearly in the production of olive oil (Figure 4). In this region, in 2016, the average yields were about 1.93 ton/ha. [11]

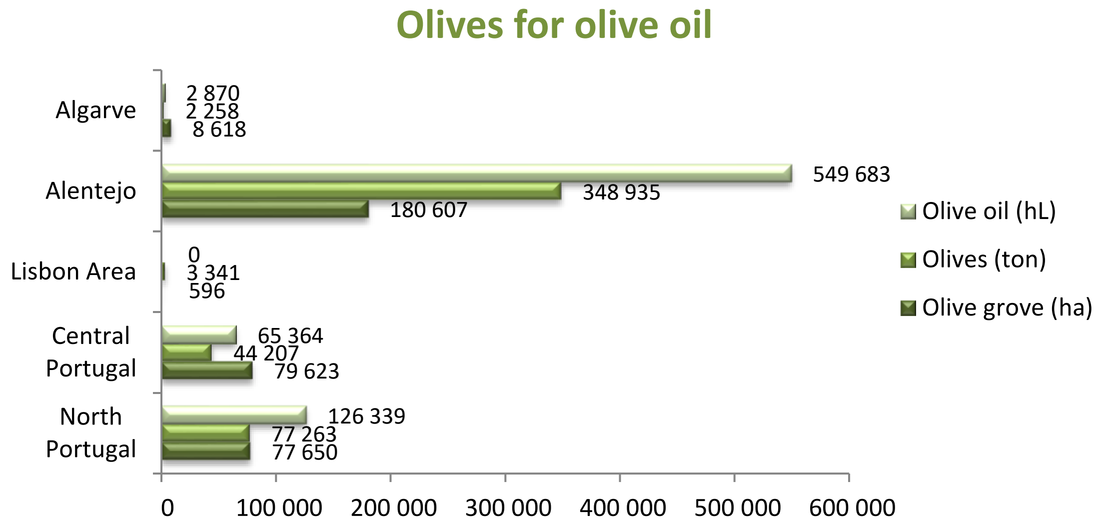

Figure 4 Provenance of olives for olive oil in Portugal [11]

2.3 Introducing the concept of the Circular Economy

In the late 1970s, architect Walter Stahel concluded that the linear economic model that was applied back then is not sustainable. It was because if people continued to increase their consumption, it would cause serious problems in the future - the demand for raw materials and the worldwide accumulation of waste was continuously increasing. Stahel's idea was to close the material cycles and reform the economy. Through years this theory has been studied and developed, and it resulted in the concept of the circular economy. [12] According to "Leading the transition - Action plan for circular economy in Portugal: 2017-2020", circular economy is "an economy which actively promotes the efficient use and productivity of the resources it has harnessed, via products, processes and business models based on the digitalization, reuse, recycling and recovery/regeneration of materials […]". [1]

Nowadays, the world is confronted with products that were not designed and produced with a purpose of re-using them. If we want to do that, we have to consider the circular approach - with raw materials that were used before recycling as a raw material again, as presented in Figure 5. The important aspect is to focus on realising the highest possible value of the material, as this does not require that much effort and/or energy. In many cases, recycling is more energy-efficient than extracting new raw materials from mining or agriculture.

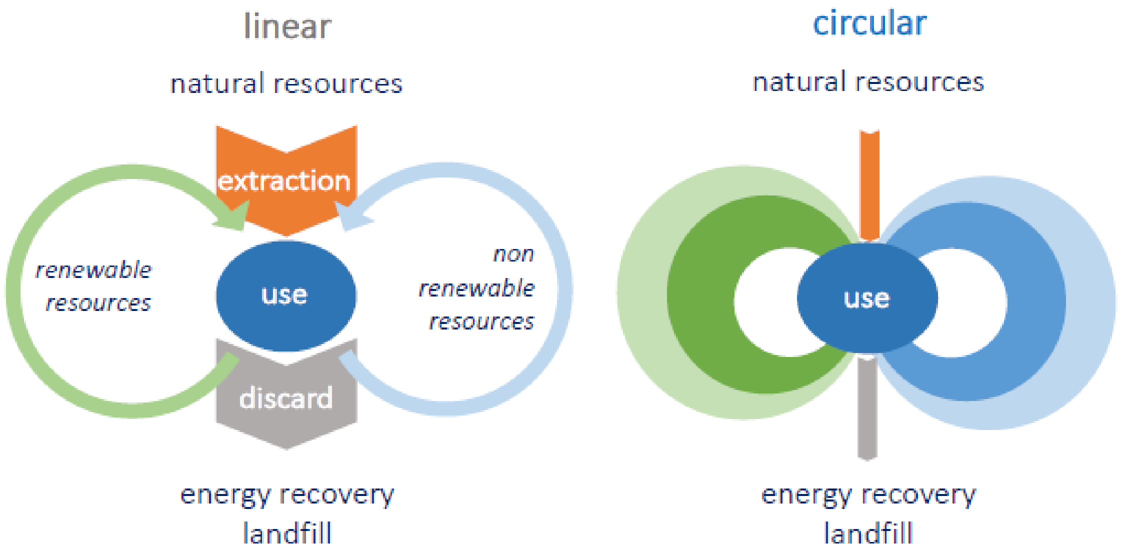

Figure 5 Linear economy vs circular economy [1]

The circular economy model distinguishes four technical cycles:

1. Maintaining the product
2. Re-using/redistributing the product
3. Upgrading/remanufacturing the product
4. Recycling product [12]

Ellen MacArthur Foundation in "Growth Within" presents the outline of a circular economy, combining two cycles – organic materials and technical materials, as in Figure 6.

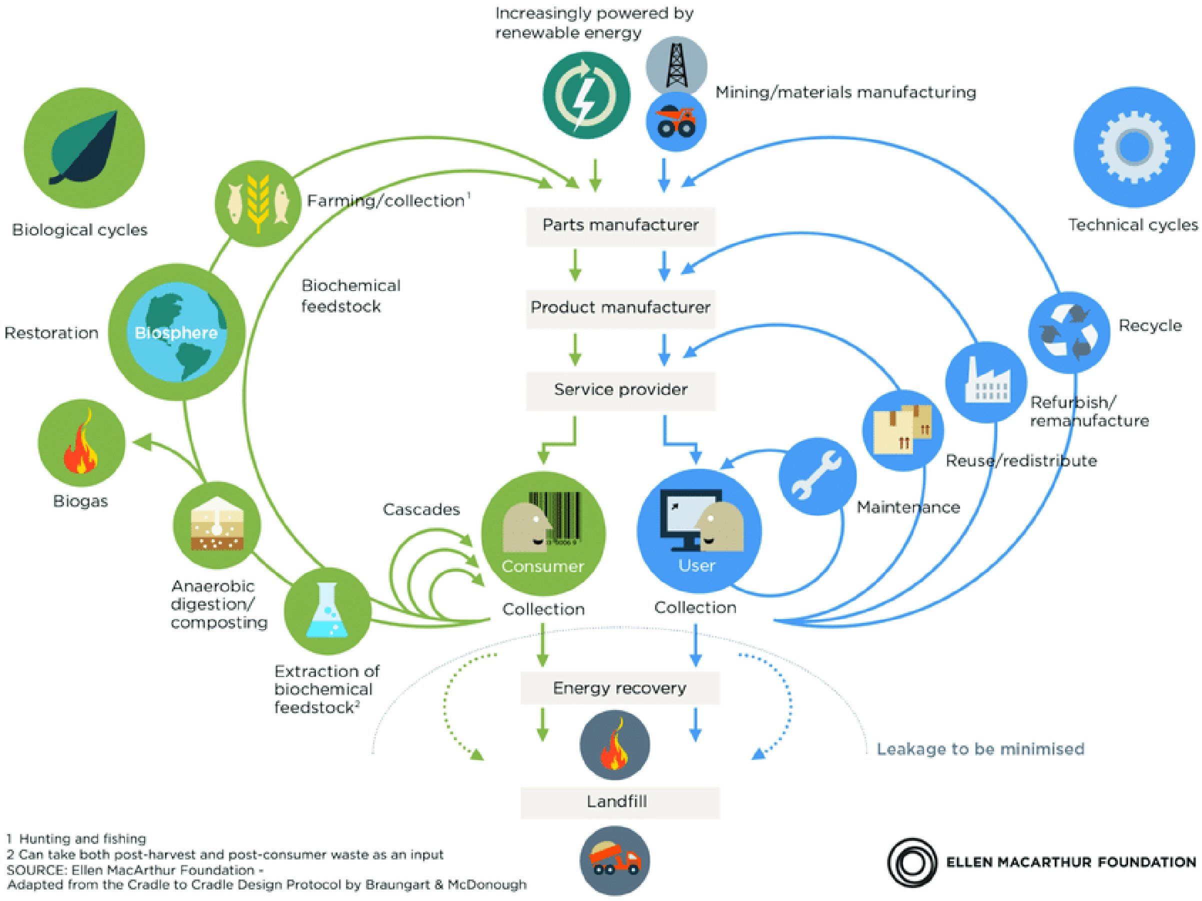

Figure 6 Circular economy cycle according to Ellen MacArthur Foundation [13]

System change is crucial for the concept of the circular economy. In this approach, one system's waste is the next system's input, and the purpose is to maximise the total utility of the materials and products being in use. [14] In the smallest cycle, the material or product maintains at its highest value, so this way it can be applied longer according to its original purpose. On the other hand, in the longest cycle, the value or the residual value of material or product is the lowest, and a different application has to be found. [12]

Ellen MacArthur distinguishes three principles of the circular economy, which are:

1. Preservation and enhancing of natural capital by controlling finite stocks and balancing renewable resource flows.
2. Optimising of resource yields by circulating materials, components and products, that are in use at their highest utility all the time in both biological and technical cycles.
3. Fostering the effectiveness of the system by revealing and designing out the negative externalities. [14]

However, the circular economy goes beyond just products. It is rather an economic concept, which consists of four building blocks that companies have to apply to come to a circular economy. These blocks are:

1. Product design – involves improving the choice of materials and products design. To make such changes include standardisation and modularisation of the components, as well as pure material flows and design for straight-forward disassembly. Applying this building block makes the processes of production much more efficient.
2. Enabling conditions – focuses on the conditions that enable society to apply the circular principles. This process requires more transparency in the material flows, determination of industrial standards and alignment of incentives. The transition has to be performed in financing, risk management, legislation, infrastructure and education. One more important aspect for implementation of the circular economy is increasing and developing customer's general awareness
3. New business model – the transition from linear to circular economy requires not only changes in the use of materials but also a change in structures of business models, ownership and responsibilities. Business models should be more innovative, more specifically by changing property to performance-driven earning models. It also requires the manufacturers to start thinking differently about the products and take responsibility for the products through their life cycle.
4. Global reverse networks – devoted to the cycle from user to manufacturer. This block includes reverse logistics, which can be even expanded on an international scale, allowing re-introducing the materials in exported goods as waste. The purpose of global reverse networks is to make manufacturers or third parties like shared services to collect materials more efficiently. [12]

The strategies of circular economy regarding each building block are presented in Figure 7. It is crucial to follow them to make the transition from the linear to the circular economy model. [1]

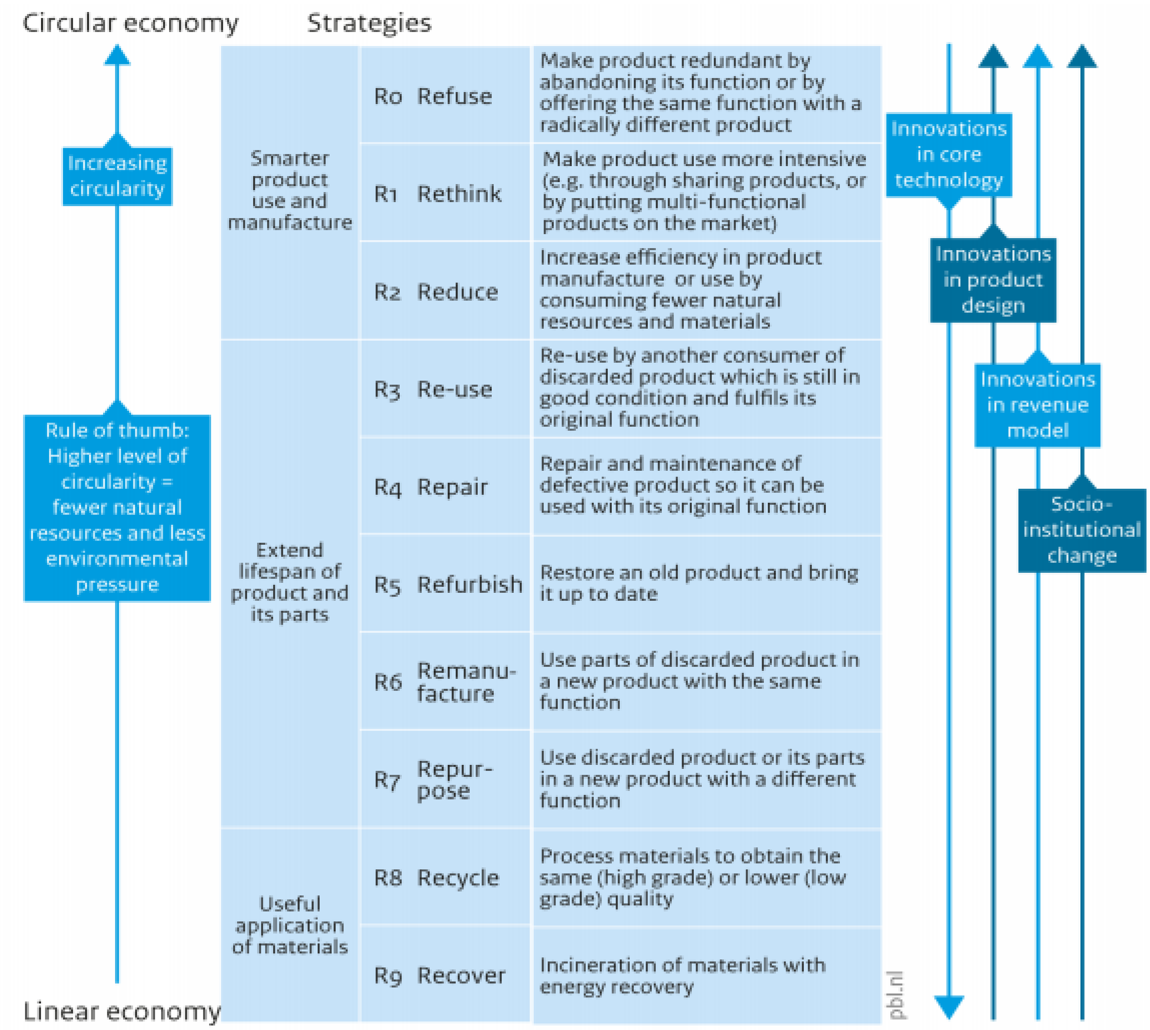

Figure 7 Circular economy strategies [1]

2.4 Promoting circular economy in agriculture and agribusiness in Portugal

According to the governmental strategy for Portugal, “Action Plan for Circular Economy in Portugal 2017-2020” [1], there are several actions planned to perform the transition from linear to a circular economy. These actions are addressing problems like waste production, environmental awareness, water and natural resources use. One of the plans related strictly to agricultural and agribusiness production sector is called “Regenerating resources: water and nutrients”. Its main goals are improving water efficiency and recirculation of nutrients and organic matter. These goals will be accomplished through working on promoting sustainable agricultural practices and biotechnologies for extracting and reusing nutrients and compost. When it comes to water use, the measures for 2020, expressed in inefficiency (waste) use of water per sector are 15% industry, 35% agriculture, 20% urban. In comparison, in 2002 these values were: 30% industry, 40% agriculture, 40% urban, so there has been big progress done, but there is still room to improve. [1]

Regarding Alentejo region specifically, a decentralised body of the central government of Portugal - Alentejo Regional Coordination and Development Commission has put in practice the Regional Agenda for the Circular Economy, which aims to boost this business model across the region. The great importance is given to waste management (reducing the amount of waste produced), energy efficiency, more efficient use of water and lowering the environmental impacts. [15]

One of the incentives that helps to promote circular economy in the agricultural sector in Portugal is the project “Alentejo Circular” that is being developed by the company Instituto de Soldadura e Qualidade (ISQ) in cooperation with the University of Évora. Its main objective is to change the model of the linear economy that most of the companies in the agricultural sector follow to the model of the circular economy. To achieve that plenty of changes need to be implemented, but the crucial task is to change the paradigm in this sector of the industry. It is fundamental to prepare the transition from the current linear model of production and consumption to a circular model - regenerative and restorative, in which the value of products, materials and resources remain in the economy for as long as possible, and production of waste is reduced to a minimum.

“Alentejo Circular” involves several objectives and actions:

- Analysis of regional reality on farms and agribusiness in Alentejo;
- Identification of good practices for the efficient use of resources and valorization of waste and by-products;
- Identification of opportunities in the sectors of olive oil production, wine production and pig farming;
- Promoting the project and the concept of Circular Economy by demonstrating the benefits of adopting the Circular Economy model and transfer knowledge of associated technologies and methodologies;
- Promoting the collaborative spirit between companies and between them and the scientific and technological system, in particular, directed to the implementation of the circular economy in value chains;
- Understanding the barriers to the realization of identified opportunities for circular economy in order to inform all stakeholders.

Based on a mature diagnosis in the field of the Circular Economy in Alentejo, and the latest international knowledge, ISQ and the University of Évora undertook a set of awareness-raising, training and mobilization activities aimed at the implementation of circular logics in the olive oil, wine and pig farming, seeking to establish the basic conditions for the future development of circular initiatives by companies in the region. Thus, the expected results with the present project are:

- Knowledge of the current regional diagnosis, regarding the implementation of practices of circular economy in the present ranges;
- Identification of solutions for the recovery of waste and efficient use of resources in the sectors under consideration;
- Changing behaviours and ways of thinking associated with the linear economic model;

- Training of corporate cadres for new skills associated with the circular economy, including current and emerging practices in the efficient use of resources and waste recovery;
- Greater communication between companies in the region and between them and the scientific and technological system as a way to promote circularity initiatives and innovation projects. [16]

There are also other incentives like the AGROnet (Alentejo Agricultural Research and Extension Network), which is a network of scientific and technological cooperation for agricultural experimentation in Alentejo. It is conducted by the Institute of Mediterranean Agricultural and Environmental Sciences at the University of Evora and by the National Institute of Argarian and Veterinary Research. Its main objective is to improve the sustainability of the region, which means the inventory of existing resources and identifying the gaps and opportunities for development. [17]

Achieving sustainable development always requires tools and methods that help to quantify and to compare the environmental impacts of providing goods and services – products. There is always a need to evaluate the impact of circular economy's actions, to check if they are profitable. Sometimes it may happen that more resources are used while implementing the new solutions, that is why Life Cycle Assessment is used.

2.5 The life cycle of a product

Each product has a "life", which starts with the design and development of the product, followed by extraction of resources, production of materials as well as manufacturing of the product, use/consumption phase, and then end-of-life activities, that include collection/sorting, reuse, recycling or waste disposal. Figure 8 presents a simplified schematic representation of a product's life cycle, as it includes loops between different life phases. [18]

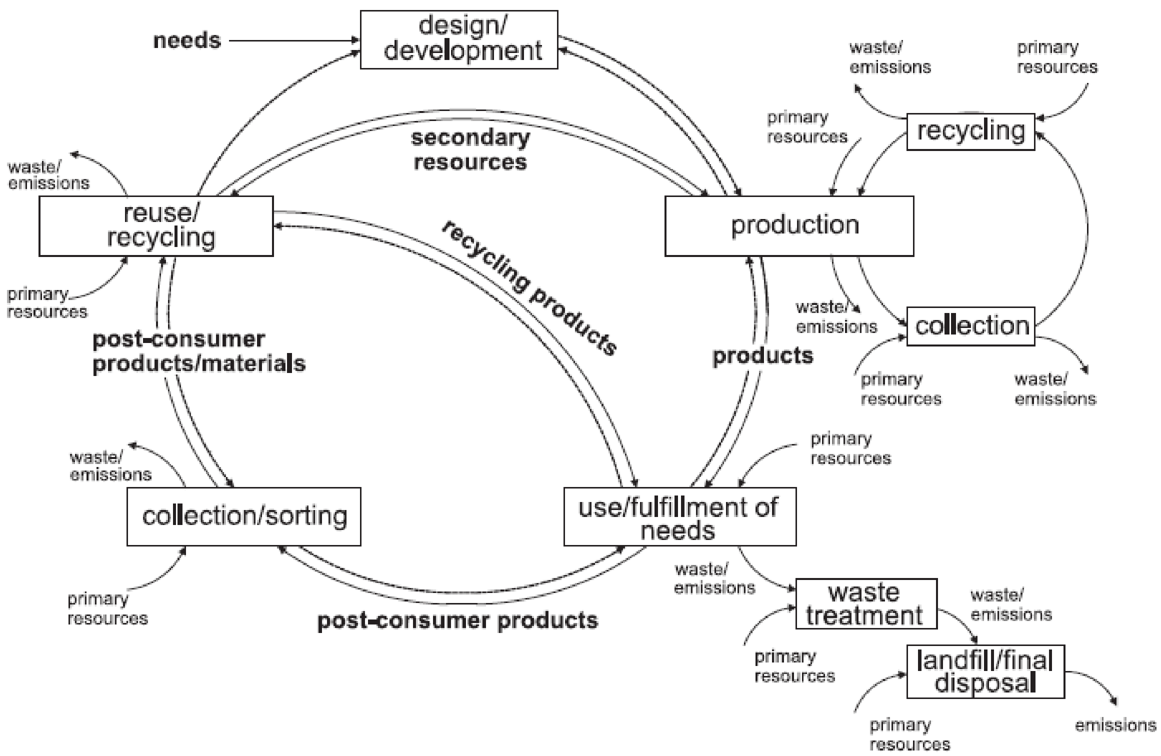

Figure 8 Scheme of a generic life cycle of the product [18]

All the processes in the life of the product result in environmental impacts due to consumption of resources, substances' emissions to the natural environment and other environmental exchanges. [18]

Life Cycle Assessment can be applied in many cases:

- To identify the opportunities of development and improvement of the product through identifying the main bottlenecks in its life cycle.
- To analyse how the stages of life cycle contribute to the overall environmental load, in most cases with the objective to prioritise improvements in processes or products.
- To compare products between each other, for internal or external communication
- As the basis for standardised metrics and identification of Key Performance Indicators, that companies use for life cycle management and decision support. [18]

Over the years Life Cycle Assessment has been adapted for agriculture to assess the environmental effects of this sector. Through the use of this method, it is possible to analyse all the inputs and outputs that are crossing the specified boundaries for a particular production system. In many cases, agricultural LCA is complex because, besides the main product, there are also by-products, wastes or emissions to the environment. [19]

2.6 Solutions used worldwide in the olive oil sector

As all industrial sectors, agriculture sector needs the innovative solutions that help reducing energy and water consumption. When it comes to olive oil sector specifically, its profitability depends on reducing the costs of production and energy consumption, which is one of the main expenses in the whole agri-food industry. This sub-chapter collects the methods and technologies for water and energy saving that are relevant for the olive oil production industry, including both, harvesting and processing stages.

2.6.1 Efficient use of energy

The main source of energy in olive mills is electricity. From the moment of receiving the olives, through all the processes: washing, grinding, mixing and beating, centrifugation and bottling, all machines work based on electrical energy. Over the years, energy efficiency and energy saving have become important objectives in Europe. By improving energy efficiency, it is possible to reduce GHG emissions and costs of production of the final product.

One of the possible and popular methods is using the olive pits as a fuel for the biomass boiler to produce heat that substitutes some part of electricity used. In this case, the fossil fuel boiler has to be changed for the one that is suitable for burning biomass. The greatest advantage of this kind of boilers is the fact that they allow using the waste that is generated during the production process, which saves energy, decreases CO_2 emissions and solves the problem of waste disposal. [20]

As in recent years the renewable energy has been becoming more popular and recommended as a power source for different types of facilities, it also can be applied in olive oil mills. Especially solar power has great potential since olive oil is mainly a product of Mediterranean sunny countries. A good solution is grid-connected PV systems, which consists of solar panels, power conditioning unit, inverters and grid connection equipment. This solution is good not only regarding energy saving but also from the environmental point of view – reducing CO_2 emissions. [21]

Another possibility is improving the separation process, as it is one of the most energy consuming stages of the olive oil processing. The main purpose of this step is oil separation from the other components of the olive, and in order to decrease the energy use, some companies install integrated Direct Drive separators, which easily separate the homogeneous paste according to different densities of each component. It uses the same technology in the separation process, but in this case, the power transmission is more efficient.

Recently a new technology is being developed to replace the vertical centrifuges by decanting tanks. Using this method, it is possible to reduce energy and water consumption. However, there is the main disadvantage – it requires more space for installation of the decanting tanks. [20]

2.6.2 Efficient use of water

Requirements regarding crop irrigation vary in time with soil conditions and weather. In olive trees cultivation sector good practices of efficient water use were verified both in the process of irrigation and in the process of crop spraying.

In irrigation, the drip system is generally used, which has greater efficiency in the use of water and is generally carried out according to the producer's objectives. It is a type of micro-irrigation system that allows water to drip slowly to the plants' roots. It can be done from above the soil surface or buried below the surface. The objective of this system is to place water directly into the root zone and to minimise evaporation. Water distribution, in this case, takes place through a network of pipes, valves, tubing and emitters. The irrigation is adapted to each case, allowing to reduce the water consumption to what is strictly necessary. [22]

Another method of irrigation is precision irrigation, which delivers water and nutrients straight to the roots in measured doses, so it keeps the root zone at optimal moisture levels. This system helps healthy root development, reduces the waste of nutrient and water and maximises input utilisation. The design of these systems is done according to the soil's ability to absorb water, and to the plants' consumption, so the air-water ratio in the soil is perfect, and nutrients are kept where they are needed. [23]

The good practice is also the use of meteorological stations, which provide data of precipitation, air temperature, relative humidity, radiation, wind speed, sheet moisture and evapotranspiration calculation with the meteorological data to be measured permanently and sent by GPRS to an online database. The management of all the information obtained with the application of these practices allows the farmer to follow the development of the plant and the surrounding conditions and can thus build their irrigation charts and monitor what is happening to make the decisions needed.

The irrigation flow control is also practiced, and irrigation lines with different flow rates are used according to the needs. Through the use of partial flowmeters, better control over the amount of water that is being used in each sector is possible and thus to act more quickly in case of leakage. The watering lines are often checked, and the pressure adjusted. [22]

2.6.3 Waste valorisation

The olive mill waste streams are a big environmental problem, especially the uncontrolled disposal of waste due to its high organic content. Lack of proper management of wastes from olive oil mills can be a threat to surface and groundwater resources. There are many solutions available to manage this issue, but it is important to select the optimum valorisation method adjusted to individual conditions. [24]

The simplest and most direct method of waste valorisation is agricultural spreading – pomace is being spread in the field after short-term storage. The advantage of this solution is the fact that the chemical composition of olive pomace provides nutrients (especially carbon and potassium) to the soil.

Nowadays, the most common way to deal with olive pomace are the extraction units where the oil is obtained from olive pomace by treatment with solvents. This way the remaining oil can be recovered from the waste of olive oil mills.

Another common way of waste valorisation is composting. The process includes transforming olive pomace into compost that can be later reused as fertilizer during the olive trees cultivation phase. Other organic waste from olive oil production like leaves and branches also can be used for composting. Applying composted wastes from olive oil mills as fertilisers can have a positive influence on soils, for instance, increase soil organic content.

Finally, wastes can be used for energy generation. The most attractive and practical methods of energy recovery from biomass are pyrolysis, gasification and combustion. Wastes from olive oil mills can be burnt in a biomass boiler and the produced heat can be used by the olive oil mills for satisfying their heat needs or it can be used to produce steam and then electricity. [25]

2.7 Identification of the opportunities for improvement in the agriculture sector of Alentejo

Even though the practices presented in the previous subchapter are being implemented and used in some olive oil mills in Europe, there is still room for improvement. The same applies to olive oil producers in Alentejo. There are some aspects that could be improved in order to reduce waste production, energy and water use and as a consequence to get closer to the concept of the circular economy.

All agricultural activities are associated with environmental impacts, and there is always room for improvement in this matter. In the olive groves, the greatest impacts are on soil, water and air. Unsustainable practices can easily lead to loss of soil productivity through increased erosion, where both nutrient and organic matter losses occur. This leads to the need of application of larger amounts of fertilisers and increases the volume of water applied during irrigation. Apart from soil and water, air quality also suffers from excesses. Agriculture is one of the activities that contribute significantly to the emission of the main GHG in the atmosphere, namely carbon dioxide (CO_2), methane (CH_4) and nitric oxide (N_2O). Alentejo region is no exception in this term.

Regarding the olives processing phase, the main problems for producers are electricity and water consumption. Significant amounts of water are used mainly for the washing of olives. In most olive oil mills in Alentejo around 93% of energy demand is satisfied by electricity, the rest is usually diesel or gasoline. These issues besides being unfavourable for the environment, also cause higher production costs.

The last addressed problem is waste produced. These are by-products from the olive oil production like crop residues, olive pomace, olive stones etc. There is a need for implementation of a waste management plan in order to mitigate or eliminate environmental impacts associated with waste. All stages that lead to obtaining the final product generate wastes: agricultural phase, processing and marketing stages. [11]

2.8 State of the art

This chapter describes the key findings from the literature review in the Life Cycle Assessment area in olive oil production sector in Europe and presents the innovation of this work in the topic.

Although there is a number of relevant studies and papers that already have been published in this topic, up to the author's knowledge, there is only one paper that presents the Life Cycle Assessment of the olive oil production in Portugal. Most of the publications are focused on other European countries that produce olive oil – Spain, Italy, Greece, France, Cyprus.

The article "Analysis of Eco-efficiency and GHG Emission of Olive Oil Production in Northeast of Portugal" presents the Life Cycle Assessment of two different organisations - middle-size and large-size olive oil production plants from Portugal. The authors in their study consider two stages of the product's life cycle: olives cultivation and olive oil extraction in mills. Their main focus is on the eco-efficiency of the olive oil production and the Greenhouse Gas emissions that this production causes. One of the conclusions of the work is that the olive harvesting stage is the major source of carbon footprint in the whole life cycle of the product. [26]

On the other hand, the publication "Carbon footprint of extra virgin olive oil: a comparative and driver analysis of different production processes in Centre Italy" focuses on five cases that represent different technologies and methods of olive oil production. The case studies vary in terms of extraction technology, size and organisational structure, cultivation method, farming system and working capacity. The main goal was to quantify the GHG emissions that are related to each production process. The study presents the "cradle to gate" assessment, so it excludes the olive tree planting and the distribution phase. The analysis is very complex and includes Monte Carlo, uncertainty and sensitivity analysis. Results are determined as total GHG emissions in kg of CO_2 equivalent per Functional Unit. [27]

In this work, the emphasis is given not only on the Life Cycle Assessment of the olive oil production in Portugal but also on improving the current situation in this area, proposing new solutions that could help to implement the circular economy instead of the linear economy. Since changing the model of the current economy is a crucial goal for next few years, it is important to propose solutions that may help in the transformation, solutions that are good not only from the environmental point of view but also from the financial aspect. By implementing the good practices that support efficient use of resources and materials or using waste as the input for another product, not only the environment can be saved but also the companies can benefit financially by saving money. This work includes a comparison of two scenarios – Business As Usual that presents the current status of the company and the good practices scenario that implements the solutions that can help bringing the circular economy to the agricultural sector. This work is addressing issues stated in the previous sub-chapter, which describes problems and bad habits in the olive oil sector in the Alentejo region. The case studies that were performed within this thesis propose improvements to identified problems.

2.9 Objectives of the work

The main purpose of this thesis is to perform the study of the energy consumption, emissions and environmental impacts associated with olive oil production in Alentejo region, Portugal. The tool that allows identifying the impacts is Life Cycle Assessment (LCA). As a result of this case study, it will be possible to identify the environmental impacts that are associated with particular stages of olive oil production and find the room for improvement of the current situation. This will contribute to bringing the agricultural sector of Portugal closer to the sustainable future, which is an important goal for the whole country, since agriculture stands for a big share of Portuguese economy. That is a general goal that involves a series of actions in order to achieve it.

The following points constitute the main goals of the project:

- Promoting the concept of Circular Economy within the agricultural sector in Portugal, focusing on the region Alentejo;
- Review and identification of the good practices that are already applied in this sector worldwide and potential good practices that could be used in Portugal;
- Analysis of the production process of olive oil and identification of the environmental impacts that are associated with it;
- Improvement of the current situation through applying the good practices in the sector.

Finally, as a result of this work, the case study of a particular olive oil producer is performed, identifying all environmental impacts related to olive oil production, focusing on the industrial phase. Moreover, the solution to improve the situation is being implemented – it includes energetic valorisation of biomass, which is a solution for effective waste management, as well as generating additional income for the company.

3 Methodology

Life Cycle Assessment (LCA) is a methodological framework used for estimation and assessment of the environmental impacts that attribute to the life cycle of the product. All activities and processes of product's life have an impact on the environment due to the consumption of resources and emissions of substances into the natural environment. The consequences are for example climate change, stratospheric ozone depletion, smog creation, water and land use, depletion of resources, human health and ecosystems, noise and many others. LCA takes into consideration the complete life cycle, starting from raw materials production to the final product disposal. While conducting a Life Cycle Assessment, the design and development stage is usually not included, because it is mentioned not to contribute significantly. However, as it is shown in Figure 9, the decisions taken in this phase have the high influence on the environmental impacts in the further stages of the product's life cycle. [18]

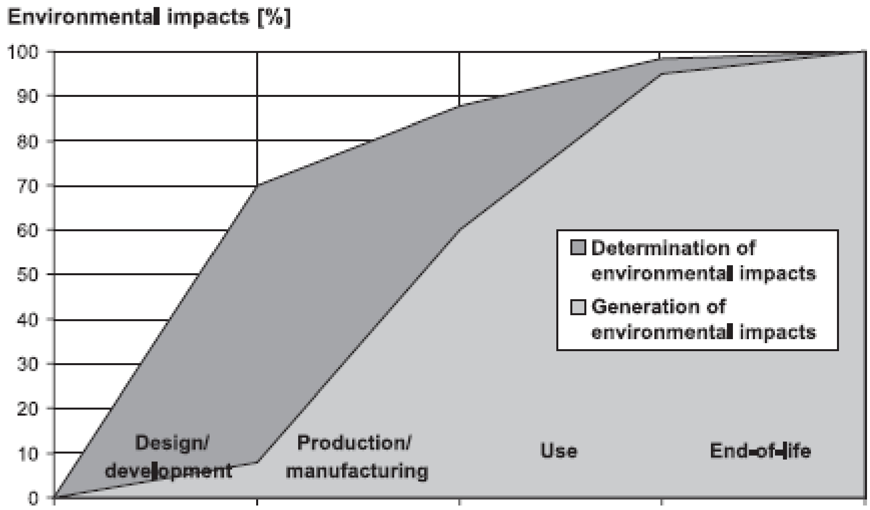

Figure 9 Generalized representation of the (pre)determination and the generation of environmental impacts in a product's life cycle [18]

The methodological framework for conducting the LCA has been standardised by the International Organization for Standardization (ISO) and the series ISO 14040 describes 4 phases in performing the Life Cycle Assessment: Goal and Scope (ISO 14041), Life Cycle Inventory (ISO 14041), Life Cycle Impact Assessment (ISO 14042) and Life Cycle Interpretation (ISO 14043). In 2006 these standards were revised and combined into a single standard – ISO 14044. These main steps of an LCA are presented in Figure 10. [28]

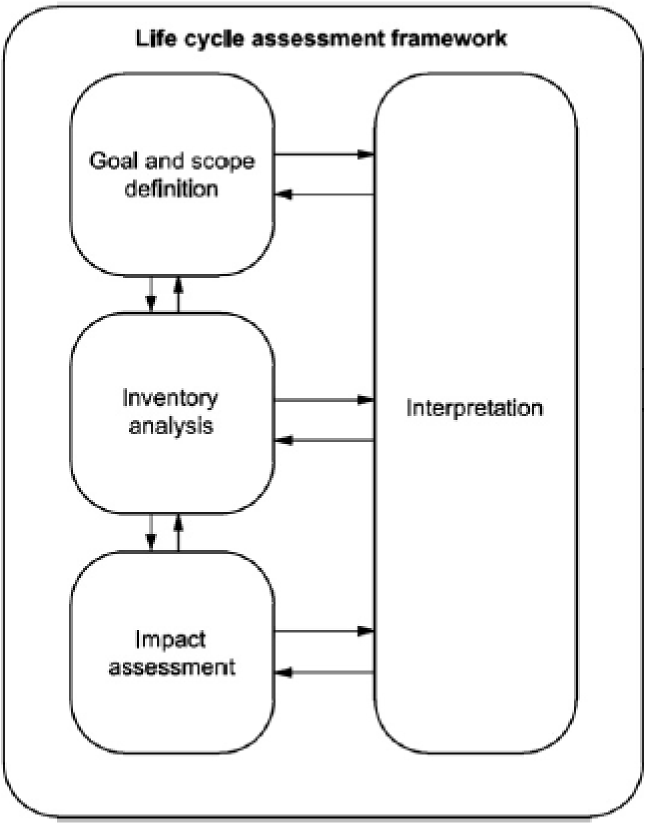

Figure 10 Life Cycle Assessment framework [29]

3.1 Goal and Scope Definition

This phase can be considered as a frame for the whole Life Cycle Assessment process, it is created specifically for each LCA case, and its purpose is to be referred throughout the whole process. It is also a help in ensuring that the analysis remains consistent. The primary step is to define the goal for the Life Cycle Assessment and to state: why is it being conducted and the intended application.

The crucial part of this phase is to realise that the model is a simplification of a complex reality, which means that the reality will be deformed in some way. That is why the model must be developed in such a way that the simplifications and distortions will not influence the results much. According to ISO standards, goal and reasons for carrying out the study should be defined clearly. The scope of the analysis includes the most important methodological choices, assumptions and boundaries. Usually, the challenge is to define the functional unit since it is not always obvious which function the product is fulfilling. Product systems are interrelated in a complicated way, so not all inputs and outputs in a system can be traced. Therefore, there is a need to define the system boundaries. By leaving some parts outside of the system boundaries, the results can be affected.

The method for conducting the Life Cycle Impact Assessment should also be decided and stated clearly before performing the LCA. In general, LCIA methods can be divided into two different categories: mid-point and end-point. Mid-point methods focus on impacts closer to the beginning of the cause-effect chain, while the end-point approach puts emphasis on the outcomes of these changes (changes to the ecosystem or human health). The impact category should be chosen according to the product or system that is studied, and that is why it should be done before performing the analysis. At this point, the description of the type and source of data used should be also included. [30]

3.2 Inventory Analysis

In general, inventory analysis is creating a model of the product life cycle with all the environmental inputs and outputs. In order to do that, all necessary data need to be collected. This step is considered the most demanding and important part of the Life Cycle Assessment. There are two types of data distinguished – foreground data, which is specific data needed to acquire for modelling the product system, and background data, that is data for the production of generic materials, energy transport and waste management. The second type can be found in literature or databases of programs.

The first step of the Inventory Analysis is creating flow diagrams for each of the unit processes that are included in the particular LCA and detailed description of the processes. When this is done, the relevant data need to be collected and adjusted, so they represent the reference flow.

Data Collection and Calculation

In Life Cycle Assessment the data collection should be both quantitative and qualitative, and it should be collected for all system's inputs and outputs. All data has to be measured in relation to the functional unit to ensure cohesion of the analysis and allow the direct comparison of the results of different scenarios. An important aspect of this step is to clearly record all the assumptions, sources and decisions in order to preserve the transparency and to allow reproduction of the results.

3.3 Impact Assessment

This step involves understanding the environmental relevance of the inputs and outputs. In most LCA cases, the impact assessment methodologies are not being developed but chosen from the ones that have already been published. Each method includes a number of impact categories, to which elementary flows are assigned.
According to the ISO 14044 standard, the LCA has to include:

- Selection of the impact categories, category indicators and characterization models;
- Classification or the assignment of Life Cycle Inventory results to the selected impact categories;
- Characterisation or the calculation of category indicator results (ISO 14044, see page 16)

In most cases, used methods are the ones that have already been established. The method should be clearly stated and explained in the Life Cycle Assessment and chosen impact categories should be reviewed to make sure that they are relevant for the study.

3.4 Interpretation of the study

The purpose of this step is to check if the conclusions are adequately supported by the data and by the procedures that have been used. First of all, it includes uncertainty analysis, since all data in the models are related to some uncertainty, i.e. variation in the data, representativeness or incompleteness of the model. Another aspect of the interpretation is the sensitivity analysis, which is used to evaluate the influence of the most important assumptions on the results. [31]

3.5 Software

In order to perform the Life Cycle Assessments that are contained in this work, the computer software SimaPro was used. It is fully integrated with many databases and impact assessments, and it can be used for different applications, such as carbon footprint assessment, water footprint assessment, sustainability performance, product design or eco-design or determination of key performance indicators (KPI). The SimaPro software has been developed according to ISO 14040 and ISO 14044 standards, and it allows the user to manage and store the necessary data, as well as perform the calculations and sensitivity analyses or Monte Carlo simulations. The great advantage of the program is that it allows for easily modelling and analysing even complex life cycles and measure their environmental impacts throughout each stage of a product’s life. SimaPro uses the databases, which contain a significant amount of information from various areas. The most used and well-known database of SimaPro is called Ecoinvent, and this database was used to perform the LCA of this work. [32]

4 Olive Oil Supply Chain

According to *Life Cycle Assessment in the Agri-food Sector*, the supply chain is “a network of organisations involved in the different processes and activities that produce value in the form of products or services delivered to the ultimate consumer” [33]. Using the different phases of the life cycle of the olive oil product, the olive oil supply chain can be described as cultivation, olive oil production, by-product management, product transportation and distribution, consumption and waste management.

4.1 Cultivation of olive trees

The cultivation phase includes activities like soil management, pruning, fertilisation, irrigation, pest treatment and harvesting. Each of them can be done in different ways depending on various factors, so the environmental impacts associated with this phase can differ in some olive farming areas. The very important stage is harvesting because depending on harvesting methods, changes in the acidity level of olives and other changes can appear. The best method is hand harvesting, but it is very expensive, while mechanical harvesting (conducted properly), brings good results. After harvesting, the olives are transported to olive oil mils, and they have to be processed within 24 hours in order to avoid occurring the fermentation phenomena. There are three types of olive trees plantation:

- Low-input traditional plantations – ancient trees planted randomly and/or terrace-planted with few or no chemical inputs and high amount of manual work
- Intensified traditional plantations – the same characteristics as the first type, but with higher tree density and weed control, soil management with the use of artificial fertilisers, pesticides, irrigation and mechanical harvesting.
- Intensive modern plantations – with high small-tree density manages with extensive use of mechanised systems and irrigation.

The type that has the lowest impact on the environment is the low-input traditional plantation, while the other two plantations’ types can increase various environmental problems, like soil erosion, degradation of habitats and landscapes and exploitation of scarce water resources.

4.2 Olive oil production

The second phase is olive oil production that includes two main steps: preparation of the homogeneous paste and extracting oil from the olives. Figure 11 presents the whole process of olive oil production.

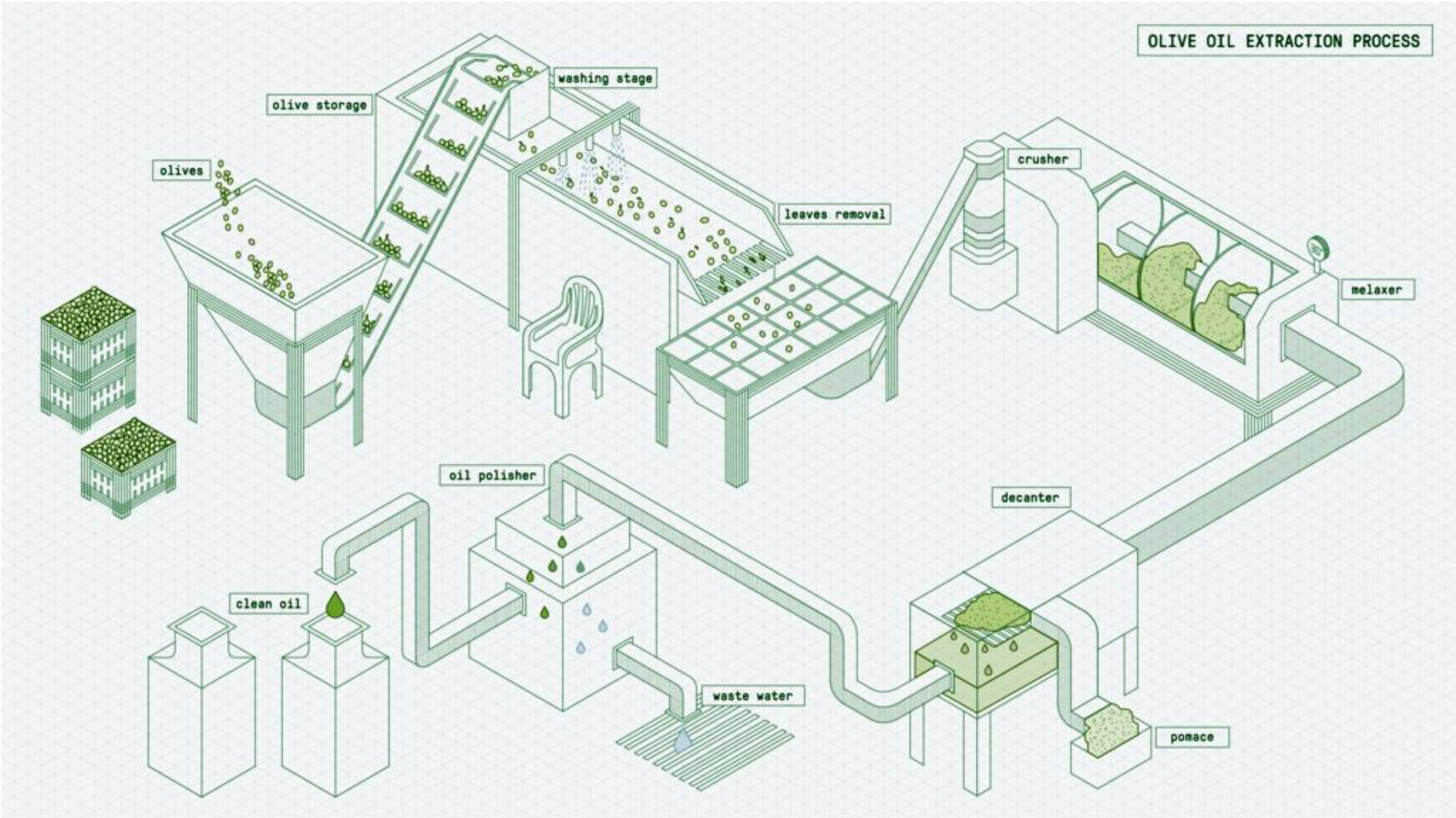

Figure 11 Olive oil production process [54]

In the beginning, olives are separated and classified by the quality, and then they are washed in order to remove impurities and dirt collected during harvesting: leaves, twigs, stems etc. Some olive mills do not wash olives before processing them. This is due to the high water consumption and the treatment of the polluted washing water and the fact that the extra moisture can cause problems during the production process. However, the stage of washing olives should not be omitted - the polluted washing water proves that olives need to be cleaned. Otherwise, the impurities and pesticides will remain on the olives and in the olive oil.

The next essential steps are crushing (tearing of the flesh cells to facilitate the release of the oil from the vacuoles) and malaxing, which involves mixing the paste to allow small droplets of oil to combine into bigger ones. Then the oil needs to be separated from the rest of the olive components – the oil is extracted with the use of press – traditional pressing, which is a discontinuous process that is used in some small mills. This method allows lowering manufacturing costs and obtaining a better quality of oil, but the time of storage of olives before processing them is shorter. Another method is continuous centrifugation, which can further use a three-phase or a two-phase decanter. Continuous centrifugation with three-phase system offers higher production capacity comparing to the traditional method, but because of the addition of warm water to dilute the olive paste, the water and energy consumption is higher too. In this process, the three-phase decanter is used, and it generates three products – solid waste (olive pomace), olive oil and wastewater. On the other hand, continuous centrifugation with two-phase system allows separating the oil from olive paste without the addition of water, and it eliminates the problem of the vegetable wastewater. This system generates only olive oil and semi-solid waste, which is called wet pomace or olive wet husk.

The olive oil production phase also includes the packaging process, even though only a few mills directly bottle olive oil with their own label – in most cases, the oil is sold unbottled to final consumers or bottling companies. In general olive oil is being bottled in stainless steel containers or glass bottles, but there are also bottles made of PET, which are 100% recyclable.

4.3 By-product management

The by-product management phase includes two methods that are used to extract pomace oil. Olive pomace oil which is obtained from the two-phase system is physically extracted by centrifugation. To extract pomace oil from the traditional and three-phase methods, solvents are used. The pomace is being mixed with the solvent hexane, which dissolves any oil that is left. Then the exhausted pomace is separated by filtration from the oil and hexane solution. Any residues of hexane in the solid pomace are being removed by desolventiser, which evaporates the solvent, that is then captured for reuse. The oil and hexane solution is later distilled, which allows the hexane to be recovered and reused, while the solvent-free oil undergoes further processing.

The by-product management phase has been considered with great importance in the olive oil supply chain because each method of olive oil production generates different amount and types of by-products that can be hazardous to the environment.

- Olive mill wastewater (OMW) – obtained from traditional pressing and the three-phase system is the main polluting mill waste. It consists of the vegetable water from the olives and water used in the oil extraction. Olive mill wastewater is highly polluting because of the organic compounds that it contains (organic acids, lipids, alcohols and polyphenols). If untreated, it can lead to serious environmental damages like colouring natural waters, altering soil quality or phytotoxicity. There are few methods of dealing with olive mill wastewater, for example, direct application to soil, co-composting or extraction of valuable organic compounds.
- Olive husk (OH) – obtained from traditional pressing and the three-phase system. It is usually sent to oil factories, that after the drying process, extract the oil with solvents (hexane). This treatment process generates oil, and solid waste called exhausted olive husk, which can be used as fuel.
- Olive wet husk (OWH) – obtained from the two-phase system. It also includes the olive vegetation waters. Comparing to olive husk, it has much higher moisture level, what causes more difficulties for its treatment – requires higher energy demand and higher costs. That is why other methods for OWH treatment are used: direct application to soil and composting.

4.4 Transportation and distribution

This phase includes activities related to transport (of raw materials, by-products and wastes) and the distribution of the product to the local, regional or international markets. Throughout the whole life cycle transport activities can also appear somewhere else – for example between two subsequent stages of the life cycle or within a particular stage.

4.5 Consumption

In the case of olive oil, the consumer phase is not significant from a perspective of the life cycle, because the product consumption does not need any further preparation or treatment.

4.6 Waste management

The phase of waste management is the end of life of the product. It includes the treatment of the bottles and packaging waste. [33]

5 Case study – Energetic valorisation of olive stones

The case study was conducted in cooperation with the company Instituto de Soldadura e Qualidade (ISQ), within the project "Alentejo Circular", that focuses on implementing the concept of the Circular Economy to the agricultural sector in Portugal. Part of the data needed in the case study comes from ISQ's reports on the project and were obtained from local companies that produce olive oil in Alentejo region. The rest was supplemented with the literature data.

In this work, the emphasis is given on improving the present practices of Portuguese companies from the sector of olive oil production. It includes one case with two Life Cycle Assessments, for the current situation of the company (Scenario 1 - Business As Usual), and the future scenario after implementing the proposed solution (Scenario 2 - Good Practices).

5.1 Description of the company

Due to the constraints experienced in acquiring in due time all the data needed from a real olive oil producer, this work presents a hypothetical company, which characteristics are based on interviews with people working in one of the biggest companies producing olive oil in Portugal and data acquired from the project "Alentejo Circular". The company has an olive trees plantation, so they use olives of their own production. The product studied in this work is extra virgin olive oil, and after production, the oil is stored in tanks and then sent to the companies that put it into bottles. Therefore the functional unit in this case study is 1 l of olive oil produced. The analysed mill works 24 hours per day, for five months during the year (it is dependent on the olives harvesting time), which gives 3600 hours of the operation.

5.2 Description of the case study

This case study puts emphasis on the industrial phase of olive oil production, so the impacts associated with olive oil production are considered from the moment of reception of the olives to the mill. It includes Life Cycle Assessment for each scenario. Since the purpose of the study is to compare the impacts from in the olive oil manufacturing stage, the analysis does not include the olives cultivation phase, because the impacts associated with this phase are the same in both scenarios and they do not influence the results.

5.2.1 Business As Usual Scenario

The first scenario – Business As Usual, considers the conventional method of olive oil production. The olive mill uses the continuous centrifugation with the 2-phase system, which means that the main products obtained in the process are olive oil and olive wet pomace. All the crucial stages of the processing of olives to get the ready product are presented in Figure 12.

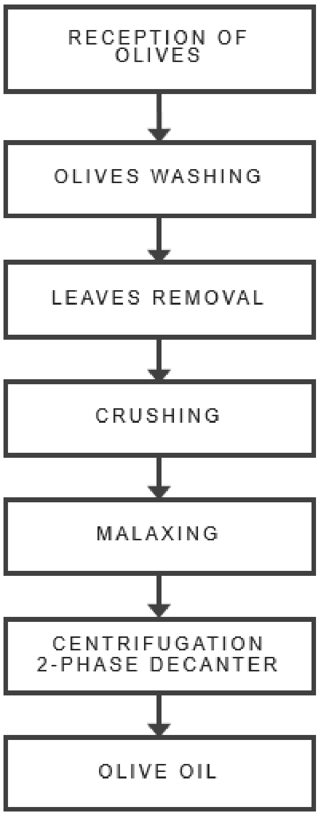

Figure 12 Stages of olive oil production in the analysed mill

As mentioned before, the ready product is stored in tanks and then sent outside of Portugal to the companies that take care of the bottling process. When it comes to olive wet pomace, it is treated as waste, and it is being sent to the landfills.

5.2.2 Good Practices Scenario

Since one of the assumptions of the Circular Economy is "reuse", the Good Practices Scenario includes a proposed solution for the waste valorisation. Energy recovery from olive oil mills residues is an interesting alternative to the disposal of these wastes. It can also reduce the environmental impacts and at the same time to generate electric energy to satisfy the needs of the mill or for sale. In general, the residual biomass from olive processing that has the potential for energy use can be divided into two groups. First one includes biomass that is produced during the olive trees cultivation – pruning and harvest residues. The second group is constituted by the biomass obtained during all the stages of extraction of olive oil. Of course, depending on the extraction method, the amounts of available energy from the residues are different. Efficient use of olive oil mill residues for energy production presents solutions for two problems: production of clean energy and acceptable disposal of olive oil mill waste. [34]

The idea in this work is to use olive stones that are a by-product of olive oil processing (contained in the olive pomace), and they are treated as waste, while they have good potential to be used in energy recovery. The olive stones are obtained by the separation from the pulp (pomace).

5.2.2.1 Olive stone as a fuel

Olive stone is a lignocellulosic material, and its main components are hemicellulose, cellulose and lignin. Because of their chemical and physical properties, the olive stone becomes a good potential source of energy.

The olive fruit consists of three parts: skin, which is 1-3% of the whole fruit, pulp (or flesh), which stands for 70-80% of the olive and the stone, that takes 18-22%. The stone itself is obtained in the olive oil extraction process by filtration of the olive pomace. [35]

The paper “Combustion Analysis of Different Olive Residues” [36] presents the results of the thermal analyses of different types of olive oil mill wastes. The wastes analysed were: olive pits separated the olive pomace (two-phases Olive Mill Solid Waste – OMSW), olive pulp and finally two components obtained from the residual OMSW after separation of stones - olive cake and Olive Mill Waste Water (OMWW). The following table contains results for the four fractions examined regarding their ultimate, proximate and chemical analysis and heating values. [36]

Table 1 Physical and chemical properties of olive pit, pulp, residual olive cake and OMWW [36]

	Pit	Pulp	Residual Olive cake	COMWW
Ultimate Analysis (% dry basis)				
Carbon	52.270	55.205	54.895	50.075
Hydrogen	7.485	7.960	8.215	7.795
Nitrogen	0.060	1.995	2.220	2.125
Oxygen	40.097	34.042	34.386	39.752
Sulfur	<0.1	<0.1	<0.1	<0.1
Chlorine	0.088	0.798	0.284	0.253
Proximate Analysis (% dry basis)				
Volatile	80.94	79.10	77.77	69.29
Ash	0.56	5.60	4.31	18.82
Fixed Carbon	18.50	15.30	17.92	11.89
Moisture (% wet basis)	9-10	6-6.5	5.5-6	70-73
Chemical Analysis (% dry-extractive free basis)				
Cellulose	18.6	12.1	12.4	0.6
Hemicellulose	25.1	12.2	14.4	0.6
Lignin	39.3	43.3	42.8	51.3
Higher heating value (MJ/kg, dry basis)	20.61	23.39	22.42	21.36
Higher heating value (MJ/kg, dry-ash free basis)	20.70	24.35	23.27	26.29
Lower heating value (MJ/kg, dry basis)	18.96	21.64	20.61	19.64

Table 2 Properties of the olive pits samples in the combustion process [36]

	Pit	Pulp	Residual Olive Cake	COMWW
Initial temperature (°C)	220	183	181	161
Maximum combustion rate (%/min)	39.82	63.01	22.81	10.27
Peak temperature (°C)	292	267	295	653
Burnout temperature (°C)	530	509	519	743
Rm (% $min^{-1}K^{-1}$)	7.05	11.66	4.01	1.11

There are few methods of generating energy from olive waste (including stones) that are already being implemented and/or developed:

- Gasification – in this thermo-chemical process biomass is being converted into a combustible gas (syngas), which can be used in many combustion systems like boiler, furnaces or gas engines. This method is still being developed because of the high cost associated with the initial setup and operation of these facilities.
- Anaerobic biogas production – this method is effective for converting a wide range of biomass for a substitution to natural gas and medium calorific gases. An advantage of this process is the fact that also the Olive Mill Waste Water (OMWW) can be processed.
- Co-combustion – combustion of solid waste from olive mill together with one more addition fuel (for example wood or coal) in the same combustion chamber. In general, this method is considered as the most cost-effective since the solid residues from olive mills have similar density and burning characteristics to coal.
- Burning olive waste in the form of pellets, powder or briquettes - this solution is low cost. However, few aspects need to be considered, for example, the fact that emissions from burning the briquettes can vary substantially and it can be harmful to the environment. [34]

When it comes to olive stones specifically, considering their high calorific value, a popular solution is a direct combustion. Usually, the purpose of it is to produce heat (for heating of buildings, facilities) or to warm up the water that is needed in the process of olive oil extraction. In this case study, another approach is presented – electricity production in the vapour (steam) cycle through the direct combustion of olive stones.

5.2.2.2 Steam cycle for olive stones combustion to produce electricity

This subchapter presents the proposed solution for the energetic valorisation of olive stones. It includes the Rankine cycle that would be added to the analysed olive oil mill to produce electricity from the olive pits. The scheme of the cycle is presented in Figure 13.

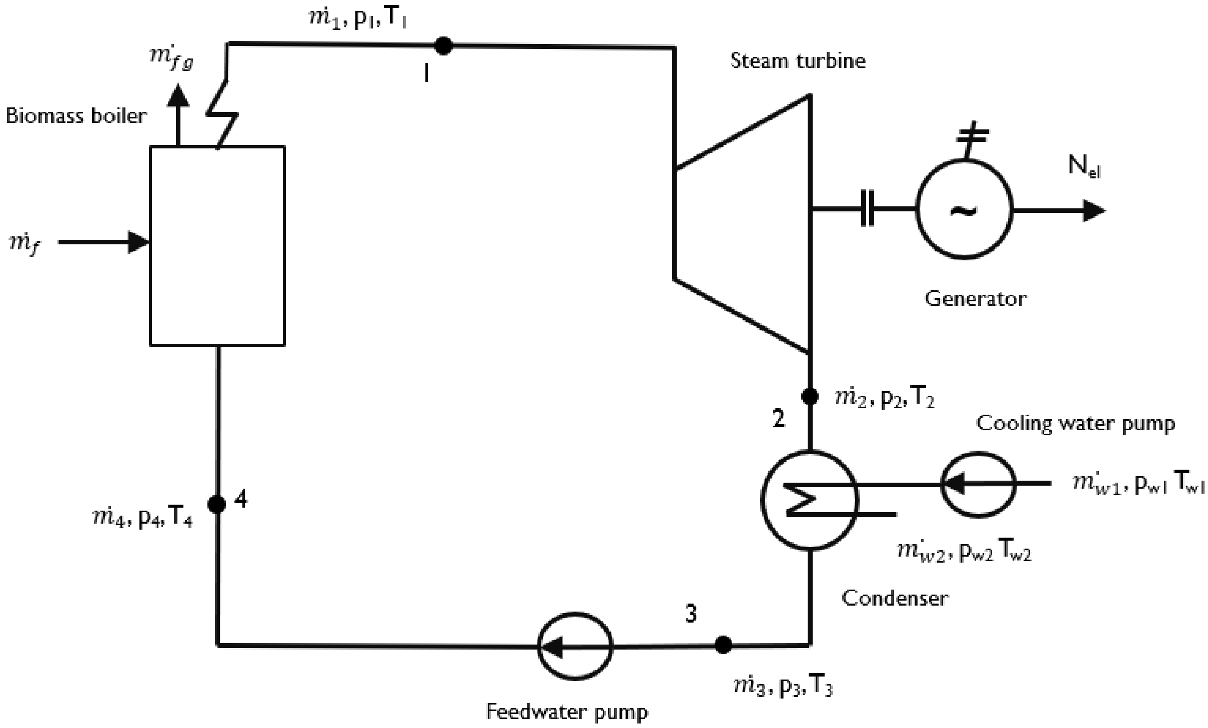

Figure 13 Steam cycle for the proposed solution

Assumptions regarding the cycle:

- Each component of the analysed cycle is considered as control volume at steady state, so the mass entering the component is equal to the mass leaving this component
- All processes of working fluid are considered as internally irreversible
- Saturated vapour enters the turbine and condensate exits the condenser as saturated liquid

The fuel for the boiler are the olive pits that are produced in the process of olive oil extraction. They are being separated from the olive pomace and then dried in the outside space (Alentejo region is rather dry, so this solution is used by the olive oil producers).

The ultimate analysis of the material (olive pits) was taken from the article "Combustion Analysis of Different Olive Residues" [36] and the Dry Ash Free (DAF), and As Received (AR) states were calculated according to the Equation 1 and Equation 2 [37]

$$X_{db} = \frac{X_{ar}}{100\% - H_2O_{ar}} * 100\% \qquad \text{Equation 1}$$

$$X_{db} = \frac{X_{ar}}{100\% - H_2O_{ar} - Ash_{ar}} * 100\% \qquad \text{Equation 2}$$

where: X – specific component of the fuel

The results are presented in Table 3.

Table 3 Calculated fuel states

Basis	H_2O	Ash	C [%]	H [%]	N [%]	O [%]	S [%]	Sum [%]
AR	9.500	0.507	47.304	6.302	0.054	36.288	0.045	100
DAF	0.000	0.000	52.564	7.002	0.060	40.323	0.050	100
DB	0.000	0.560	52.270	6.963	0.060	40.097	0.050	100

Then, the Lower Calorific Value (LCV) was calculated according to Equation 3 [38]:

$$LCV = 339.15C^{ar} + 1030H^{ar} - 108.9(O^{ar} - S^{ar}) - 25.1W^{ar} \left[\frac{kJ}{kg}\right] \qquad \textit{Equation 3}$$

And the following value was obtained by:

$$LCV = 18.34 \left[\frac{MJ}{kg}\right]$$

The data regarding energetic valorisation of olive stone was obtained from one of the biggest producers in Portugal, and it is presented in Table 4.

Table 4 Data regarding energetic valorisation of olive stone

Name of the property	Unit	Quantity
Olive stones produced per 1 kg of olive oil]	kg	0.59
Olive oil produced per year	kg	3533247
The density of olive oil	$\frac{kg}{l}$	0.917
Olive oil produced per year	l	3853050
Olive stones produced per year	kg	2084616
Operation of the mill per year	h	3600

Considering the working time of the mill and the density of olive oil [39] and other data contained in Table 4, it was possible to calculate the mass stream of the fuel that will enter the boiler ($\dot{m}_f$):

$$\dot{m}_f = \frac{2084616}{3600} = 579.06 \left[\frac{kg}{h}\right] = 0.161 \left[\frac{kg}{s}\right]$$

The next step was to calculate the mass flow of the steam at the exit of the furnace in order to be able to pick a specific model of biomass steam furnace. For that Equation 4, Equation 5 and Equation 6 [38] will be used.

$$\dot{Q_{in}} = \dot{m}_1(h_1 - h_4)$$ *Equation 4*

$$\eta_B = \frac{\dot{Q}_d}{\dot{E_{ch,f}}}$$ *Equation 5*

$$\dot{E_{ch,f}} = \dot{m}_f \cdot LCV$$ *Equation 6*

Where: $\dot{Q_{in}}$ – heat delivered to the boiler [kW], $\dot{m}_1$ – mass flow of the steam at the exit of the boiler $\left[\frac{kg}{s}\right]$, h_1 and h_4 - enthalpies of the steam respectively in points 1 and 4 $\left[\frac{kJ}{kg}\right]$, $\dot{E_{ch,f}}$ – chemical energy of the fuel $\left[\frac{MJ}{s}\right]$, η_B – efficiency of the boiler.

The efficiency of the boiler was assumed based on the website of Polish producer of biomass boilers [40] and later the specific model of the furnace will be recommended. The parameters of the steam (temperature and pressure) at the exit of the boiler were also assumed according to the producer's website, and they are presented in Table 5 together with the enthalpy and entropy of the steam at that were obtained from the enthalpy-entropy diagram for water and steam [41].

Table 5 Properties of the steam in state 1

Name of the property	**Symbol**	**Unit**	**Value**
Pressure of the steam at the exit of the boiler	p_1	bar	17
Temperature of the steam at the exit of the boiler	T_1	°C	300
Enthalpy of the steam at the exit of the boiler	h_1	$\frac{kJ}{kg}$	3020
Entropy of the steam at the exit of the boiler	s_1	$\frac{kJ}{kg°C}$	6.85

Knowing these properties and using Equation 4, Equation 5 and Equation 6 [38], the mass flow of the steam at the exit of the boiler $\dot{m}_1$ was calculated and the results are presented in Table 6.

Table 6 Calculations for the boiler

Name of the property	**Symbol**	**Unit**	**Value**
Mass stream of fuel	$\dot{m}_f$	$\frac{kg}{s}$	0.161
Lower Calorific Value of the fuel	LCV	$\frac{MJ}{kg}$	18.34
Chemical energy o the fuel	$\dot{E_{ch,f}}$	$\frac{kJ}{s}$	2949.99
Efficiency of the boiler	η_B	%	87.5
Mass flow rate of the steam at the exit of the boiler	$\dot{m}_1$	$\frac{kg}{s}$	2.93

Then, knowing the mass stream of the steam that will be produced in the boiler, it is possible to pick the specific model from the producer mentioned above - Compte Fortech, model ATC for the flow rate of 11 t/h.

The next step was to calculate the parameters of the steam in state 2 and to choose the steam turbine. The pressure of the steam in state 2 was assumed according to the producer's website [42]:

$$p_2 = 0.08\ [bar]$$

Knowing that the entropy in the state 2 is equal to entropy in state 1, according to the Equation 7 and Equation 8 [41], it was possible to calculate x in state 2, which is the quantity of saturated vapour in unit mass of wet vapour. All the properties needed were taken from the table "Properties of Saturated Water (Liquid-Vapor): Pressure table" [41].

$$s_2 = s_1$$ *Equation 7*

$$x_2 = \frac{s_2 - s_{f2}}{s_{g2} - s_{f2}}$$ *Equation 8*

Where: x_2- quantity of saturated vapor in unit mass of wet vapor in state 2 [-], s_{f2} – entropy of saturated liquid in state 2, $\left[\frac{kJ}{kg \cdot K}\right]$, s_{g2}- entropy of saturated vapor in state 2 $\left[\frac{kJ}{kg \cdot K}\right]$.

The following value was obtained:

$$x_2 = 0.819$$

After that, it was possible to read the enthalpy in the state 2 from the Enthalpy-Entropy Diagram for water and steam [41] :

$$h_2 = 2140\ \left[\frac{kJ}{kg}\right]$$

Having the enthalpy in state 2 calculated, it was possible to calculate the internal power of the turbine ($\dot{W}_t$), using the mass and energy balance for control volume around the turbine [41]:

$$\frac{\dot{W}_t}{\dot{m}_1} = h_1 - h_2$$ *Equation 9*

$$\dot{W}_t = 2.93 \cdot (3020 - 2140) = 2581.24\ [kW] = 2.58\ [MW]$$

State 3 is a saturated liquid at $p_2 = 0.08\ [bar]$, so $h_3 = 173.88\ \left[\frac{kJ}{kg}\right]$.

State 4 is fixed by the boiler pressure p_4 and specific entropy $s_4 = s_3$. The enthalpy in the state 4 can be found by using the

$$h_4 = h_3 + v_3(p_4 - p_3) \quad \text{Equation 10}$$

The thermal efficiency of the cycle is expressed accordingly the Equation 11 [41]:

$$\eta = \frac{(h_1 - h_2) - (h_4 - h_3)}{h_1 - h_4} \quad \text{Equation 11}$$

$$\eta = \frac{(3020 - 2140) - (175.59 - 173.88)}{3020 - 175.59} = 0.309 = 30.9\ [\%]$$

Heat delivered to the system was calculated according to Equation 4:

$$\dot{Q_{in}} = 2.93(3020 - 175.59) = 8305.68 \left[\frac{kJ}{s}\right] = 8.3\ [MW]$$

Assuming the mechanical efficiency of the turbine as $\eta_{mT} = 0.98$ and the efficiency of the generator as $\eta_G = 0.97$ and using the Equation 12 [41], it was possible to calculate the electrical power generated from the system.

$$N_{el} = \dot{W}_t \cdot \eta_{mT} \cdot \eta_G \quad \text{Equation 12}$$

$$N_{el} = 2.45\ [MW]$$

To calculate the flow rate of cooling water Equation 13 [41] was used:

$$\dot{m_{cw}} = \frac{\dot{m}(h_2 - h_3)}{(h_{cw,out} - h_{cw,in})} \quad \text{Equation 13}$$

The cooling water is stored in the natural pool, which is a typical solution in the Alentejo region and it enters the condenser at $T_{cw,in} = 18°C$ and leaves at $T_{cw,out} = 45°C$, so according to the table "Properties of Saturated Water (Liquid-Vapor) [41], the respective values of enthalpies are: $h_{cw,in} = 75.58 \left[\frac{kJ}{kg}\right]$ and $h_{cw,out} = 188.45 \left[\frac{kJ}{kg}\right]$. Using these properties and Equation 13, the mass flow rate of cooling water is:

$$\dot{m_{cw}} = \frac{2.93(2140 - 173.88)}{(188.45 - 75.58)}$$

$$= 51.09 \left[\frac{kg}{s}\right] = 183.94 \left[\frac{m^3}{h}\right]$$

The water that leaves the condenser is divided, and a part of it goes to the olive oil mill and is used in the olive oil processing instead of using Diesel to heat the water. The rest (major part) is stored back in the natural pool and used again as cooling water.

Knowing the mass flow rate of the cooling water, it was possible to choose the pump for the cooling water – from the Polish producer Powen-Wafapomp Group SA, model 15D17-2 [43].

Using the mass and energy balance for control volume around the pump, Equation 14 can be obtained to calculate the power required for the feedwater pump [41]:

$$\dot{W}_p = \dot{m}(h_4 - h_3) \quad \text{Equation 14}$$

$$\dot{W}_p = 2.93 \cdot (175.59 - 173.88) = 5.01 \text{ [kW]}$$

Since these parameters are known, it is possible to recommend the specific model of feedwater pump – 10K22A (producer: Powen- Wafapomp Group SA).

This cycle will be powered by electricity from the grid and the electricity generated from the cycle will be used for the own needs of the mill. Taking into consideration the installed capacity (2.5 MW), and the time that the mill operates per year (3600 h), it was possible to calculate the electricity generated during one year:

$$El_{produced} = 2.5 \cdot 3600 = 9000\ [MWh]$$

The mill only needs 0.295 kWh of electricity per 1 l of olive oil produced [11], which calculating per one year gives 1136.264 [MWh]. In that case, all remaining electricity should be managed.

5.2.3 Cost analysis of the proposed solution

For the proposed solution, the cost analysis has been performed in order to establish how big the investment would have to be and after how many years the investment would pay off. Since the main goal of this solution is to reduce the amount of electricity that is being bought from the grid, and reduce diesel use, the analysis takes into account the cost of electricity from the grid and diesel, that the company is paying per year in Scenario 1 (Business As Usual), and it is being compared with all the respective costs of implementing and operation in Scenario 2 (Good Practices).

5.2.3.1 Scenario 1 – Business As Usual

In this scenario, the costs of electricity from the grid is being considered. According to the data obtained from the company, yearly $m_o = 3533247$ [kg] of olive oil is produced. Assuming the density of olive oil $\rho_o = 0.917 \left[\frac{kg}{l}\right]$ [39], and using Equation 15 [44], it was possible to calculate how many liters of olive oil is produced per year:

$$V_o = \frac{m_o}{\rho_o} \quad \text{Equation 15}$$

$$V_o = 3853050\ [l]$$

The next step was to calculate the cost for electricity that is provided to the mill from the grid per one year. For that, the electricity cost for the industrial needs in Portugal was assumed for the year 2017: 0.1408 € per kWh [45]. Taking into consideration the known amount of electricity that is needed to produce 1 l of olive oil: 0.295 kWh [11], the total cost of electricity from the grid was calculated: 159 986 € per year. Additionally, the producer uses 0.0004 kg of diesel per 1 l of olive oil [11], which assuming the price of diesel in Portugal as 1.37 € [46], gives the total cost of Diesel: 2130 € per year. These costs will be considered in Scenario 1 and, the objective is to see the comparison between the two scenarios and after how many years would the investment in Scenario 2 pay off.

5.2.3.2 Scenario 2 – Good Practices

In this scenario, the cost of investment to build the vapour cycle is taken into consideration, as well as the amount of electricity from the grid that is needed to power this cycle. However, this amount is significantly smaller than in Scenario 1, and the electricity produced from the cycle is used for the own needs of the olive oil mill.

To calculate the investment needed to install the cycle in the facility, the particular producers of the machines mentioned in the previous sub-chapter were contacted. However, due to the lack of responses of some of them, it was not possible to get the information on the prices of the particular components of the cycle.

After contacting the company Power, it has been stated that there is a possibility of them designing the whole cycle suited to the personal needs of the facility. The price including the design and construction is 12 285 714 €. This is only one of the solutions, probably it is possible to do it with a lower price, but since only the company Power Electric has replied, the cost of investment is assumed as 12 285 714 €. The purpose of it is to show approximately how much would the investment have to be and to calculate in how many years the investment will pay off.

The cost of electricity in this scenario is calculated assuming the electricity from the grid use based on the calculations for the cycle (power needed for the pumps to run) as 0.015 kWh per 1 l of olive oil produced - both pumps together need 16.01 kW of power, which gives 57656.95 kWh per year. Assuming the same price for electricity as in Scenario 1, the total cost of electricity from the grid in Scenario 2 will be 8118.1 € per year. Knowing this value and the money spent for electricity and diesel in Scenario 1, it is possible to calculate how much money will be saved per 1 year by applying this solution – it is the difference between energy costs in Scenario 1 and Scenario 2, expressed by the following equation:

$$Money\ saved\ per\ year = (Cost\ of\ electricity + Cost\ of\ diesel)_{Scenario1} - Cost\ of\ electricity_{Scenario2}$$

$$Money\ saved\ per\ year = 159986 + 2130 - 8118.1 = 153997.9\ [€]$$

Another important aspect of this analysis is the idea of selling the excess electricity that is produced from the steam cycle to the grid in order to generate income. Considering how big is the expected electricity production and basing on the article about the biomass power plant that will be built in Chamusca, Portugal [47], it would be possible to sell all the remaining electricity to the grid at the market price and the olive oil company would have at the same time sort of small biomass power plant. The price assumed for selling the electricity was 0.223 € (for households in Portugal in 2017) [48].

As presented in Table 7, taking into account presented assumptions, the investment will pay off in approximately seven years and five months.

Table 7 Cost analysis of proposed solution

Cost analysis of the proposed solution per 1 year		
Name of the property	**Unit**	**Value**
Electricity produced in the cycle	kWh	9000000.000
Electricity needed for olive oil mill needs	kWh	1136264.493
Excess electricity	kWh	7863735.507
Earnings from selling electricity	€	1753613.018
Money saved from applying Scenario 2	€	153997.900
Total money saved and earned (Gain on investment)	€	1907610.918
Cost of investment	€	14285714.000
Time for the investment to pay off	years	7.489

The Return On Investment (ROI) was calculated according to Equation 16 [49]. The assumed time frame is 10 years.

$$ROI = \frac{(Gain\ on\ investment - Cost\ of\ investment)}{Cost\ of\ investment}\ [\%] \qquad \textit{Equation 16}$$

$$ROI = \frac{(19076109.18 - 14285714)}{14285714} = 33.5\ [\%]$$

Obtained value of ROI is 33.5% in 10 years, which is not very high, but it was calculated without considering any financial support (subsidies etc.), so this assumes the worst-case scenario. As in the article mentioned above [47], maybe it would be possible to get some financial help from the community, (or the European Union), which in the other case was 5 000 000 €. Assuming the same value in this case, it would make the investment to pay off in only two years.

6 LCA of olive oil production

The following chapter presents the Life Cycle Assessment of the case study described in the previous chapter. It includes methodology, assumptions used, results of the analyses and interpretation of the results.

6.1 Goal and Scope Definition

6.1.1 Introduction

The study identifies the differences between the conventional production of olive oil and the production with applying the good practices according to the Circular Economy concept. The goal was to understand the inputs and outputs of both systems and figure out how to make the olive oil production process more sustainable and environmental-friendly.

The literature review related to the olive oil production in Portugal (and in Europe) has been conducted in order to gather the good practices that are being applied and identify the possibilities of improvement in Portuguese sector of olive oil. The readings regarding Life Cycle Assessment methodologies have been done as well to understand all the stages better.

6.1.2 Purpose of the study

The main purpose of this study is to evaluate and compare the impact of two different scenarios of olive oil production in region Alentejo, Portugal. By the comparison of these methods, the good practices of olive oil production were identified. The LCA is made for academic purposes, as a part of the dissertation.

6.1.3 System boundaries

The data used to perform this study was collected mainly from the reports of the company ISQ and few information also from one of the biggest Portuguese producers of olive oil, but there was no possibility to visit the olive oil mill, nor to perform needed interviews to get the specific and detailed data. Each scenario included in this study considers only the industrial stage of olive oil production since the data provided for this dissertation was insufficient to perform a full analysis of the life cycle of olive oil product. The data obtained from ISQ's reports were collected from few different producers of olive oil in the whole country. Therefore the average amount was calculated for the water use, electricity use and olives needed to produce 1 l of olive oil. This data mentioned above was supported with the literature data obtained from the literature review of different LCA studies that have been performed. Later on, there will be provided a more specific explanation regarding the source of each input/output data.

Scenario 1 considers the system from the moment of receiving the olives in the mill and processing them until obtaining the ready product, which is 1 l of olive oil. In Scenario 2, the system is also considered from receiving of olives, but it also includes the steam cycle to burn olive stones to produce electricity. However, it does not include the storage pool for water that is needed for implementing the proposed solution.

6.1.4 General assumptions

Taking into account the fact that very specific data regarding each stage of olive oil production was impossible to obtain, the industrial phase that takes place in the mill is considered as a whole process. Therefore the amounts of energy, water and Diesel that are used in the production, are given for the whole process.

The following processes of olive oil production are excluded from the study:

i. Planting of olive trees;
ii. Construction of infrastructure and facilities of the olive oil mill;
iii. Olive trees cultivation and harvesting;
iv. Transportation of olives to the mill
v. Maintenance of the mil and machinery used;
vi. Bottling and packaging of the ready product;
vii. Distribution of olive oil;
viii. Storage of waste;
ix. Consumption of olive oil;
x. Production of diesel

6.2 Life Cycle Inventory

Specific data regarding the olive oil processing stage was obtained from a few different sources. Namely, amount of olives, water, electricity and diesel use come from ISQ's report on the project "Alentejo Circular". [11] When it comes to the number of olive stones produced in the process, the data comes directly from one of the biggest producers of olive oil in Portugal (telephone contact), and it is presented in Table 8 and Table 9. Figure 14 and Figure 15 present the most relevant flows that are considered in this study.

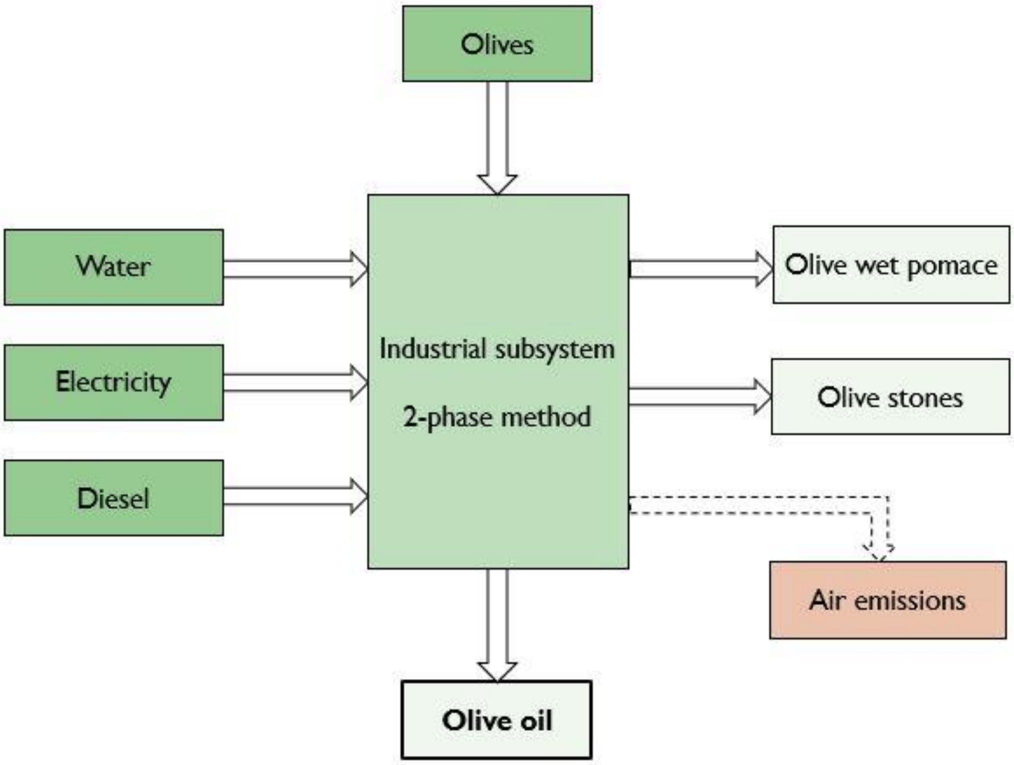

Figure 14 Input/output diagram for Scenario 1

Table 8 Primary data for olive oil processing, per 1 l of olive oil - Scenario 1 (Business As Usual)

Inputs		
Name	**Unit/1 l of olive oil**	**Amount**
Olives	kg	6.617
Water	l	1.263
Electricity	kWh	0.295
Diesel	kg	0.0004
Outputs		
Olive oil	l	1
Olive wet pomace	kg	6.200
Olive stones	kg	0.541
Leaves	kg	0.190
CO_2	kg	3.260

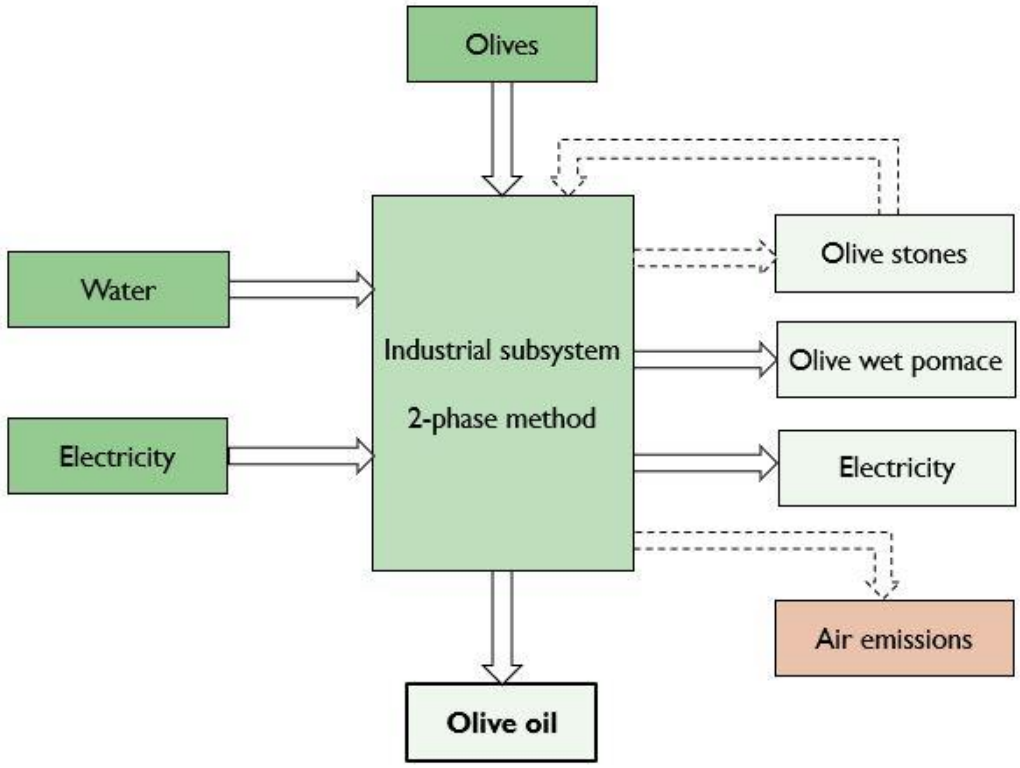

Figure 15 Input/output diagram for Scenario 2

Table 9 Primary data for olive oil processing, per 1 l of olive oil - Scenario 2 (Good Practices)

Inputs		
Name	**Unit/1 l of olive oil**	**Amount**
Olives	kg	6.617
Water	l	1.263
Electricity	kWh	0.015
Olive stones	kg	0.590
Outputs		
Olive oil	l	1
Olive wet pomace	kg	6.200
Olive stones	kg	0.541
Leaves	kg	0.190
Electricity	MWh	0.0023

In the outputs' emissions, CO_2 is not considered as the result of burning olive residues. Although biomass releases carbon dioxide (CO_2) into the atmosphere when combusted, the amount of CO_2 released is equal to (or less) than the amount that the crop absorbs while growing (net emissions of CO_2 are zero). [34]

6.3 Life Cycle Impact Assessment

In the Life Cycle Impact Assessment, the results from the inventory are turned into the information to which environmental impacts they contribute. The LCIA is done within the SimaPro, using the impact assessment method ReCiPe Endpoint (H) 2008 V.1.13.

ReCiPe is the most recent and harmonised indicator approach that is available in the Life Cycle Impact Assessment. The main objective of this method is the transformation of the huge amount of life cycle inventory results into a limited number of indicator scores. These indicator scores express the relative severity on a category of the environmental impact. Within the ReCiPe method, there are two levels of indicators determined: midpoint and endpoint. Both of them contain factors according to three cultural perspectives. Comparing to other approaches, ReCiPe has important advantages:

7 The broadest set of midpoint impact categories
8 It uses impacts mechanisms that have global scope when it is possible
9 It does not include the potential impacts from future extractions in the impact assessment, but it assumes that these impacts have been included in the inventory analysis. [50]

6.3.1 Impact Categories

The seventeen impact categories of ReCiPe Endpoint (H) can be divided into three different damage categories: Human Health, Ecosystems and Resources.

6.3.1.1 The damage category: Human Health

The human health can be damaged either by reduction of its duration (premature death) or by causing a temporary or permanent reduction of body functions (disabilities). The sources for these damages are mainly:

- Infectious and respiratory diseases, as well as forced displacement caused by climate change
- Cancer as a result of the ionising radiation;
- Cancer and eye damages caused by the ozone layer depletion;
- Respiratory diseases and cancer due to the toxic chemicals contained in the air, food and drinking water.

6.3.1.2 The damage category: Ecosystem Quality

Since the ecosystems are very complex, it is difficult to determine all damages on them. Ecosystem damage is expressed in a percentage of species that are threatened or that disappear from a given area during the certain time. The most important issues in this damage category are ecotoxicity, acidification and eutrophication and land use.

6.3.1.3 The damage category: Resources

The risk that humanity will run out of resources for the future generations is an often discussed and important issue. In many cases, resource depletion and shifts in material demand will have an impact on market prices. The ReCiPe method is basing on the geological distribution of mineral and fossil resources and assesses how the use of these resources causes marginal changes in the efforts to extract future resources. [51]

The specific categories addressed in this method are:

- Climate change Human Health;
- Ozone depletion;
- Human toxicity;
- Photochemical oxidant formation;
- Particulate matter formation;
- Ionising radiation;
- Climate change Ecosystems;
- Terrestrial acidification;
- Freshwater eutrophication;
- Terrestrial ecotoxicity;
- Freshwater ecotoxicity;
- Marine ecotoxicity;
- Agricultural land occupation;
- Urban land occupation;
- Natural land transformation;
- Metal depletion;
- Fossil depletion.
- Freshwater eutrophication
- Mineral resources
- Land use/transformation
- Water use.

The results will focus on the four most relevant in this case impact categories, and there will be provided a more detailed description of these categories. Since the functional unit is 1 l of olive oil produced, and due to the lack of data, all the values of impacts are very small, and the four chosen categories show most representative results: Climate change Human Health, Climate Change Ecosystems, Ionising Radiation and Particulate Matter Formation. The damage from these impacts is expressed in DALYs (Disability Adjusted Life Years) per kg of substance.

- Climate Change

There are two chosen impact categories related to the climate change issue – Human Health and Ecosystems. Emissions contributing to climate change are for example CO_2, CH_4, and N_2O. The human health can be affected by climate change in a few ways, for example, the change in climate can cause changes in agricultural production, which can give malnutrition and hunger. It is important to realise the fact that climate change affects not only human health but also ecosystem quality. [52]

- Ionizing Radiation

Ionising radiation is radiation with enough energy so that during the interaction with an atom, it can remove tightly bound electrons from the orbit of an atom and it causes the atom to become charged or ionised. Being exposed to ionising radiation can increase the risk of cancer even at lower doses. Other effects on human health can be skin redness, hair loss and radiation burns. [53]

- Particulate Matter Formation

Fine Particulate Matter, which diameter is lower than 10 μm (PM10) represents a complex mixture of organic and inorganic substances. PM10 causes health problems as it can reach the upper part of the airways and lungs when it is inhaled. The effects on human health can be: asthma, lung cancer, cardiovascular disease, birth defects or premature death. [51]

6.3.2 Results

After creating the respective processes, introducing all data to the software, and choosing the LCIA method, the analyses for both scenarios were performed, as well as a comparison of both scenarios. Figure 16 and Figure 17 show the networks/trees of the flows of the specific inputs and outputs in a particular model, which is a good representation of the processes that take place there. It is also possible to see in the networks which component has the biggest share when it comes to impacts - already at this point; it is clear which input will contribute the most to the environmental impacts.

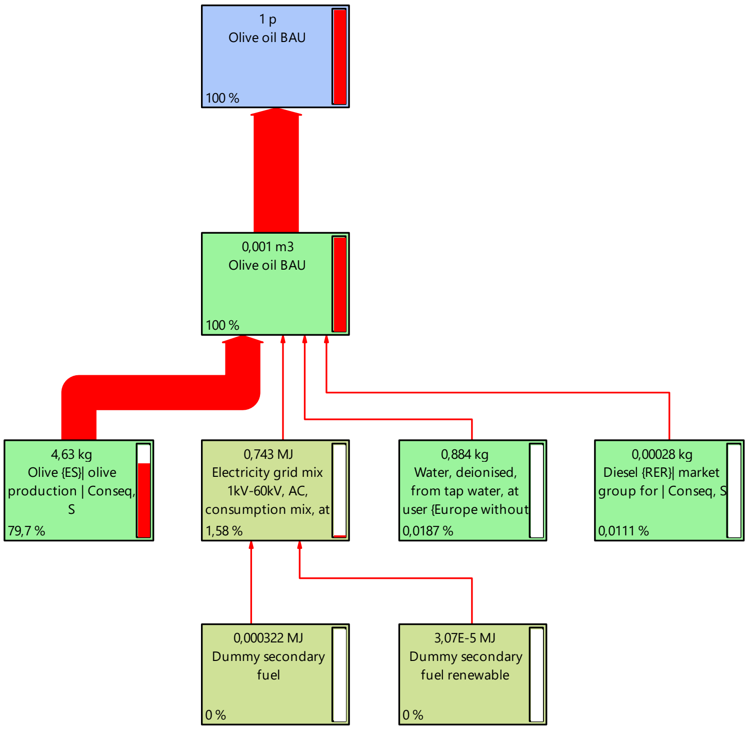

Figure 16 The network for Scenario 1 - Business As Usual

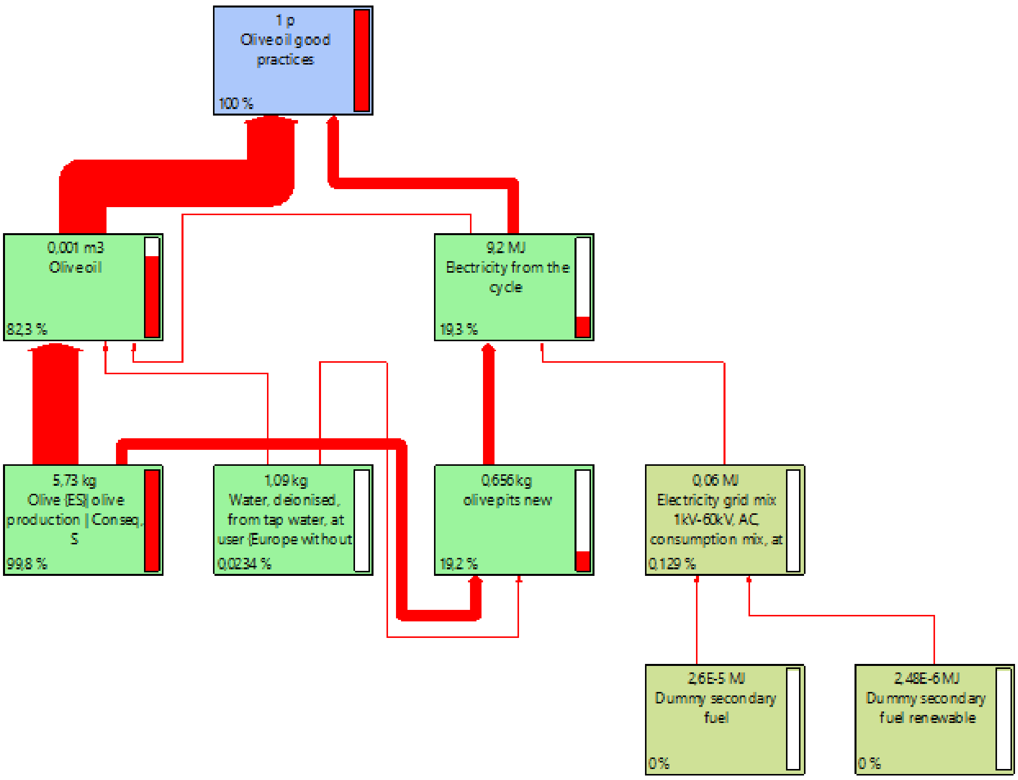

Figure 17 The network for Scenario 2 - Good Practices

Figure 18 presents the comparison of characterisation between the two analysed scenarios. Almost in all impact categories, Scenario 1 performed better than Scenario 2. Only in two categories: Climate change Human Health and Climate change Ecosystems, Scenario with Good Practices obtained better results, and the difference is huge.

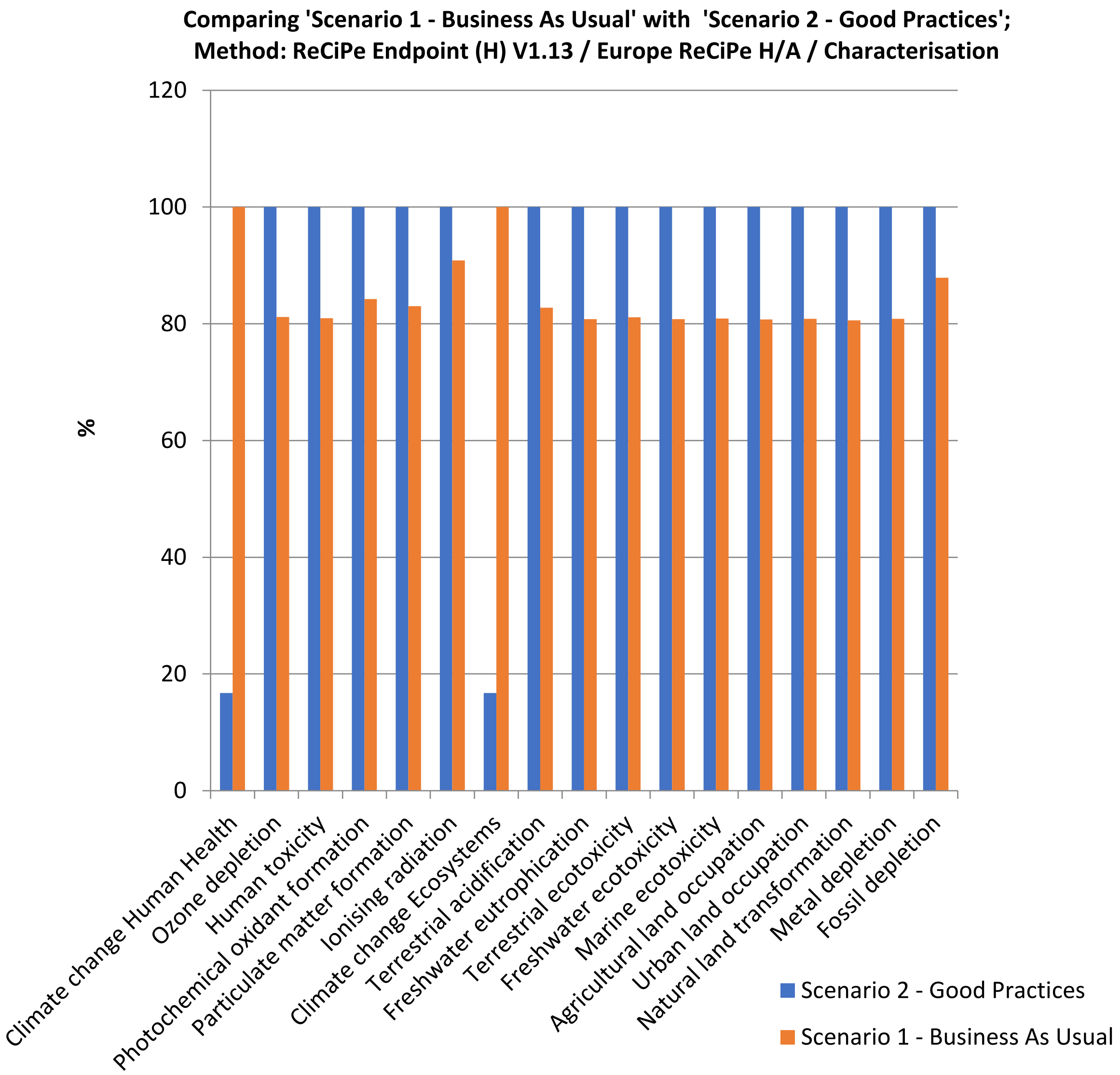

Figure 18 Characterization of the results

In relation to the previous graph, Figure 19 presents the comparison of the two analysed Scenarios regarding Damage Assessment in three categories: Human Health, Ecosystems and Resources. In the category of Human Health, Scenario 2 – Good Practices performed much better, but in the two remaining categories Scenario, 1 was slightly better.

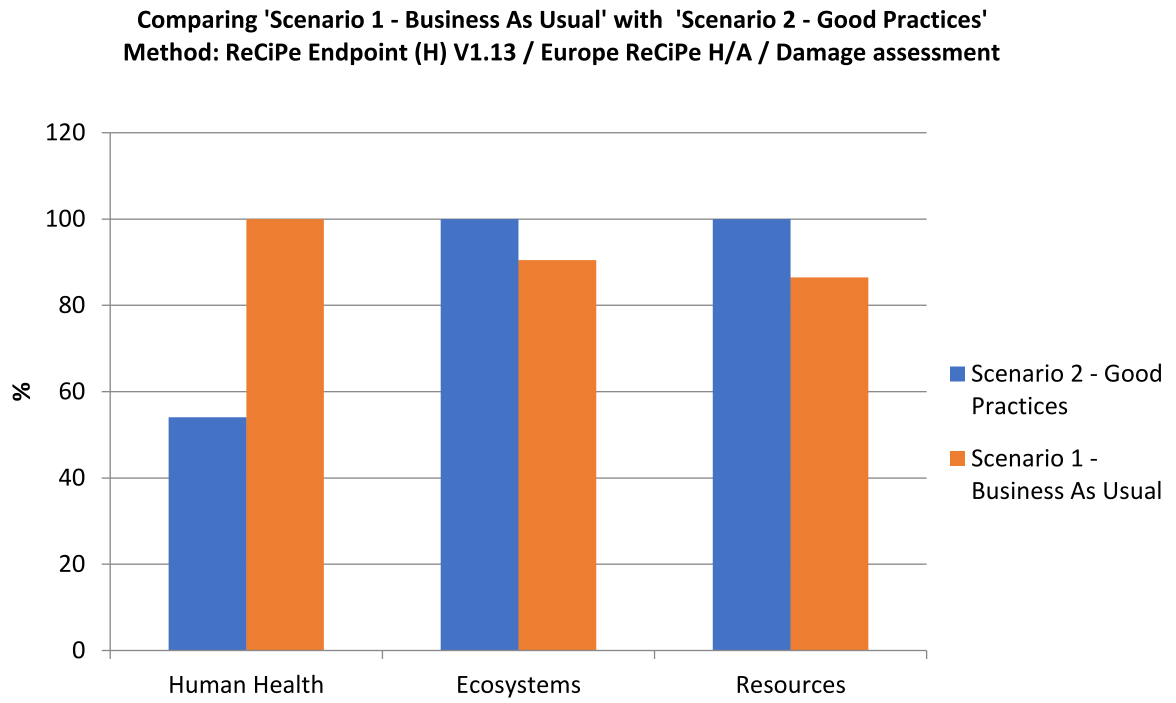

Figure 19 Damage assessment

Figure 20 presents the normalisation of Damage Assessment. Normalisation can be helpful in LCIA results, providing and communicating information on the relative significance of the impact category indicator results. This graph shows that in fact the impacts on Ecosystems are bigger than on Human Health or Resources.

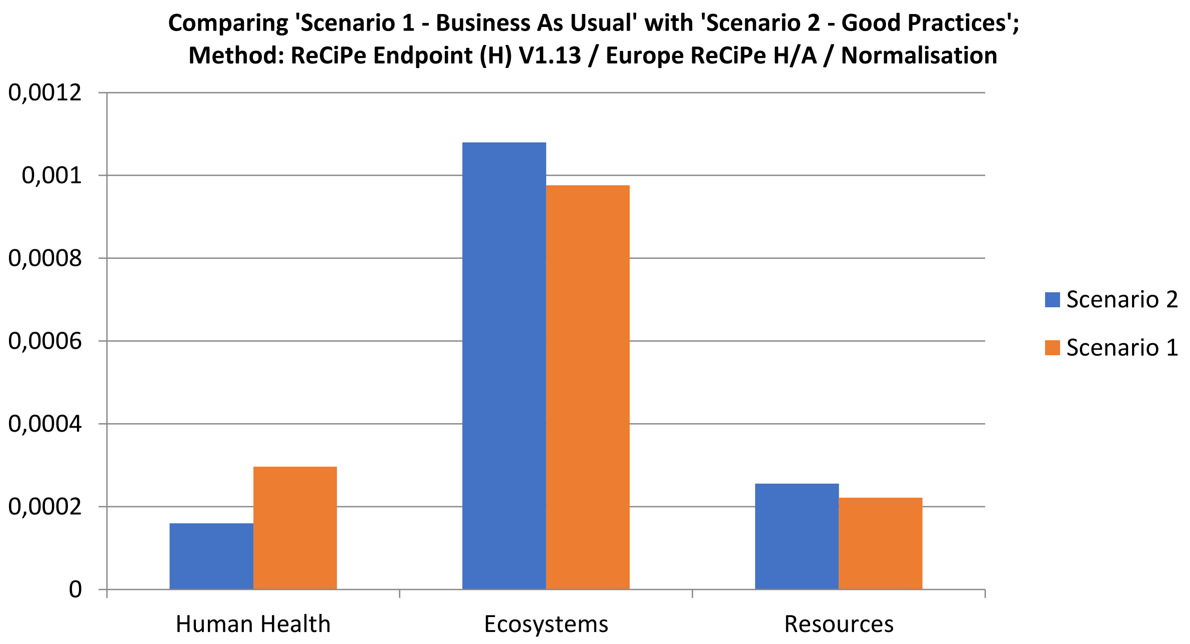

Figure 20 Damage assessment normalisation

Figure 21 shows that only the processes needed to obtain olives have a huge environmental impacts. Another input that has importance is electricity from the grid, but the rest is very small, and it has been neglected.

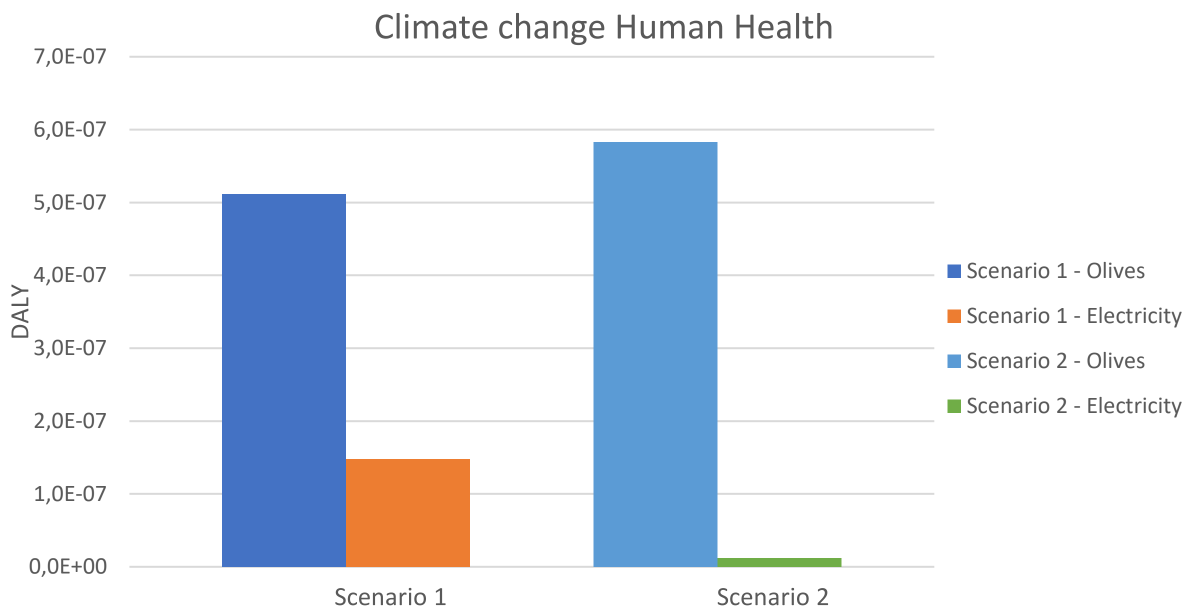

Figure 21 Climate change Human Health

6.4 Interpretation of the study

The goal of this Life Cycle Assessment was to analyse the olive oil production of the company from Alentejo region in Portugal and compare the standard method of olive oil manufacturing with a possible solution that includes energetic valorisation of waste, namely burning olive stones in a boiler to produce electricity. The main objective of this study was to check if implementing this solution will cause any major changes in terms of environmental impacts.

Due to the lack of relevant data, in this study, only the olive oil manufacturing phase was analysed, which makes it hard to compare this study to other studies in this area. However, as in other studies, it can be clearly noticed that the cultivation and harvesting of olives contribute the most to the environmental impact in every single impact category, in both scenarios. The industrial phase of olive oil production does not bring significant impacts on the environment; mainly it is electricity from the grid and water.

In the characterisation of the results, when the specific bar in the graph reaches 100%, it means that 100% of processes in this scenario contribute to the environmental impacts in a particular category.

When it comes to a comparison of the two scenarios, in most of the impact categories the proposed solution does not bring much improvement, it performed a little less than Business As Usual Scenario.

However, when it comes to climate change specifically, it is visible in Figure 21 that the impacts related to the electricity from the gird were reduced, which is due to the own electricity production in the mill.

Since the functional unit was 1 l of olive oil, all the values obtained in the impact categories are very small. Therefore they are not very representative.

7 Conclusions

This chapter presents the summary and conclusions from the whole presented work. It includes the importance of the tools like LCA and SimaPro in that kind of studies, conclusions about the proposed solution and its implementation, as well as conclusions from the Life Cycle Analysis. This chapter also contains the suggestions and recommendations for further actions that could be done in order to improve the solution.

7.1 Conclusions about the proposed solution

Olive solid residues represent a great potential for the energy from biomass in the regions of olive oil production in Portugal. The calculations done within this work show that the proposed solution of burning olive stones in the steam biomass furnace to produce electricity is possible to implement in the facility like the analysed olive oil mill. However, because the solution requires a big reservoir of water available, this could be a potential problem, and it would need to be checked before implementing. On the other hand, the big amounts of water needed in the steam cycle to cool down the steam in the condenser can be recovered and put back in the storage pool, which makes this solution more viable.

A big disadvantage of this solution is the fact that constructing that kind of facility would take a lot of space. Basically, it is a small-scale power plant. It would have to be considered if the space needed is available in the facility of the olive oil mill. Following this concept of being a small-scale power plant, the electricity produced from biomass would have to be sold to the grid at the market price, which would generate income.

On the other hand, a great advantage of this scenario is the energetic valorisation of biomass, which is a by-product of olive oil production. Even though olive stones are already being used for the purpose of energy production, this work presents a different approach – generating electricity. Another advantage of using biomass is a reduction of CO_2 emissions, which is a common issue nowadays.

When it comes to the economic aspect, the investment needed for installation of the vapour cycle is huge (14 285 714 €). However, as it is presented in the chapter 5.2.3, the pay off time of the investment depends on few factors, for example: if the company would be able to get the financial support from the community (in this case it would be around two years).

7.2 Conclusions from LCA

Life Cycle Assessment is a good approach to measure the environmental impacts associated with particular processes of the life cycle of the product. However, in this case, for the LCA to be more precise and representative, more specific data would be needed. The analyses showed some specific results, but for the LCA to be complete and to be able to see the impacts from the whole life cycle of olive oil, data from other stages would be needed too (cultivation and harvesting of olives, transport of olives to the mill, packaging, consumption etc.). In this work, some inputs and outputs used in the analysis were coming from the Ecoinvent database of SimaPro, which makes the analysis less detailed and less accurate.

Even with the little data available, it is possible to see that the highest environmental impacts are strictly related to the olives, not to the industrial phase of olive oil manufacturing. This trend also appears in other works that present the LCA of olive oil production.

Considering the data available for this study, it seems that the proposed solution brings worse effects on the environment than the standard method of olive oil manufacturing. However, the more detailed study would have to be performed to fully evaluate the real impacts related to both scenarios.

This study has proved that the LCA is a very demanding tool and the whole process is difficult. In this work, some assumptions had to be made before performing the analysis in order to complement the lack of data, while for the Life Cycle Assessment to be accurate, very detailed and good quality data is needed, preferably obtained from the interviews with people working in a specific facility.

7.3 Recommendations and possible further actions

Taking into account all previously mentioned issues, this sub-chapter presents a set of suggestions and recommendations for the future actions that could improve the LCA as well as the proposed solution to make it more profitable.

- Regarding the LCA itself, it would be recommended to get the detailed data of good quality, so the information provided in the software will demonstrate the real processes in the highest possible level. The most data possible should be obtained through visiting of the analysed facility and interviews with people involved in its operation.
- First of all, the cycle presented in this work would need more research and development (more specific calculations of the cycle, and later implementing a pilot line) in order to check its performance in a real environment.
- As it has been concluded previously, the proposed solution is possible to implement, but it requires a big reservoir of water. Even though the cooling water for the condenser is being stored again, the natural pool for water storing needs to be big enough. There are also possibilities to implement measures to catch and store rainwater or recirculate groundwater. The person responsible for implementation of the idea would have to consider all benefits and possible problems related to it.
- If this solution were decided to be implemented, the more specific cost analysis would have to be done. The analysis included in this work is based on many assumptions that are results of research, and its purpose is to give a general overview of expected costs, but the situation would have to be deeply analysed, considering all factors, in order to estimate the real costs of implementing this solution.
- As assumed in this case study, right now the mill operates for 5 months per year, but there is a possibility of buying olive stones from other, smaller producers in the region and running only

the cycle for the whole year (excluding the time needed for the maintenance of the cycle). This way it would be possible to produce more electricity and sell it to the grid, which would make the investment pay off faster and would bring more profit.

- Nowadays, governments in each country are promoting and supporting sustainability and all kinds of actions that involve the concept of Circular Economy. Maybe it would be possible to apply for subsidies and financial support from the government for that kind of installations for biomass burning.
- In the process of olive oil production, the leaves, branches etc. are considered as organic waste, while they also could be reused. In the paper "Market for Olive Oil Residues" [34], one of the solutions being considered is to use that kind of waste for subsequent heating. It would have to be checked if this solution is applicable in this case.

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