Environmental Impact Assessment of Olive Oil Production

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Abstract

Olives and olive oil are a critical agri-business sector, especially for the European Union (EU) countries of the Mediterranean basin. Spain, Italy and Greece are the main producers and exporters of olive oil and its production significantly contributes to local economy and income. However, the olive oil production supply chain is associated with numerous environmental adverse affects, depending on the production methods adopted. Over the last thirty years, olive growing has become more intensified and mechanised, while, in most cases, irrigation and chemical fertilisation is standard practice. Olive processing has, also, been intensified, resulting in large quantities of solid waste and wastewater being generated. Evidently, addressing and assessing the environmental impacts of the olive oil supply chain becomes imperative. Scientific tools such as Life Cycle Assessment (LCA) can assist in understanding and evaluating those impacts and identify the areas for improvement.
This dissertation focuses on analysing the different steps of the olive oil supply chain in Greece and Spain, and identifying, through the application of the Life Cycle Assessment (LCA) methodology, how and to which extent they impact the environment. It, mainly, focuses on the Agricultural and Processing phases, since they have the highest environmental impact. Special attention is given on the treatment of By-products. Finally, the Distribution phase, is, also, examined

Keywords: olive oil production; environmental impact; life cycle assessment; case studies

Preface

This dissertation was written as part of the MSc in Environmental Management and Sustainability at the International Hellenic University. It acts as the last step in a two-year experience that has empowered me academically and prodessionally, broadened my horizons and provided me with knowledge and perspective regarding the importance of sustainability and the way it integrates into society. More specifically, this dissertation has given me the opportunity to understand and analyse the way, the olive oil industry, an important business sector for Europe, in general, and Greece, in particular, affects the environment, through the application of the commonly scientifically accepted methodology of Life Cycle Assesment.

It has been a mentally stimulating process, for which I would like to thank, my academic supervisor, Dr. Georgios Banias, for the opportunity to work on a subject of personal interest. I would, also, like to thank my family and friends for their continuous support, from the beginning until the completness of my degree.

Spyridoula Tzima
22/12/2018

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CHAPTER 1

INTRODUCTION

1.1. OVERVIEW

The Olive tree (*Olea europaea L.)*, is an evergreen, slow-growing species that belongs to the family *Oleaceae*. It is one of most widespread agricultural plants worldwide. In 2016, global olive production expanded in an area of 10.7 Megahectares (Mha) and reached 19 ('000 tonnes) (FAOSTAT, 2016). As a crop, it is particularly tolerant to dry conditions and has an average life expectancy of about 500 years (Rhizopoulou, 2007). It is one of the oldest cultivated trees in the world. Evidence can be traced back to 700 B.C., when winners of the Olympic Games were awarded a wreath of olive branches (Kapellakis, et al., 2008).

Olive farming originated in Greece, with other countries along the Mediterranean coastline, most notably Spain and Italy, soon being introduced to the cultivar (Loumou and Giourga, 2003). In recent years, new producing countries have emerged, including States in Latin America and the Caribbean, the State of California in the United States, South Australia, South Africa and even China (Rhizopoulou, 2007). To this date, however, olive cultivation is mostly, associated with Mediterranean countries, in terms of economy and society, as olives are a significant source of income and employment for many citizens (Labrador, et. al, 2011). Moreover, olive trees have, historically, been an integral part of the Mediterranean culture, tradition and social life (Kapellakis, et al., 2008).

Most of the global olive cultivation is dedicated to olive oil production. According to some studies, it has been estimated that, on average, 1 tonne of olives produces approximately 200 kilogrammes of olive oil (Salomone, et al., 2015). Undoubtly, olive oil is of great economic and social importance for producing countries. However, the olive oil sector is responsible for a series of environmental impacts in terms of depletion of natural resources, land degradation, air and soil emissions and waste generation. These impacts can be identified both in the agricultural and industrial phases and may differ significantly, depending on the approaches adopted. Olive tree cultivation and olive oil extraction processes consume natural resources, release emissions to air, water and soil and produce pruning and harvesting residues, as well as large amounts of waste and wastewater that greatly impact soil and aquatic environments (Salomone and Ioppolo, 2012).

For this reason, it is critical to address and evaluate the environmental impacts of the olive oil production supply chain, with an in-depth analysis of the different practices adopted (Salomone and Ioppolo, 2012) and identify the areas of negative contribution.

1.2. AIM AND OBJECTIVE

The aim of the study is to explore the practices adopted throughout the olive oil production chain in Greece and Spain, two of the major global olive oil producers, and assess the environmental impacts deriving from it.

The objective of the study is to:
-address the different methods and techniques applied throughout the olive oil lifecycle
-compare the methods and techniques applied in Greece and Spain and identify their relative level of adverse effects on the environment.

1.3. METHODOLOGICAL FRAMEWORK

The analysis is conducted by an extensive literature review of the commonly adopted olive oil production processes, along with the most significant environmental considerations, deriving from them. The *Regulatory Framework* that governs olive oil production, especially in the European Union, is, also, addressed. It should be noted that special attention is given on the practices and legislation adopted in Greece and Spain, since these differentiations, formulate adopted practices, which in turn, affect the environmental impact of local production. The theoretical analysis is complimented by the application of *Life Cycle Assessment (LCA)* methodology, where through two real-life *Case Studies*, for Greece and Spain, we evaluate and compare the environmental footprint of each olive oil supply chain.

1.4. SECTION SUMMARY

In this section, the structure of the study is, briefly, outlined. After having defined its *Aim* and *Objective*, Chapter 2 explores the International Olive Oil and European Union (EU) market structure, in terms of economic figures. Then, follows a presentation of the techniques applied in world olive oil production, and the way these have been integrated into the Greek and Spanish sector. Furthermore, the main environmental considerations are addressed, along with a brief discussion of the resulting socio-economic considerations. Chapter 2 concludes with an overview of the *International Olive Oil Regime*, along with the *Regulatory Framework* that governs the European Union (EU) and the way Greece and Spain conform to it. In Chapter 3, the *Life Cycle Assessment (LCA)* methodology is explained. Chapter 4 explores the production practices adopted in Greece and Spain, by means of *Case Studies* that represent those applied in specific olive oil producing regions. Data available from the *Case Studies* are tested through the application of the *Life Cycle Assessment (LCA)* methodology. In Chapter 5, the *Results* of the *Life Cycle Assessment (LCA)* analysis are presented. Finally, in Chapter 6 general *Conclusions* are drawn.

CHAPTER 2

THE OLIVE OIL SECTOR

2.1 THE INTERNATIONAL OLIVE OIL SECTOR

The international olive oil sector has experienced significant changes in the last ten years, due to a rapid increase in demand and supply of the product, despite minor fluctuations,

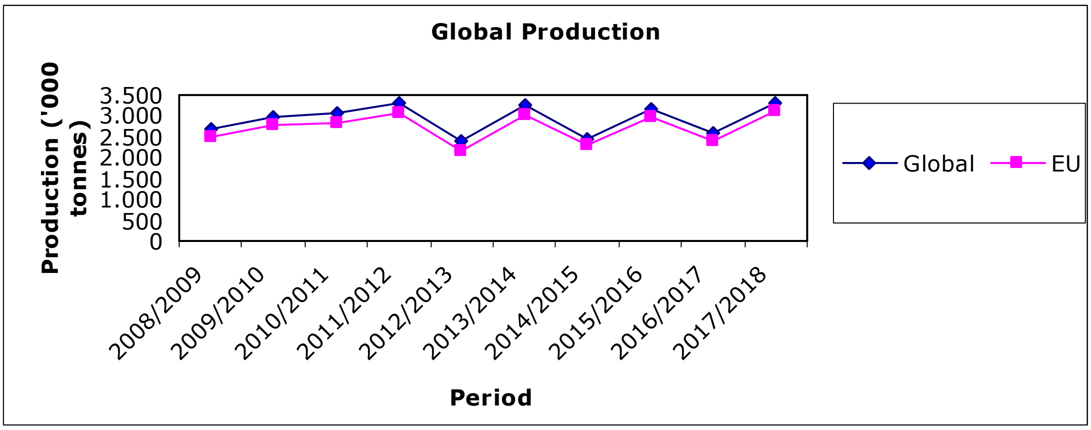

Figure 2.1.: Global Olive Oil Production (IOC, 2018)

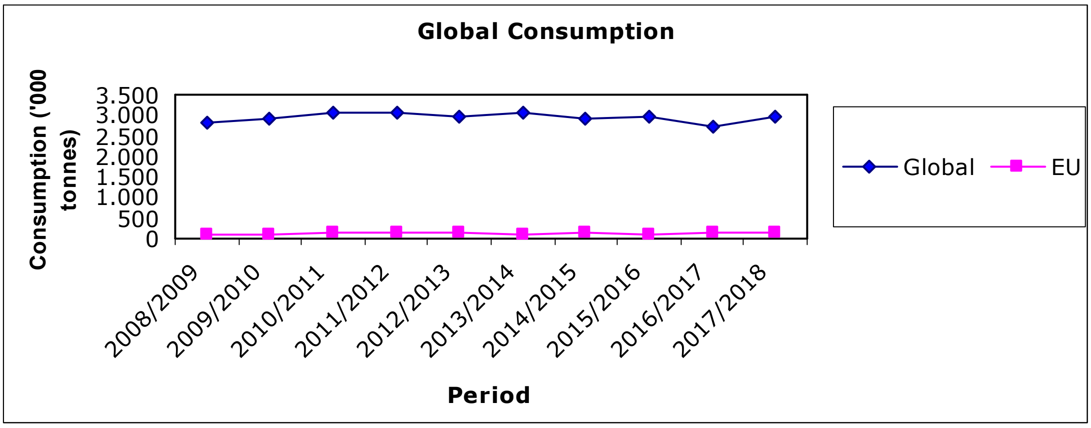

Figure 2.2.: Global Olive Oil Consumption (IOC, 2018)

the entrance of new producing countries, intensification of competition in terms of production and marketing and changes in environmental legislation (Mili, 2006).

As a market, it presents a highly complex structure. Olive trees can grow even in the most adverse conditions (IOC, 2018), allowing cultivation to be expanded from developed to developing countries. Moreover, there is not a uniform pattern of production: different practices and techniques in the agricultural and processing phases apply, not only between countries, but between regions within the same

country (Anania and Pupo D'Andrea, 2008). At the same time, the market is characterised by significant differences in sizes: big, established companies competing against small, individual or cooperative firms (Anania and Pupo D'Andrea, 2008).
As a product, olive oil is highly tradable, with states of the European Union (EU) leading the way. According to the International Oil Council (IOC, 2018) during the last decade, with minor exceptions, olive oil imports and exports have been on the rise

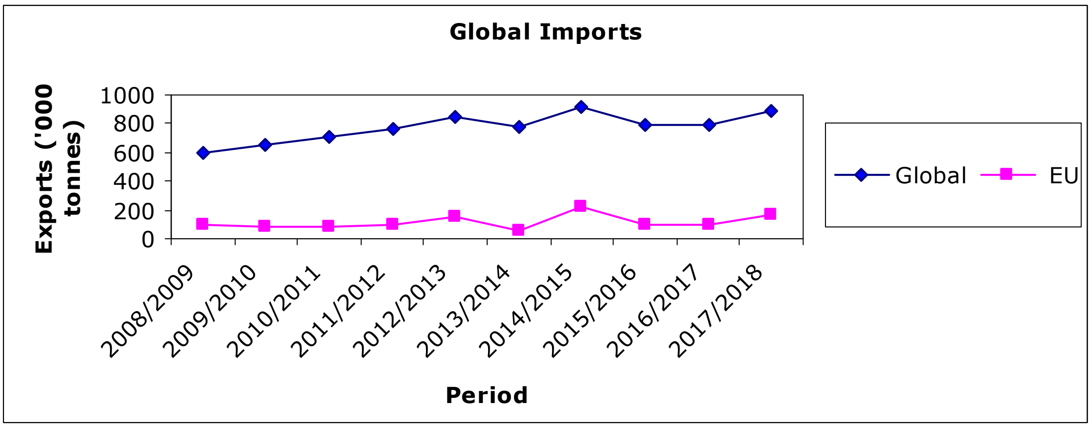

Figure 2.3.: Global Olive Oil Imports Excluding EU Intra-Trade (IOC, 2018)

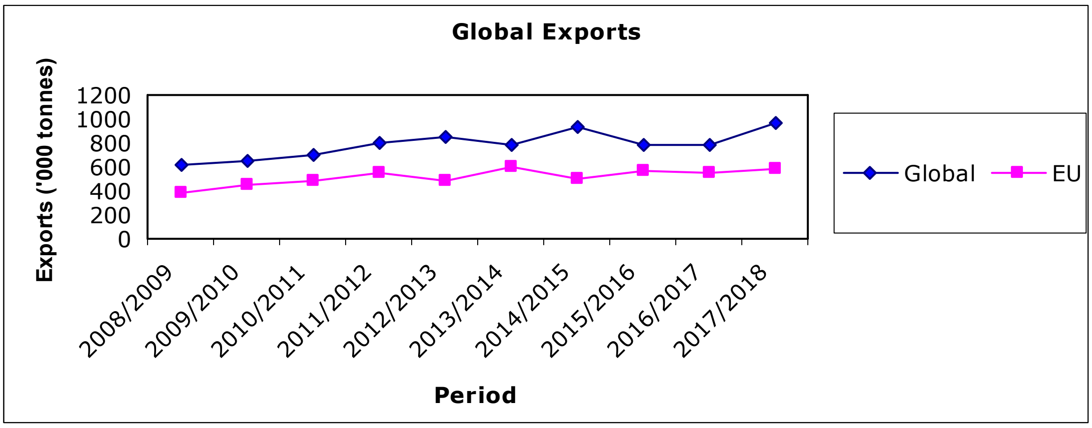

Figure 2.4.: Global Olive Oil Exports Excluding EU Intra-Trade (IOC, 2018)

2.2. THE OLIVE OIL SECTOR IN THE EUROPEAN UNION

The European Union (EU) is, globally, the biggest olive oil producer. For the period 2017-2018, it is estimated that *66%* of total global production will be produced by Member States. Within the Union, major producing countries are Spain (*53%*) Italy (20%) Greece (18%) and Portugal (6%) of total European Union production (IOC, 2018), followed by France, Cyprus, Slovenia and Malta (European Commission, Directorate-General for Agriculture and Rural Development, 2012). At the same time, the European Union (EU) is the biggest global olive oil consumer (IOC, 2018), holding a 53% of total consumption (IOC, 2018).
Similarly, international trading activities are dominated by EU Member States. According to the International Olive Council (IOC, 2018), for the period 2017-2018,

total exports[1] are expected to reach 579 ('000 tonnes), while total imports[2] are expected to reach 160 ('000 tonnes). Spain and Italy are leading the way, with exports[3] forecasted to achieve a 53% and 38% percent market share, respectively, and imports[4] forecasted to achieve a 39% and 53% percent market share, respectively, for the period 2017-2018 (Tables 2.1. and 2.2.)

Table 2.1.: Olive Oil Global Exports ('000 tonnes) for 2017-2018 (IOC, 2018)

Exports	('000 tonnes)
Global	971
European Union	579
Spain	304
Italy	218
Greece	10
Portugal	40
France	2
Other	5
Non-European Union	932

Table 2.2.: Olive Oil Global Exports ('000 tonnes) for 2017-2018 (IOC, 2018)

Imports	('000 tonnes)
Global	880
European Union	160
Spain	62
Italy	85
Greece	n/a
Portugal	n/a
France	9
Other	4
Non-European Union	720

The European Union (EU) olive oil market structure is highly fragmented. According to the most recent Eurostat figures (Eurostat, 2013), the average size of olive holdings in EU countries is rather small, at *2.8* hectares, however, holding size differs significantly amongst Member States. For example, in Greece, the average olive holding is at *1.5* hectares, while in Spain it is at *5.8* hectares (Eurostat, 2017). Small olive plantations urge farmers to cooperate. This is the case, particularly in Spain, Italy, Greece and Portugal, where small growers are organised in cooperatives, with intent to, either, process the olives and extract olive oil, or sell it directly to processing companies. Processing is more concentrated, with multinational industrial bottling companies

[1] Excluding intra-trade
[2] Excluding intra-trade
[3] Excluding intra-trade
[4] Excluding intra-trade

setting market rules (Salomone and Ioppolo, 2012). Small plantations, may, also, indicate that olive oil production is a secondary activity, or olive oil is produced for personal use only (European Commission, Directorate-General for Agriculture and Rural Development, 2012).

Typically, an olive plantation needs about five to seven years to become fully productive. Growing activities peak during winter, making it compatible with other agricultural and non-agricultural activities. Production varies and depends on different factors such as, the biological alternation of the olive tree (a good harvest followed by a poor one), farming practices, olive varieties and soil and climate conditions (European Commission, Directorate-General for Agriculture and Rural Development, 2012). Olive farming in the European Union (EU) varies considerably between producing countries, and in some cases even between farms within the same country and/or region (Camarsa, et al., 2010).

2.3. THE OLIVE OIL SECTOR IN GREECE

Greece is the third olive oil producer in the world. For the period 2017-2018 the Greek olive oil production is expected to reach 346 ('000 tonnes), or 16% of total global production (IOC, 2018). Its plantations cover an area of about 16% of total European Union (EU) (Eurostat, 2017). Domestically, production is dominated by the region of *Peloponnese*, followed by the *Island of Crete*, and the *Ionian Islands* (IOC, 2012). The country is, also, the third largest exporter, at international and European Union (EU) level. For the period 2017-2018, Greek olive oil exports are expected to reach 143 ('000 tonnes), of which, 133 ('000 tonnes) within the European Union (EU), thus obtaining a market share of 9% and 14% respectively (European Commission, 2018). In 2017, olive oil represented 11% of total Greek agricultural output (European Commission, 2017).

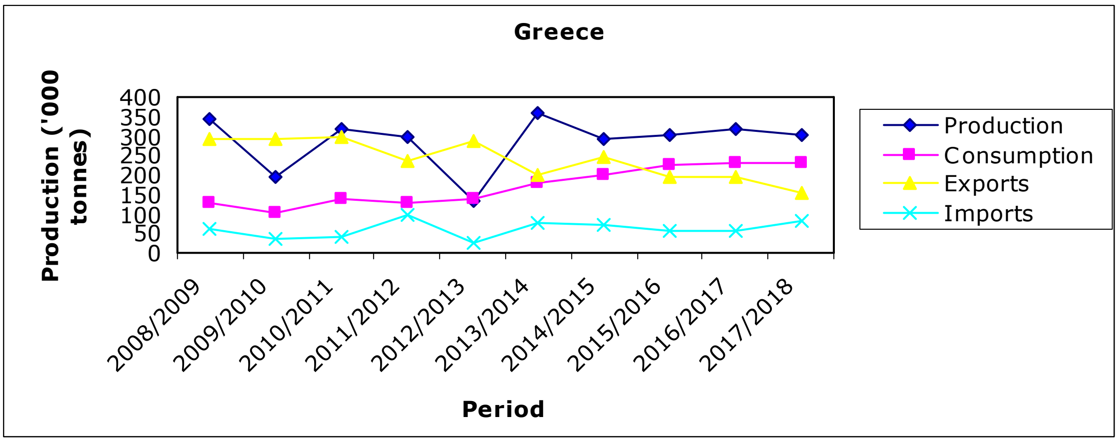

Figure 2.5.: Key Olive Oil Figures, Greece (IOC, 2018)

After the country's accession into the European Union (EU) in 1981, the Greek olive oil sector has been reformed (Beaufoy, 2001). Excessive financial contributions received under the *Common Agriculture Policy (CAP)* increased the number of olive groves in the country, with new producing areas emerging (Beaufoy, 2001). Traditionally, olive groves were situated in mountainous areas, such as the *Chalkidiki Peninsula* (IOC, 2012). Soon production expanded to semi-mountainous and coastal areas, such as the

Regions of *Messinia* and *Ilia* in the *Peloponnese*, the regions of *Iraklio* and *Chania* in Crete and *Corfu Island* in the *Ionian Sea* (Beaufoy, 2001). *CAP* financial rewards motivated Greek farmers to increase production. As a result, traditional farming practices were discarded in favour of mechanised and intensified ones. *Irrigation* became widespread. However, there still exists a considerable proportion of olive oil production that takes place under traditional practices, mainly, in small islands, or remote areas, due to socio-economic reasons, such as ageing population. Improved cultivation practices have, also, contributed to the structural reform of the sector. Traditionally, olive trees were planted in farms with mixed cultivars. Over the years, this practice has been abandoned for a single type of olive species (Beaufoy, 2001). The industrial practices of olive oil have, also, undergone structural changes and have shifted from traditional *Pressure* processes to *Three-phase Systems* processes, which, although they are more efficient, they generate more waste and wastewater (both systems will be analysed in detail in following sections). The industrial process of olive oil takes place in *Olive Mills (OM)*. *OMs* in Greece are, generally, *Small to Medium Enterprises (SMEs).* While their number approximates 2.200, most of them do not bottle or market olive oil. Therefore, Greek market is dominated by a few corporate groups (European Commission, 2012).

2.4. THE OLIVE OIL SECTOR IN SPAIN

With *58%* out of total global production, Spain is the largest olive oil producer in the world. For the period 2017-2018 the Spanish olive oil production is expected to reach 1.251 (‘000 tonnes) (IOC, 2018). Its plantations cover an area of about 53% of those within the European Union (Eurostat, 2017). Domestically, production is dominated by the region of *Andalusia*, followed by *Castilla La-Mancha*, *Extremadura* and *Catalonia* (IOC, 2012).

Figure 2.6.: Olive Oil Producing Regions in Spain (IOC, 2012)

The country is, also, the largest exporter, at international and European Union (EU) level. For the period 2017-2018, Spanish olive oil exports are expected to reach 900 (‘000 tonnes), of which, 596 (‘000 tonnes) within the European Union (EU), thus, obtaining a market share of 59% and 62% respectively (European Commission, 2018). In 2017, olive oil output represented 6.8% of total Spanish agricultural output (European Commission, 2017).

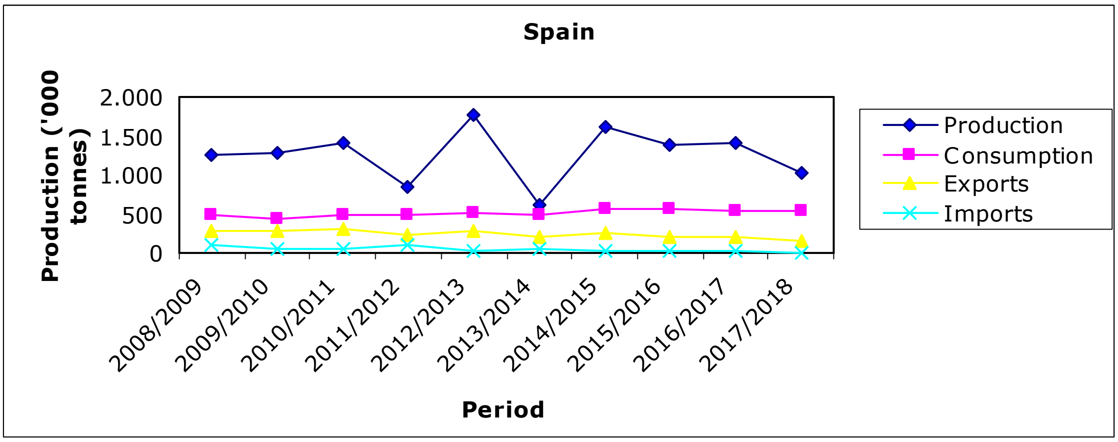

Figure 2.7.: Key Olive Oil Figures, Spain (IOC, 2018)

After the country’s accession to the European Union (EU) in 1986, the domestic olive oil sector experienced structural changes. In Spain, olive plantations had reached their pick by the mid-1960s, followed by a period of abandonment, mainly due to national subsidies being directed towards other cultivars, until the mid-1980s. The application of the *Common Agriculture Policy (CAP)*, which, at the time, heavily subsidised olive cultivation, gave Spanish farmers the incentive to shift back to such crops (Beaufoy, 2001). Consequently, increase in olive groves resulted in increase in olive production (Guzmán and Alonso, 2008) and under *CAP* practices, more agricultural output favoured more financial compensation. To maintain and improve production levels, *Cultivation* (but organic) was intensified, *Irrigation* became widespread and the use of chemical fertilisers and pesticides increased (Guzmán and Alonso, 2008). Intensive plantation practices, also, changed plantation characteristics, Most Spanish holdings moved from low to high density systems. Although *Harvesting* remained a manual activity for the majority of plantations, in new ones it became mechanised (Beaufoy, 2001). The industrial practices of olive oil have, also, undergone structural changes and have shifted from traditional *Pressure* processes to *Two-phase Systems* processes, which, although they are more efficient they generate more waste and wastewater (both systems will be analysed in detail in following sections). The industrial process of olive oil takes place in *Olive Mills (OM)*. Their number is estimated at about 1.700 (of which about 950 are *Cooperatives*), with most of them not bottling or marketing olive oil. Therefore, local market is dominated by a few corporate groups (European Commission, 2012).

2.5. THE OLIVE OIL SUPPLY CHAIN

2.5.1. Types of Olive Oil

According to the International Oil Council (IOC), olive oils obtained from the olive tree, either mechanically or other physical means and "under, particularly thermal conditions, that do not lead to alterations in the oil, and which have not undergone any treatment other than washing, decantation, centrifugation and filtration" are named *virgin olive oils* and they are the only ones that can be consumed. Based on the level of acidity, all other characteristics complying with IOC requirements, *virgin olive oils* can be categorised as:

- *extra virgin olive oil*: high quality *virgin olive oil* of no more than 0.8 per 100 grammes of free acidity, expressed as oleic acid
- *virgin olive oil*: *virgin olive oil* of no more than 2.0 per 100 grammes of free acidity, expressed as oleic acid
- *ordinary virgin olive oil*: *virgin olive oil* of no more than 3.3 per 100 grammes of free acidity, expressed as oleic acid

The above types of *virgin olive oils* may be sold directly to consumers, if permitted by country of retail sale. If not, the product has to comply with national legislation (IOC, 2018).

- *virgin olive oil not fit for consumption or lampante virgin olive oil*: *virgin olive oil* of more than 3.3 per 100 grammes of free acidity, expressed as oleic acid, all other characteristics complying with IOC requirements

It may be used for refining or for technical use (IOC, 2018).

- *refined olive oil*: obtained from *virgin olive oils* by refining methods which do not lead to alterations of its initial glyceridic structure and of no more than 3.3 per 100 grammes of free acidity, expressed as oleic acid, all other characteristics complying with IOC requirements

It may be sold directly to consumers, if permitted by country of retail sale (IOC, 2018).

- *olive oil*: mix of *refined olive oil* and *virgin olive oils*, suitable for consumption as they are, of no more than 1.0 per 100 grammes of free acidity, expressed as oleic acid, all other characteristics complying with IOC requirements

The country of retail sale may apply more specific requirements (IOC, 2018).

- *olive pomace oil*: obtained after the treatment of olive pomace with solvents, or other physical treatments, so as to exclude oils obtained by re-esterification processes and of any mixture with oils of other kinds. It can be further categorised as:
- *crude olive pomace oil*: all of its characteristics comply with IOC requirements. It is used for refining, human consumption and technical use
- *refined olive pomace oil*: obtained from *crude olive pomace oil* by refining methods which do not lead to alterations of its initial glyceridic structure and of no more than 0.3 per 100 grammes of free acidity, expressed as oleic acid, all other characteristics complying with IOC requirements. It may be sold directly to consumers, if permitted by country of retail sale
- *olive pomace oil*: mix of *refined olive pomace* and *virgin olive oils*, suitable for consumption as they are, of no more than 1.0 per 100 grammes of free acidity, expressed as oleic acid, all other characteristics complying with IOC requirements. The country of retail sale may apply more specific requirements (IOC, 2018).

2.5.2. Phases of the Olive Oil Supply Chain

According to Christopher (2011) a supply chain can be defined as a "network of connected and interdependent organisations mutually and co-operatively working together to control, manage and improve the flow of materials and information from suppliers to end users". In the context of olive oil its supply chain can be described as per below phases (Salomone, et al., 2015):

Agricultural Phase: the first phase of the olive oil lifecycle includes olive tree *Growing* and *Harvesting* processes. The *Growing* process can be further analysed into several sub-process, such as *Soil Management*, *Irrigation, Fertilisation*, *Pest Control* and *Pruning.* Differences in the first four sub-processes derive from the adoption of different farming methods. The most commonly identified, among farmers in the European Union (EU), are *(*Salomone, et al., 2015):

- *Traditional or Extensive*: farming systems requiring high input of labour and low input of resources. In such systems, soil is neither fertilised nor irrigated. Usually, traditional systems can be applied either on mountainous, low-density plantations (less than 140 tree per hectare), or large-sized trees (Russo, et al., 2016), often of ancient origin (Camarsa, et al., 2010). Furthermore, these systems allow for the grazing of animals under the olive trees, which gives them high natural value in terms of biodiversity and landscape, and a positive environmental impact (Camarsa, et al., 2010). However, these systems are characterised by low productivity and limited profitability (Russo, et al., 2016), which makes them subject to abandonment (Camarsa, et al., 2010).
- *Semi-intensive*: these systems require some use of chemical *Fertilisers* and *Pesticides* for *Pest Control*. *Weed Control* is carried out, either by *Tillage* or the use of *Herbicides*. Typically, in such systems soil is irrigated, while *Harvesting* can be performed, either mechanically or semi-mechanically. *Semi-intensive* systems are applied on high-density plantations (from 140 to 399 trees per hectare) (Russo, et al. 2016).

Figure 2.8.: Intensive Plantation (Ecoil, 2006)

- *Super-intensive:* these systems require high use of chemical *Fertilisers* and *Pesticides* for *Pest Control,* while water consumption, to meet *Irrigation* demand is particularly high. In *Super-intensive* systems *Growing* and *Harvesting* are completely mechanised procedures. Usually, such practices are applied in very high-density plantations (up to 2.500 trees per hectare), located at flat areas (Russo, et al., 2016). Although, *Super-intensive* systems may contribute to decreases in production costs, they can cause higher environmental impacts, due to the increased use of *Fertilisers* and *Pesticides*, the *Mechanisation* of production (Romero-Gamez, et al., 2017), or the extensive use of *Water Resources* (Camarsa, et al., 2010).

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Figure 2.9.: Intensive Plantation (Ecoil, 2006)

- *Organic:* these systems do not use any type of chemical *Fertilisers*, or *Pesticides* and operate under strict standards. Though, they, currently, hold a small proportion of olive farms among Member States, they are steadily increasing, given the fact that the European Union (EU) is actively engaged in the promotion of organic agriculture. However, it must be noted that they may require higher subsidies to become competitive (Camarsa, et al., 2010).

Pruning is an important factor in olive tree cultivation, since it allows the tree to adjust to the specific area's climatic and soil condition and increases the farm productivity. Three main *Pruning* practices are identified:

- at *Early Stages* of tree growing: to develop the tree shape during the first years of plantation and facilitate successive practices (*Cultivation, Irrigation and Harvesting*)
- for *Fruiting*: to induce branches that will bear fruits in upcoming years
- for *Rejuvenation*: to ensure its longevity (Roussos, 2018).

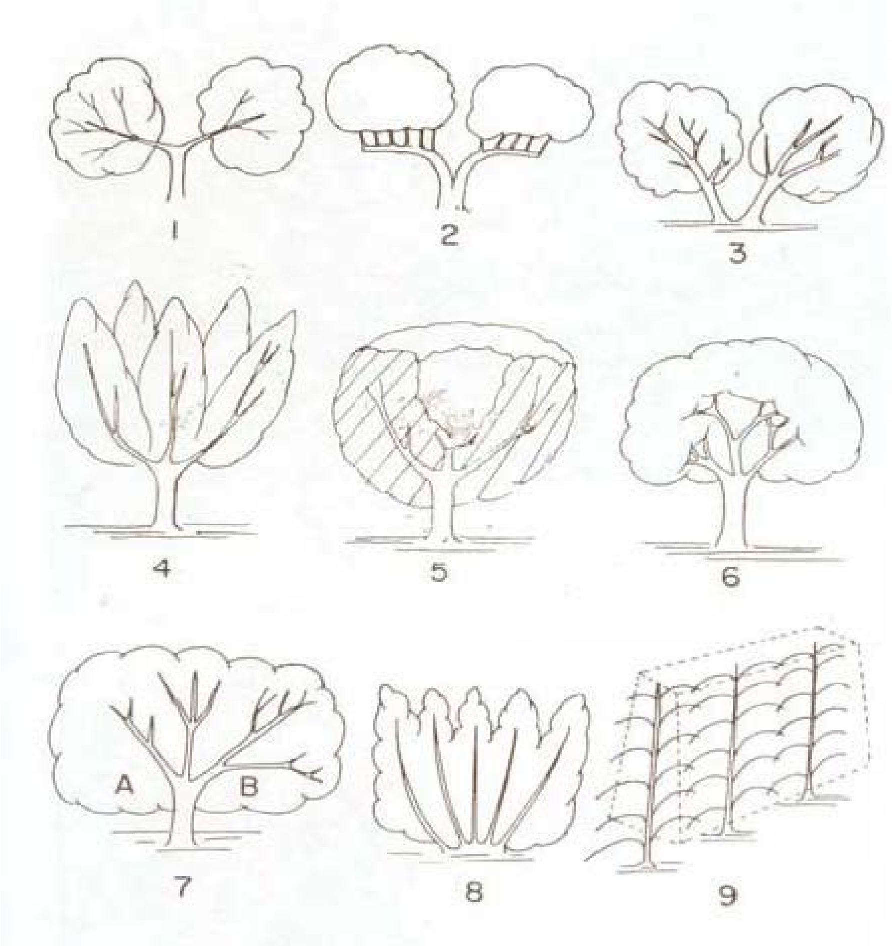


Figure 2.10.: Types of Pruning (Ecoil, 2006)

The *Harvesting* sub-process holds a critical position in the olive oil supply chain, as the method used can affect the acidity level of olives (Salomone, et al., 2015) and, consequently the type of olive oil that will be later produced. Preferably, *Harvesting* should be exercised manually, however such a method is rather expensive. Mechanical *Harvesting*, if exercised cautiously, can provide satisfactory results. When *Harvesting* is completed the next step is to transfer the olives to the *Olive Mill (OM)* within 24 hours to avoid *Fermentation* (Salomone, et al., 2015) for the next phase of the supply chain.

Production Phase: the *Production Phase* can be further separated into the sub-phases of *Preparation* of a homogenous *Paste*, *Extraction* of *Oil* from the olive fruit and *Packaging* (Salomone, et al., 2015). The *Preparation* sub-phase can be further divided into: *Olive Washing, Crushing, Mixing (*or *Malaxation) (*Kappelakis, et al., 2008).

- *Washing*: after the olives have been collected from the olive fruit, they are placed into a large feeding hopper attached to a moving belt. There, any remaining unnecessary material, such as leaves, or dust that may affect product quality (for example its taste) or harm machineries is removed through washing *(*Kappelakis, et al., 2008). *Washing* is, also, used as a means of *Pesticides* and dirt removal (El Abbassi, et al., 2017).

Figure 2.11.: Olive Washing (Ecoil, 2018)

- *Crushing:* critical to the overall extraction process, since it affects the quality of the final product (El Abbassi, et al., 2017), *Crushing* involves the process of releasing the oil from the vacuoles, by tearing the cells *(*Kappelakis, et al., 2008). The process produces a liquid mixture of oil and water and a solid mixture of pit, skin and pulp fragment (El Abbassi, et al., 2017). For this sub-process olives are placed on a large bowl with two or three heavy wheels rotating at high speeds, which crush them *(*Kappelakis, et al., 2008).
- *Mixing or Malaxation:* during this sub-process the previously created olive paste is mixed by stirring for approximately thirty minutes at a slow and constant pace. *Mixing* ensures that the highest percentage of available oil will be achieved. Additionally ensured, is the transformation of small oil drops into larger ones, so as to facilitate the distinction of the oil and water mixture generated at the previous phase. Malaxators vary in size, shape and format, per *Olive Mill (OM)* and are made by stainless steel. They can be classified as vertical or horizontal. The use of vertical malaxators is not as widespread, due to the demand of additional access requirements (Kappelakis, et al., 2008).
- *Olive Oil Extraction:* the final production sub-process involves the separation of oil from any remaining components of all previous phases and its actual extraction. Two different extraction practices may be applied *(*Kappelakis, et al., 2008):
- *Pressure Process:* this is the oldest extraction practice *(*Kappelakis, et al., 2008) and in some cases, still used, especially in small mills, using hydraulic presses (Salomone, et al., 2015). The paste is placed between pressing mats with an aim to eject the mixture of oil and water, followed by its rest into a tank, so that gravity and the different densities separate the two. Since this process does not require water use the amount of waste generated is minimal. The end products include *Oil*, *Dry Pomace* and *Oil Water* (Prosodol, 2012).
- *Centrifiguration Process:* extraction is based on the different densities of components constituting the olive paste created at the *Mixing* sub-process. A horizontal centrifuge or decanter ensures their separation. The olive oil to be extracted is either in the form of small drops (inside micro-gels, or emulsified in the aqueous phase) or free. Free

olive oil is separated by the decanter, while the oil in the micro-gel is released with the addition of water *(*Kappelakis, et al., 2008).
The output is a mix of *Olive Pomace* or *Husk* or and *Olive Oil*, which is mechanically separated from the *Wastewate*r produced (Salomone, et al., 2015).
Centrifigure Systems can be further categorised in:
- *three-phase systems*: the process involves a three-phase decanter. Within these systems water and paste are inserted into a horizontal centrifugal machine so as to be separated. Any unpurified oils are, in turn, inserted into a vertical centrifugal machine, where oil is separated from wastewater (vegetable water). At the end of the process three fractions are generated: *Oil, Olive Pomace* or *Husk* and *Wastewater,* known as *Olive Mill Wastewater* (*OMWW*) (Prosodol, 2012). Although, such systems have some advantage over the traditional *Pressure Process* ones, they demand higher energy consumption and water use (Salomone, et al., 2015).
- *two-phase systems*: similar to *three-phase*, *two-phase systems* involve a two-phase decanter. The extraction process remains the same, the only difference being that the quantity of water inserted into the decanter is minimum and water is recycled. The output produced is *Oil* and *Humid Pomace*, also, known as *Two-Phase Olive Mill Wastewater* (*TPOMWW),* which is not considered to have the same environmental effect as *Olive Mill Wastewater* (*OMWW)*. The adverse effect of *TPOMWW* generation is that, it is dried on site, with the drying process being expensive and produces *Greenhouse Gases* (*GHGs*) and fumes (Prosodol, 2012).

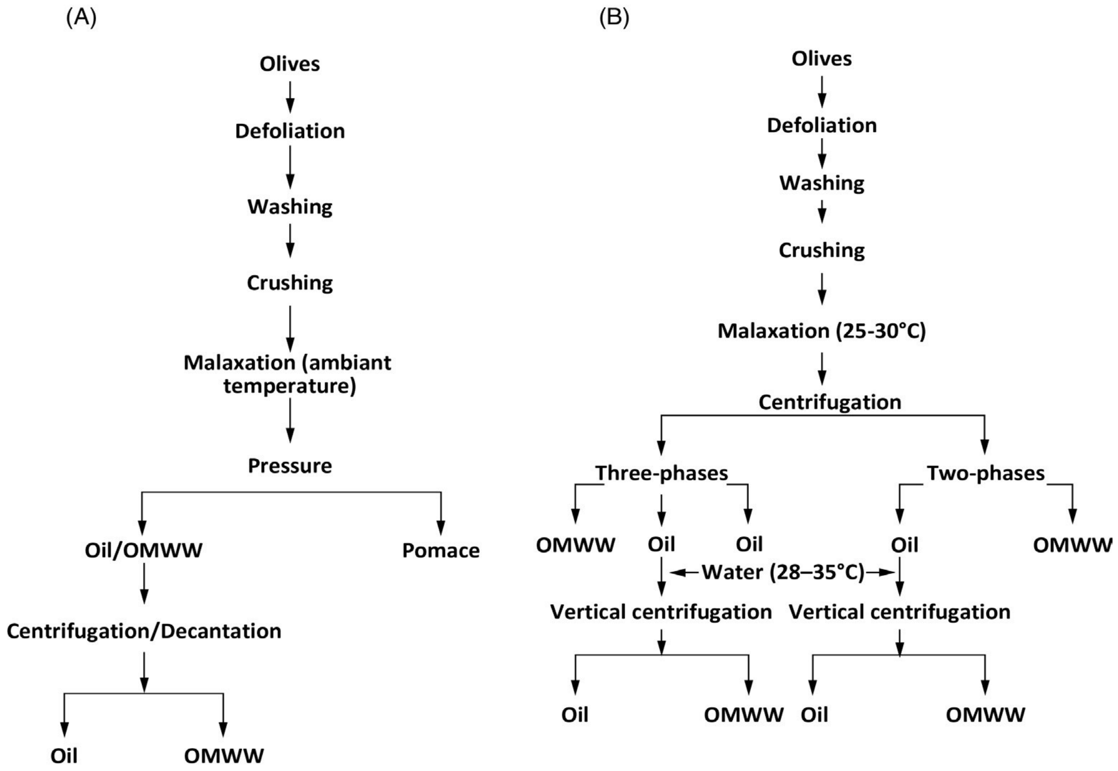


Figure 2.12.: Olive Oil Extraction Process: (A) Pressure Process, (B) Centrifiguration Process (El Abbassi et al, 2017)

Salomone, et al. (2015) identify two additional extraction practices, namely *two and a half or modified* or *water-saving systems* and *extraction from de-stoned olives.*

- *two and a half or modified* or *water-saving systems*: bridge the gap between *two* and *three-phase ones*. They combine the advantages of the previous two systems, in terms of water consumption minimisation and *Olive Mills Wastewater (OMWW)* generation (Salomone, et al., 2015).
- *extraction from de-stoned olives*: during this process removal of the pits occurs before the kneading. The process can be applied both in *two-phase and three-phase Centrifigural Systems*. Some researchers (Del Caro, et al. 2006, Pattara, et al. 2010) argue that this can result in improved virgin-olive oil quality, while others (Di Giovacchino, 2010) argues that lower yields are produced (Salomone, et al., 2015).
- *Packaging*: only a small fraction of *Olive Mills (OM)* bottle olive oil under their own label. Most of it is sold unbottled, either to bottling companies or directly to consumers. Generally, olive oil is bottled in steel containers or glass bottles (Salomone, et al., 2015).

By-Products Management: critical to the olive oil supply chain, by-product management has been given much attention during the last years, since the level of by-product environmental effect depends, largely, on the different systems applied during the production process (Salomone, et al., 2015). During the olive *Life Cycle* three by-products are generated: small *Branches* and *Leaves, Olive Pomace* and *Olive Mill Wastewater (OMWW)*. *Olive Pomace* has some commercial value which depends on the quantity of oil and water. *Three-phase systems* produce low-moisture *Pomace*, which is more commercially valuable, compared to that of *two-phase systems (*Kappelakis, et al., 2008). For its extraction, *Pomace,* is mixed with solvents so as to release any oil waste. *Pomace* and *Oil* are separated through filtration. *Oil* is, then, distilled and may undergo further processing, such as *Refining* (Salomone, et al., 2015). Compared to *Pomace*, *Olive Mill Wastewater (OMWW)* poses a much higher threat to the environment. *OMWW* is a liquid of dark red to black colour, of mild acidity and high conductivity, which is produced during the olive oil *Production Phase (*Kappelakis, et al., 2008). It may cause the colouring of natural waters, changes in soil quality, phytotoxicity, or odour nuisance (Salomone, et al., 2015). In recent years, much attention has been given to its management since: a. increase in global olive oil production has increased the amount of *OMWW* generated, b. adoption by many *Olive Mills* (*OM*) of *three-phase systems* which generate such waste, c. geographic dispersion of many small *Olive Mills (OM)* in olive producing countries and d. increased public attention to environmental issues *(*Kappelakis, et al., 2008).

Given that *Olive Mill Wastewater (OMWW)* components vary in nature, numerous methods have been suggested for their treatment, based on biological, physical, and physico-chemical methods, the most commonly used being: *Biological Treatment (Aerobic* and *Anaerobic* processes*)* to degrade pollutants found in water, *Physico-Chemical Treatment* (*Thermal* and *Distillation* and *Evaporation* processes, *Combustion* or *Incineration*, *Flocculation-Clarification, Fenton Reaction, Absorption and Ion Exchange*) and *Natural Treatment (*Application of O*MWW* as *Fertilisers*, *Application of OMWW* to crops to improve their characteristics). However, caution must be taken when applying *Natural Treatment* processes, as careful planning and knowledge of side effects ensure that no adverse environmental impacts occur *(*Kappelakis, et al., 2008).

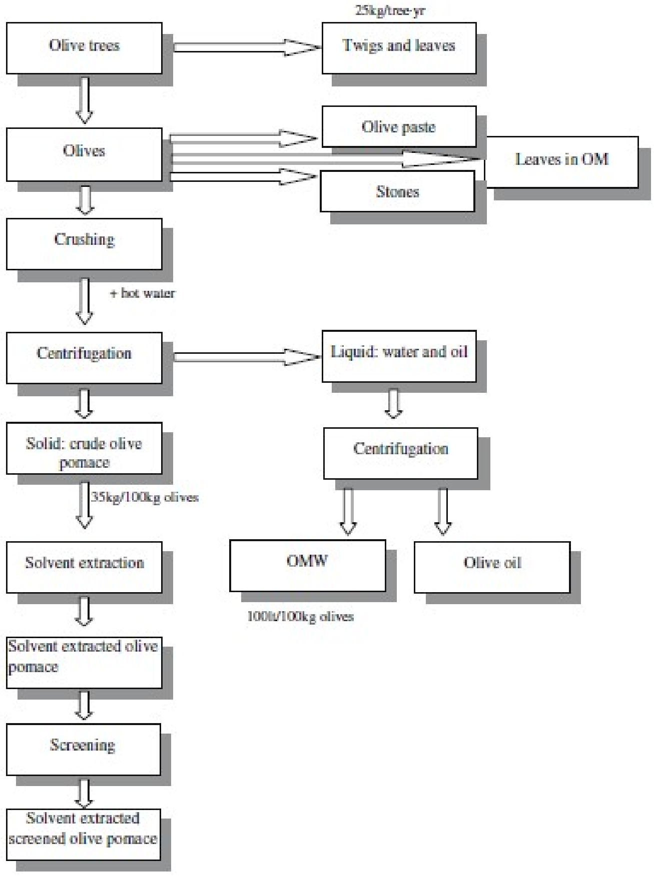


Figure 2.13.: By-products of the Olive Oil Production Process (Kappelakis et al., 2008)

Transportation and Distribution Phase: this phase includes any *Transportation* activity throughout the product lifecycle (from *Raw Materials* to *Waste*) and its *Distribution* to local, regional, national or international markets (Salomone, et al., 2015).
*Consume or Use Phase***:** activities related to consumer product use are included. Russo et al. (2016) provide indicative olive oil uses such as *Salad Dressing, Deep Frying* and *Cooking*. *Use* phase is not considered to severely affect the supply chain (Salomone, et al., 2015).
Waste Management Phase: this phase refers to the management of packaging waste (bottles, cardboard boxes, etc.). It holds an important role in the olive oil supply chain, since the method of disposal (reuse, recycle, landfill) causes different environmental effects (Salomone, et al., 2015).

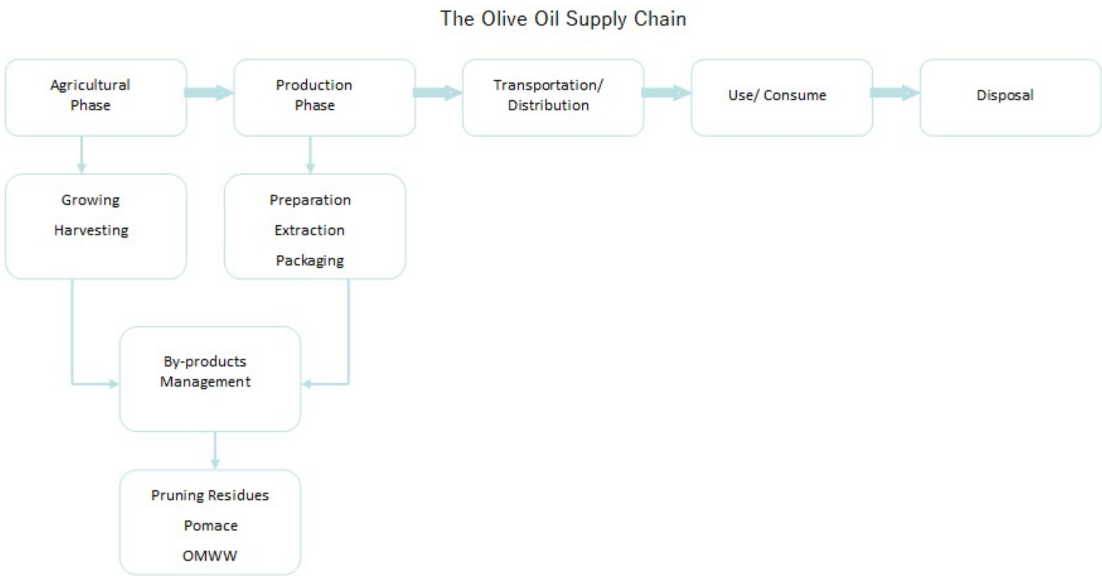


Figure 2.14.: The Olive Oil Supply Chain (Salomone, et al., 2015)

2.6. OLIVE OIL POLICY FRAMEWORK

2.6.1. International Olive Oil Regime: The International Olive Council

The *International Olive Council* (IOC) is a global intergovernmental organisation, founded in 1959 under the auspices of the *United Nations* (*UN*) and the *International Olive Oil Council* (*IOOC*). Set in Madrid, Spain, IOC's mission is to contribute to the "sustainable and responsible development of olive growing" (IOC, 2018). Membership is open only to *Governments, States* and *International Organisations* with an authority and responsibility to negotiate international agreements. The *European Union (EU)* has been a member since 2016, as one entity, rather as individual countries (IOC, 2018).

The *Council* is governed by three distinct *Bodies*: the *Council of Members and* Committees, the *Chairperson of the Organisation* and the *Executive Secretariat. The Council of Members* is the principal decision *Body,* consisting of one delegate per *Member*. The *Council* may set up as many *Committees* as it wishes. Currently, there are five *Committees*: the *Administrative and Financial Affairs*, the *Chemistry and Standardisation*, the *Technology and Environment,* the *Economic and Promotion* and the *Advisory* Committee on olive oil and table olives. The role of *Committees* is the preparation of proposals and of four-year action plans, which are then submitted to the *Council of Members* for review and decision. The *Chairperson* is elected every year and is assisted by a *Vice-President* who succeeds the *Chairperson* in power for the next year. Finally, the *Executive Secretariat* ensures the implementation of decisions and strategic path. The *Secretariat* comprises of five *Units*: the *Administrative Management and Human Resources,* the *Financial Management*, the *Promotion and Economic Affairs*, the *Standardisation and Research,* the *Olive Growing,* the *Olive Oil Technology and Environment* and the *Internal Controller* Unit, in addition to the *Office of the Executive Director* and the *Observatory and Information Systems*, the *Legal* and the *Translation Departments* (IOC, 2018).

As for the Council's responsibilities, these include the:
- encouragement of international cooperation in *Research and Development, Training* and *Knowledge Transfer*
- encouragement of *Trade Activities*
- update of product *Trade Standards* and the improvement quality
- rationalisation of the environmental footprint of the olive and olive oil supply chain
- promotion of global consumption campaigns and action plans
- provision of market data and statistics
- encouragement of discussion of market-related concerns
- collaboration with the private sector (IOC, 2018).

Since 1995, under the *International Olive Oil Regime*, six *Agreements* on olive and olive oil supply chain have been adopted, with the latest one entering into force in 2015. Following its ratification in 2017, it has been signed by 14 parties, including the newly accepted State of Palestine. The *Agreement* will remain in force until 31 December 2026 (Rossi, 2017). The sixth *Amendment of the Agreement* has been prepared with a purpose to design a "modern, more efficient Organisation, which can better respond to the continuous globalisation and evolution of the olive market" (European Commission, 2015). It, also, caters for changes in the operational and decision making process of the *International Olive Council,* given the entrance in new consumer markets (European Commission, 2015).

2.6.2. The European Union Policy Framework

The agri-food industry is one of the most important economic and political sectors within the European Union (EU), with significant implications on economic growth, the natural environment and quality of human life (Iakovou, et al., 2014). Rising environmental, social and ethical concerns and increased awareness on the impacts of production and consumption of agri-food products expressed by consumer and advocacy groups have increased the pressure on policy makers and industry stakeholders to identify and manage them (Iakovou, et al., 2014). As a result, the agri-food market has become one of the most regulated and protected industries in the *European Single Market* (Iakovou, et al., 2014). Consequently, olive oil production has followed the trend.

The European Union (EU) olive oil sector is managed by various *Legislations*, covering regulating issues in different areas of concern, such as *Quality, Marketing Standards, Financial Assistance* and *Waste Management.* The main objective of the European Union (EU) olive oil *Policy* is to "maintain and strengthen its position in world markets by encouraging production of a high quality product for the benefit of growers, processors, traders and consumers" (European Commission, 2012).

The main European Union (EU) *Legislation* related to olive oil production is elaborated in the next sections.

2.6.2.1. The Common Agriculture Policy (CAP)

In general, European Union (EU) *Legislation* on olive oil falls under the framework of the *Common Agricultural Policy (CAP). CAP* is a common policy, to which all Member States are subject, managed and funded at the European Union (EU) level from resources of its budget. It was firstly introduced in 1962 with an aim to:

- improve agricultural productivity
- support farmers in attaining and maintaining a fair standard of living
- ensure that consumers can purchase affordable agricultural products
- maintain rural areas and landscapes across the European Union (EU)
- assist in combating climate change and preserve natural resources
- sustainably manage natural resources
- strengthen rural economy, promote employment in farming, agri-food industry and associated sectors (European Commission, 2018).

2.6.2.2. Action Plan for the Olive Oil Sector

As part of the *Common Agriculture Policy*, a more specific *Action Plan for the Olive Oil Sector* was introduced in 2012, in an attempt to enhance its competitiveness and enforce its public image as a quality product (Rossi, 2017). The plan spans on six areas, all integrated into the revised *CAP* for the period 2014-2020 and includes measures on:
- *Quality and Control*: with provisions on quality control improvements and establishment of marketing standards
- *Sector Restructuring*: including rural development programmes that verify that region-specific demands are taken into consideration. Restructuring initiatives include support of investments that improve operating, marketing and product development activities
- *Market Rationalisation*: undertaking actions such as, mitigating imbalances across the production supply chain, or local producer organisations empowerment
- *Promotion of Marketing Campaigns*: for new markets entrance
- *Support of International Olive Oil Regimes and Organisations*: most notably the *International Olive Council* (*IOC*)
- *Respect of International Trade Practices:* such as refusing barriers to trade (European Commission, 2012).

Besides the abovementioned general policy and guidelines, a series of *Regulations* govern the olive oil market. Depending on the area they cover, these can be classified as:

2.6.2.3. Common Market Organisation (Regulation (EU) No 1308/2013)

The *Regulation* covers issues on the establishment of a *Common Market Organisation (CMO)* for the European Union (EU) agricultural markets and the identification of policy instruments to improve their functioning. The *Regulation*, also, sets specific clauses with respect to:
- assistance to grant private operators additional product storage in case of unforeseen circumstances
- financial assistance, in the form of three year programmes, to established producer organisations, so as to undertake marketing, environmental impact improvement, competitiveness and production quality initiatives (as detailed in *Regulation (EU) No 611/2014*)
- definition of marketing standards (*as explained in Regulation (EU) No 29/2012*), in the areas of labelling and packaging, as well as monitoring the application of those standards

- definition, designation and sales description (as explained in *Regulation (EEC) No 2568/91* and its successive amendments) on the characteristics of olive oil and olive residue oil, as well as on methods of analysis
- recognition of producer organisations (*Articles 159*), inter-branch organisations (*Articles 162*) and of the respective rules set when negotiating contracts on their members' behalf (*Articles 169*)
- trade-related matters such as, import-export licences, import tariffs (one particular case is the impose of an import quota for Tunisian olive oil, set under *Regulation (EC) No 1918/2006 and Commission Implementing Regulation (EU) 2016/605)* (Rossi, 2017).

2.6.2.4. Direct Payments-Voluntary Coupled Support (Regulation (EU) No 1307/2013)

The *Regulation* includes provisions on income support per hectare to Member State farmers, independent of production level, in the form of *Direct Payments*. Additionally, the *Regulation* caters for *State* voluntary income support, in case of unpredictable circumstances (as detailed in *Article 52 of Regulation (EU) No 1307/2013*). It must be noted that Italy is the only Member State that has not agreed on this voluntary scheme (Rossi, 2017).

2.6.2.5. Rural Development (Regulation (EU) No 1305/2013)

The *Regulation* proposes measures to support rural development, affecting either directly or indirectly the olive oil sector, such as, programmes dedicated to specific needs of areas of special interest, participation in quality certification schemes, investments in infrastructure upgrade, innovation and business development, conversion to organic farming, financial and insurance premiums and mutual funds contributions (Rossi, 2017).

2.6.2.6. Promotion of EU Farm Products (Regulation (EU) No 1144/2014)

As part of the *Regulation,* clauses on promoting sector-related products within the European Union (EU) and third countries are detailed (Rossi, 2017).

2.6.2.7. Disease Control (Council Directive 2000/29/EC)

The *Directive* includes provisions on the protection of European Union (EU) flora from harmful pests and diseases. When such pests and diseases are monitored, ad hoc, targeted *Legislation* may compliment the *Council's Directive*. One such case is *Commission Implementing Decision (EU) 2015/789* and its successive amendments with measures to manage the outbreak of the *Xylella Fastidiosa* bacterium in the Region of Puglia, in Southern Italy (Rossi, 2017).

2.6.2.8. Water Framework Directive (Directive 2000/60/E)

Water Management activities within the olive oil supply chain are governed by the *Water Framework Directive 2000/60/EC*, which provides general guidelines for the sustainable management of water resources, addressing water quality issues as well (Prosodol, 2012).

2.6.2.9. Urban Wastewater Treatment Directive (Directive 91/271/EEC)

Wastewater from olive oil production falls under the general *Urban Wastewater Treatment Directive 91/271/EEC*. The *Directive* includes provisions on the treatment and discharge of *Wastewater* from particular industrial sectors, including manufacture of fruit and vegetable products, to which olive oil production belongs. The *Directive*, also details actions related to the discharge of particular biodegradable industrial wastewater, under which *Olive Mill Wastewater (OMWW)* falls, so that it is not being discharged into receiving waters, before being appropriately treated (Prosodol, 2012). However, there can be some localities on the application of the *Directive*, at country level, which are discussed in the next two sections regarding Greece and Spain.

2.6.2.9.1. Greece

There is no specific legislation regarding *Olive Mill Wastewater (OMWW)* discharges in the country. The basis for *Olive Mill Wastewater* Management is defined in *Law 1650/86 ''For the Protection of the Environment''*, which imposes on *Olive Mill (OM)* owners to perform an *Environmental Impact Assessment (EIA). Olive Mill Wastewater* limits are not defined at national level, though under *Law 1180/1981*, *Benchmarking* values are established, passing the responsibility of *OMWW Management* to *Prefectures*, which, on their turn, are responsible to apply best practices. Moreover, under *Law 1650/86* discharges of untreated *Olive Mill (OM)* wastes to soil is not allowed. Finally, the 2011 *Joint Ministerial Decision (KYA) 145116/2011* regulates the reuse of treated *Wastewater* for several purposes, such as *Irrigation* in *Arable* lands *(*Inglezakis, et al., 2012).

2.6.2.9.2. Spain

Since 1981, Spain prohibits the discharge of untreated *Olive Mill Wastewater (OMWW)* into the aquatic environment. Matters relating to *Olive Mill Wastewater (OMWW)* are managed by *Ministerial Decrees.* Wastewater limits are defined, at national level, by *Real Decreto 849/86,* which sets emission limits for specific industrial sectors. Additionally, *Real Decreto 258/1999,* regarding water discharges into sea water, either directly, or through interior waters, and *Law 46/1999,* forbidding discharges of *OMWW* to hydraulic networks compliment *Olive Mill Wastewater (OMWW) Regulation* of the country *(*Inglezakis, et al., 2012).

2.6.2.10. Waste Framework Directive (Directive 2008/98/EC)

Regarding waste generated during the olive oil production process, most European Union (EU) regulations come in the form of *Legislative Acts*, providing, thus Member States the opportunity to enforce complimentary, national legislation, which in any case, must comply with EU guidelines. (Inglezakis, et al., 2012).

2.6.2.10.1. Waste Framework Directive

The fundamental *European Legislative Act* is the *Waste Framework Directive (2008/98/EC)*, into which, all previous, single *Regulations* on hazardous waste and waste oils have been integrated. Under the *Waste Framework Directive*, waste should be treated with the hierarchical order of: *Prevention, Reuse, Recycling, Recovery* (conversion to reusable form or incineration) and *Disposal* (Prosodol, 2012).

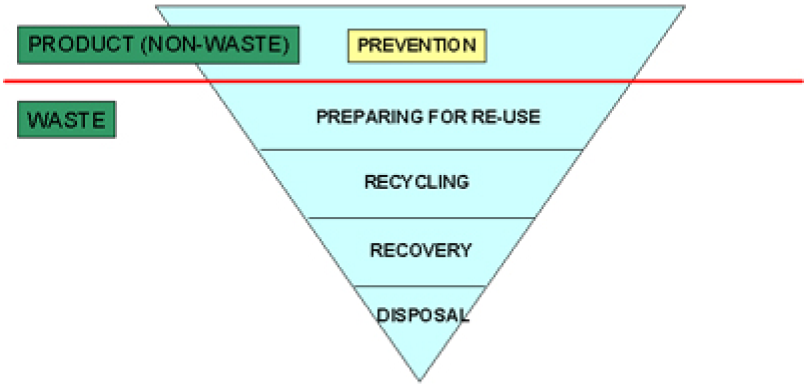


Figure 2.15.: The Waste Hierarchy (European Commission, 2018)

In case the *Disposal* option is landfill, which is the least preferable choice, it must be guaranteed that relevant actions fall under the *Landfill Directive 99/31/EC* that defines the types of waste and the landfill requirements for disposal (European Commission, 2016).

2.7. OLIVE OIL PRODUCTION ENVIRONMENTAL CONSIDERATIONS

The olive oil production chain is associated with various adverse environmental effects, mainly in the *Agricultural* and *Production* stages. Firstly, large quantities of by-products, such as residues and waste are produced. Moreover, both stages require the consumption of significant amount of natural resources and energy. Furthermore, the olive oil production chain involves additional sub-processes, such as *Soil Management*, *Fertilisation,* or *Transportation* both of the agricultural and end product, which add to the detrimental environmental effects (Avraamides and Fatta, 2008). Environmental issues identified throughout the olive oil lifecycle can be attributed to activities performed within each individual phase.
The most commonly identified are *Soil Erosion*, *Depletion of Scarce Water Resources,* pollution due to *Fertilisation* and *Pest Control*, *Loss of Biodiversity*, *Waste Generation*, *Olive Mill Wastewater* and *Energy Consumption* (Violaa and Marinelli, 2016). These are briefly discussed below:

2.7.1. Soil Erosion

Considered as one of the most critical environmental issues, *Soil Erosion* is associated with intensive *Farming* and *Harvesting* practices (Violaa and Marinelli, 2016). By nature, olive plantations produce yield every second year (Beaufoy, 2001). The introduction of intensive and super-intensive mechanised farming practices, in an attempt to satisfy the growing global olive oil demand, has achieved annual yield (Beaufoy, 2001). However, this intensive use of land can lead to *Soil Erosion*, which reduces soil productive capacity and, consequently production (Violaa and Marinelli, 2016). Furthermore, in intensified plantations, farmers tend to keep the soil clean of vegetation throughout the year, by means of mechanical *Tillage* or *Herbicides*. Although they ensure flat land, they expose soil to the erosive effects of rainfall. Additionally, they may increase soil vulnerability through the reduction of its organic matter (Dessane, 2003). In severe cases, *Soil Erosion* can, even, lead to land degradation (Camarsa, et al., 2010).

(A) (B)

Figure 2.16.: Soil Management by (A) Mechanical Tillage and (B) Application of Herbicides (Ecoil, 2006)

2.7.2. Water Consumption

Both the *Agricultural* and *Processing* phases of olive oil production require the consumption of significant amounts of water. In the *Agricultural* phase, this consumption, as will be discussed in the next sections, besides *Irrigation*, derives, also, from *Fertilisation* (Avraamides and Fatta, 2008), the effectiveness of which is severely improved by the addition of water (Violaa and Marinelli, 2016). Regarding the *Production* phase, water is required for the separation of oil from other components, as analysed in the supply chain section. It must be noted, that water consumption, at this stage, very much depends on the selected system. As previously stated, *two-phase systems* require minimum water consumption (El Abbassi, et al., 2017).

2.7.3. Irrigation

Since the olive tree is particularly resistant to dry conditions, traditional olive farms were only rainfed (Beaufoy, 2001). As time went by and became evident that even small quantities of water could assist in productivity increase and consistency, *Irrigation* was integrated into olive cultivation practices. The level of necessary *Irrigation* depends on the type of *Irrigation System* used, micro climate, soil conditions and tree density (Beaufoy, 2001). As the global demand for olive oil increases, the application of farm *Irrigation* increases, as well. However, this trend suggests that water resources, even scarce, are being consumed (Fernandez-Escobar, et al., 2013). Moreover, *Irrigation* demands the construction of water reservoirs to be used for agricultural purposes, even in areas with water scarcity, depriving it from local people, flora and fauna (Camarsa, et al., 2010).

Figure 2.17.: Olive Tree Irrigation (Ecoil, 2006)

2.7.4. Fertilisation

As previously stated, soil productive capacity and yield consistency can be sustained through the use of fertilisers. *Fertilisation* is a common practice in olive oil plantations, as it assists crops to obtain necessary nutrients for growth, when soil by itself cannot supply the required quantities (Fernandez-Escobar, et al., 2013). Overall, *Fertilisation* methods may be categorised as:

- *No Fertilisation*: this practice can be, still, met in some remote areas
- *Organic Fertilisation*: organic fertilisers can be obtained by animal manure, leaves, compost, or manufactured organic fertilisers
- *Chemical Fertilisation*: chemical fertilisers can be applied beneath tree canopy, either manually or mechanically. The most commonly used chemical fertilisers are Nitrogen (N), Phosphorus (P) and Potassium (K). *Chemical Fertilisation* has become, nowadays, the most widespread adopted practice

(A) (B)

Figure 2.18.: (A) Manual and (B) Mechanical Chemical Fertilisation (Ecoil, 2006)

- *Fertilisation* though *Irrigation Water* and *Leaf Sprays* (applied in modern systems) (Beaufoy, 2001).

In the end, fertilisers are discharged into water. Their excessive use, can therefore, pollute it (Dessane, 2003). This is particularly the case when the *Fertilisation* process is unplanned, with farmers not complying with guidelines or recommended fertiliser quantities (Camarsa, et al., 2010).
The pollution of water has an overall effect on the environment and human health. Animals consuming such waters are negatively affected, water living organisms may be extinct, nearby plantations may be polluted, as well, since polluted water may run through them, ultimately posing a threat on humans who consume both of them.

2.7.5. Pest Control

In traditional farming systems, *Pesticide* use is, if any, is relatively low. However, as we move towards more intensive farming systems, scheduled and repeated applications of inexpensive, chemical *Pesticide*s assure the viability of the plant. Relative costs may be further decreased by mixing *Pesticides* and *Fungicides* (organisms to kill parasites) to *Fertilisation* sprays (Beaufoy, 2001). Like fertilisers, the abovementioned chemicals are, again, discharged into water, thus polluting it. For similar reasons to fertiliser use, the environment and human health are endangered.

Figure 2.19.: Application of Pesticides (Ecoil, 2006)

2.7.6. Weed Control

Weed Control is an important farming process, which protects crops, from weeds, especially from loosing their moisture. In the early years of olive oil production, there was a tendency to use the undergrowth of olive plantations, either for cultivation of other crops or for grazing. Thus, *Weed Control* was performed either by cultivation and grazing or manually. As production patterns changed, traditional *Weed Control* was abandoned for mechanised *Tillage* and more recently *Herbicides* (Beaufoy, 2001). Earlier we discussed that such *Weed Control* practices, though they may ensure flat land, they expose soil to the erosive effects of rainfall and they may increase soil vulnerability (Dessane, 2003). To deal with such phenomena, farmers may resort to the use of fertilisers, which, in turn, harm the environment through their discharge into water.

2.7.7. Biodiversity

Biodiversity, particularly, in traditionally cultivated olive plantations, is high, with a plethora of flora and fauna identified. However, the need for increased and continued yield, that can be achieved through intensive and mechanised farming practices, have negatively impacted the local natural environment and habitats. Particularly, the excessive use of chemical *Fertilisers* and *Pesticides* has eliminated the animal and plant population within olive plantations (Camarsa, et al., 2010).

2.7.8. Energy Consumption

Although significant, *Energy Consumption* is not considered as the most critical environmental problem derived from olive oil production. The most commonly applied source of energy is electricity. In the *Agricultural* phase, energy consumption should be considered, mostly, in plantations where intensive farming practices are applied, since, typically, energy demand is high. Furthermore, in the *Production* phase, energy is consumed throughout the different stages of the olive oil industrial process and the overall operation of the *Olive Mill (OM). Energy Consumption* may, also, be measured as part of the *Transportation* and *Distribution* phases of the olive oil supply chain, especially in the form of fossil fuels consumption, but it is not perceived as a "pain point" in the olive oil lifecycle.

2.7.9. Waste

Waste produced as part of the olive oil process is separated in *Solid Waste* and *Olive Mill Wastewater (OMWW). Solid Waste* is generated during the *Agriculture* and *Production* phases in the form of *Pruning Residues* and *Olive Pomace (or Husk* or *Crude Olive Cake)* respectively, while *Olive Mill Wastewater (OMWW)* is generated within the *Production* phase*.*

2.7.9.1. Solid Waste

Solid Waste generated within the *Agriculture* phase is mostly *Branches* and *Leaves* as a result of tree *Pruning*. *Pruning* also generates larger *Logs*, which are usually, used as firewood. Although, *Pruning* acts against growth of certain pests and fungus and as a means to ensure tree health, there is not a common pruning practice (Rovas, et al., 2014). Usually, *Pruning Residues* are considered useless, with the majority of farmers collecting and burning them in the farm, releasing, therefore, CO_2 emissions into the atmosphere and producing *Biochar* and *Ash* (Gomez-Munoz, et al., 2016).

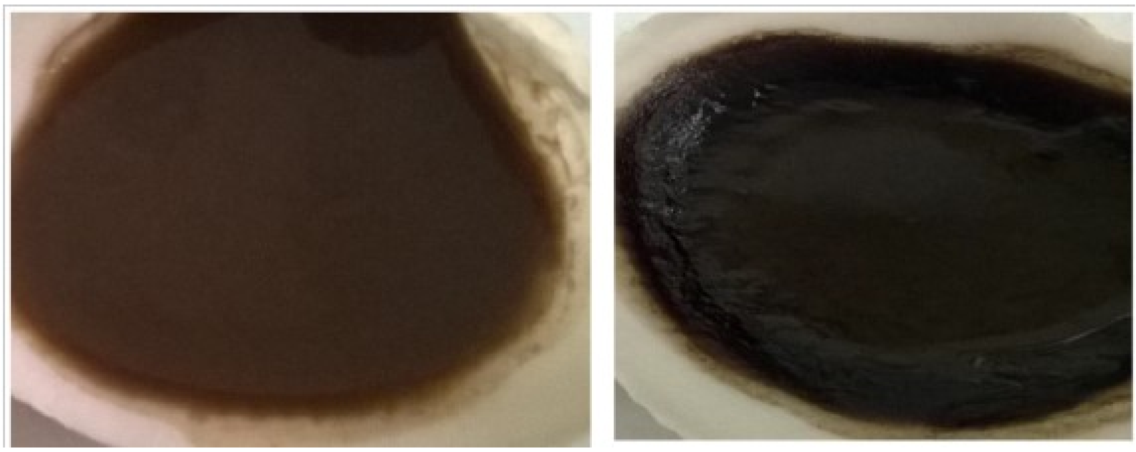
Figure 2.20.: Pruning Residues (Ecoil, 2006)

Solid Waste generated within the *Production* phase is a residual *Paste,* resulting from the *Oil Extraction* process. It is a mixture of *Olive Pit*, debris of *Olive Pulp* and *Skin*, *Pomace Olive Oil*, as well as the *Water* added in the *Olive Mill (OM)* as part of the *Extraction* process. The mix is of about 50-75% moisture depending on the olive oil production practice adopted. *Residual Paste* dries out very slowly, due to high mill *Wastewater* concentration and is environmentally polluting (Cossu, et al. 2013).

2.7.9.2. Olive Mill Wastewater (OMWW)

Olive Mill Wastewater (OMWW) comprises of *Water, Sugars, Nitrogenous Substances, Organic Acids, Pectins, Mucilages* and *Tannins, Lipids* and *Inorganic Substances*, of low biodegradability and high phytotoxicity due to the presence of a large amount of *Phenolic Compounds*, free *Fatty Acids* and *Inorganic Salts* (Zafra et al., 2006).
The main identified environmental impacts attributed to *OMWW* are:
- *effect on aquatic life:* when discharged into water*,* its oxygen availability is reduced, thus affecting the balance of the ecosystem. Moreover, since their concentration of *Nutrients* is high, it is possible for *Algae*, therefore *Eutrophication* to be developed *(*Kappelakis, et al., 2008).
- *odours:* as previously mentioned, after the completion of the *Agriculture* phase and just before the *Production* phase, harvested olives are transferred to the *Olive Mill (OM)* within 24 hours to avoid *Fermentation* (Salomone, et al., 2015). *Fermentation* can occur when *OMWW* is stored in open tanks, or when discharged to land or water. This may lead to the emission of *Methane* (CH_4)*, Hydrogen (H)* or *Sulphide* (S_2) among other gases and, consequently to odour pollution *(*Kappelakis, et al., 2008).
- *creation of an impenetrable film*: on the water surface, formed by *OMWW* lipids, which prevents water micro-organisms from sunlight and oxygen from, reducing, therefore, plant growth and increasing erosion (Kappelakis, et al., 2008).
- *discolouring of natural waters*: due to the oxidation and polymerisation of *Tannins*, which in turn, produce dark-coloured *Polyphenols*, difficult to remove from the effluent *(*Kappelakis, et al., 2008).

- *toxicity*: as a result of *Phytotoxic Volatile Acids* and *Phenolic Compounds (*Kappelakis, et al., 2008).



(A) (B)

Figure 2.21.: Olive Mil Wastewater (OMWW) (A) before and (B) after Treatment (Jeguirim et al., 2017)

2.8. SOCIO-ECONOMIC CONSIDERATIONS

Besides the environmental impacts of the olive oil supply chain, socio-economic considerations should not be neglected. In recent years, new producers, outside the Europe Union (EU), have entered the olive oil market, intensifying competition (Metzidakis, et al., 2008). Intensified competition, on the one hand leads to increased production, improved products and services, technological innovations, better production and process networks. On the other hand, these competitors pose a threat to European Union producers. Labour in non-European Union (Non-EU) countries is significantly lower than in European Union (EU) ones, which contributes to decreasing production costs and, ultimately, olive oil price. As a result, consumers preference may shift to the product of those markets, thus the traditional European Union (EU) olive oil market may suffer income losses throughout the supply chain, from farmers, to producers to distributors. To balance income losses, industry labour may decrease, (Metzidakis, et al., 2008) or product prises may rise.

Adding to the above, especially in the *Agricultural* phase, most of the human capital is employed, only for the *Harvesting* period, meaning that workers should be either employed in alternative crops or sectors for the remaining period. Furthermore, as previously discussed, over production leads to land over exploitation. To preserve lands, farmers must invest in specialised techniques. This implies either capital expenditure or income loss, which in turn, affects prices. As production costs rise, prices, also, tend to rise (Metzidakis, et al., 2008).

Finally, on the other hand, the sector can positively impact local economy and community. It is estimated that in the European Union (EU), alone, there are approximately 2.000 companies engaged in olives and olive oil-related activities (Awad, et al., 2006). One such case is the adoption of an innovative economic and business development model, that of “artisan” olive sector, which connects olive oil production with rural and cultural tourism. Tuscany in Italy is an example of such practice (Beaufoy, 2001).

2.9. LITERATURE REVIEW

Olive oil production is considered as one of the most significant agricultural sectors globally. Even more significant, is considered for Mediterranean countries, especially Spain, Italy and Greece, which are, also, the largest producers and exporters of olive oil in the world. For those countries, olive oil is associated with local economy, social life, tradition and culture. However, as its production requires the consumption of natural resources, it may cause adverse environmental effects.

Excessive research can be found on the identification of environmental impacts of olive oil production, in particular on those deriving from the *Agriculture* and *Production* phases and on the evaluation of their significance, through the use of specific tools and techniques, most notably *Life Cycle Assessment (LCA)*, which appears to be the most suitable method for the industry. Regarding the *Production* phase excessive literature can be found regarding waste generation and treatment, and in particular, the management of *Olive Mill Wastewater (OMWW)*. Finally, the vast majority of available literature is focused on countries in the Mediterranean basin, particularly Spain and Italy.

CHAPTER 3

THE LIFE CYCLE ASSESSMENT FRAMEWORK

3.1. LIFE CYCLE ASSESSMENT FRAMEWORK

The olive oil industry is an important global agro-industrial sector (Salomone, et al., 2015). Within each phase of its production process different techniques may be applied, depending on a series of factors such as, the geographic region, methods adopted, regulation enforced, climatic conditions, to name but a few (Beaufoy, 2001). Depending on these different procedures olive oil production may be associated with different environmental adverse effects (Salomone, et al., 2015). Therefore, the continuous monitoring and management of olive oil production-related *Environmental Impacts* has become imperative. On that note, various methodologies and tools have been developed and used, with *Life Cycle Assessment (LCA)* being one of the most commonly accepted by scientists and researchers and the one most commonly applied in the sector (Salomone, et al., 2015).

Life Cycle Assessment (LCA) is a methodology used to assess the potential environmental and human health impacts over the entire *Life Cycle* of a product, as well as to quantify the effects on resource stocks (Mendez da Luz, et al., 2018), by means of:

- *Inventory Compilation* of *Inputs* and *Outputs* relevant to a *Product System*
- *Assessment* of potential *Environmental Impacts* associated with those *Inputs* and *Outputs*
- *Interpretation* of the *Findings* of the *Inventory Analysis* and *Impact Assessment* in terms of the objectives of a study (ISO14040, 1997).

Life Cycle Assessment (LCA) is considered a valuable tool, since it addresses and assesses *Environmental Impacts* occurring throughout a product's *Life Cycle*, from *Raw Materials*, to *Production*, to *Distribution* to *Use* and, ultimately, to *Disposal*. *LCA* studies can, also, assist in:

- identifying "pain points" and opportunities for improvement of the environmental aspects of products at various points in their *Life Cycle*
- the decision-making process
- selecting relevant *Indicators* and *Measurement Techniques* of environmental performance
- *Marketing Techniques,* such as *Environmental Claim*, *Eco-Labelling*, or *Environmental Product Declaration (EPD)* (ISO14040, 1997).

The *International Standard Organisation (ISO)* suggests four phases to conduct a *Life Cycle Assessment* analysis: *Goal and Scope* definition, *Inventory Analysis (LCI)*, *Impact Assessment (LCIA)* and *Interpretation* of results.

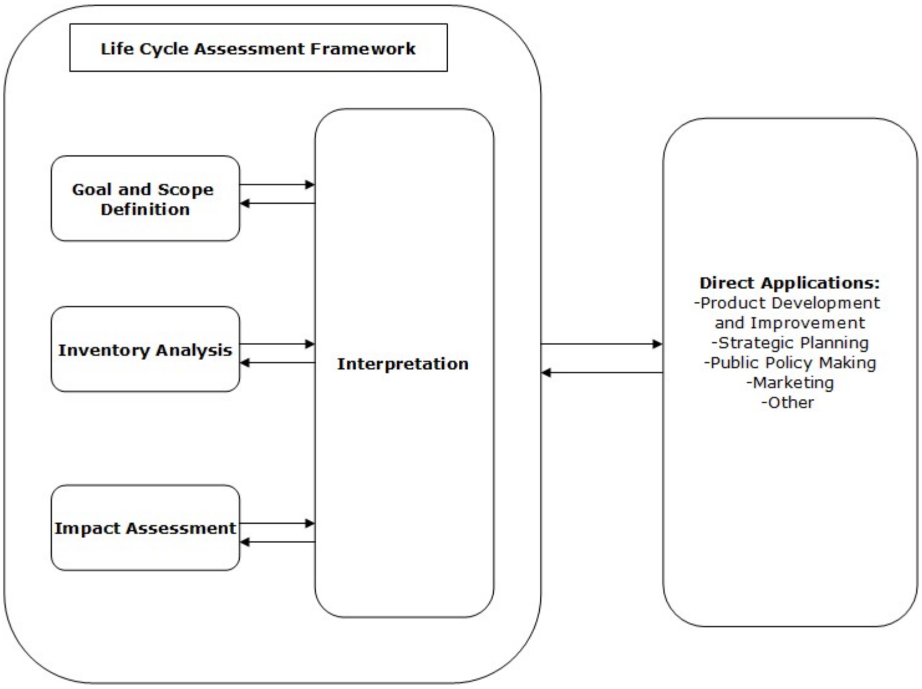


Figure 3.1.: The four phases of Life Cycle Assessment as defined by ISO Standard 14040 (ISO14040:2006)

3.1.1. Goal and Scope Definition

Goal and Scope definition is the first phase in an *LCA* study. It is the stage where the aim of the study is established. The *Goal* of an *LCA* study is to clearly define the intended application, the reasons for carrying it out and the intended audience results will be communicated to. When defining the *Scope* the following parameters must be taken into consideration:
- the *Functions* of the *Product System* (*s*) and the *Functional Unit*: a *Functional Unit* acts as a reference to which *Inputs* and *Outputs* of a *Product System* are related and a measure of the performance of the functional *Outputs*
- the *Product System* to be studied and its *Boundaries*: *Boundaries* determine the *Unit Processes* to be included in the *LCA* study
- *Allocation* procedures
- Types of impacts and *Methodology* of *Impact Assessment* and *Interpretation*, including:
- *Data Requirements*
- *Assumptions*
- *Limitations*, if any
- initial *Data Quality Requirements*: including time-related, geographical, technology coverage, precision, completeness and representativeness of data, consistency and reproducibility of methods used throughout the analysis, sources of data and their representativeness, uncertainty of information
- *Type of Critical Review*, if applicable: to verify whether a study has met the ISO requirements for methodology, data and reporting
- *Type* and *Format* of the *Report* required for the study

As *Life Cycle Assessment (LCA)* is a dynamic process, the *Scope* may be reviewed and revised (ISO14040, 1997).

3.1.2 Inventory Analysis (LCI)

Inventory Analysis (LCI) is the second phase of an *LCA* study and involves the *Collection of Data* and the *Quantification* of relevant *Inputs* and *Outputs*, such as use of resources, releases to air, water and soil, related to the *Product System*. The deliverables of the *Inventory Analysis* are used to feed the next phase of the *Life Cycle Assessment (LCA)* study, that of *Impact Assessment* (ISO14040, 1997).

3.1.3 Impact Assessment (LCIA)

In the *Impact Assessment (LCIA)* phase an *Interpretation* of the *Inventory Data* is attempted by assessing the *Significance* of potential *Environmental Impacts*. *Assessment* is achieved by associating *Inventory Data* with specific *Environmental Impacts*. The level of detail, choice of *Impacts* and *Methodologies* depends on the *Goal and Scope* of the study. As part of the dynamic *LCA* process, the *Goal and Scope* definition phase may be reviewed to determine whether the aim of the study has been achieved and if not, it should be revised. The *Impact Assessment* phase may, also, involve the following three activities:
- *Classification*: assignment of *Inventory Data* to *Impact Categories*
- *Characterisation*: modelling of *Inventory Data* within *Impact Categories* and
- *Weighting*: results' *Aggregation* in very specific cases, only when assessed as being meaningful (ISO14040, 1997).

3.1.4. Interpretation

The final phase of a *LCA* study, *Interpretation* combines, consistent with the defined *Goal and Scope*, the findings of, both, the *Inventory Analysis (LCI)* and the *Impact Assessment (LCIA)* phases to reach *Conclusions* and *Recommendations*. Similarly, the *Goal and Scope*, as well as the *Quality of Data* collected may be reviewed and/or revised (ISO14040, 1997).

3.2. SIMA PRO SOFTWARE

SimaPro is a software tool designed to perform *Life Cycle Assessment*. It is used by academic institutions, organisations and businesses in more than 80 countries around the world to *collect, analyse* and *monitor* the sustainability performance data of *products* and *services*. The software can be, also, used for several applications, ranging from *Sustainability Reporting*, *Carbon* and *Water Footprinting* to *Product Design*, the generation of *Environmental Product Declarations (EPDs)* and the determination of Key *Performance Indicators (KPIs*) (SimaPro, 2018).

CHAPTER 4

ENVIRONMENTAL IMPACT ASSESSMENT OF OLIVE OIL PRODUCTION: THE CASE STUDIES OF GREECE AND SPAIN

The section explores the practices adopted throughout the olive oil production chain in Greece and Spain, two of the major global olive oil producers, and assesses the environmental impacts deriving from it, through the analysis of two real-life *Case Studies*.

4.1. DATA COLLECTION

The data used in this study are obtained by *Ecoil*, a project, co-financed by the European Commission's environmental instrument, the *LIFE Programme*. The objective of the project was to design and implement, over a period of 24 months, a *Life Cycle Inventory (LCI)* and a *Life Cycle Assessment (LCA)* tool for the complete cycle of olive oil production in three different Mediterranean regions: *Voukolies-Crete, Greece*, *Lytrhodontas-Nicosia, Cyprus* and *Navarra-Aragon, Spain*. As part of the project the effects of olive oil production on the environment and public health were determined. Additionally, the stages within the product cycle that caused the most adverse effects were identified, with an aim to be optimised. Finally, the *Life Cycle Assessment (LCA)* methodology developed acted as a decision making tool, so as to apply the optimal practices within the olive oil production supply chain (Ecoil, 2006).

4.2. OLIVE OIL PRODUCTION IN GREECE: THE CASE STUDY OF VOUKOLIES, POLEMARCHI

4.2.1. Description of the Geographic Area

With a population of 574.286 (Elstat, 2011) and expanding in an area of *8.331* square kilometres (Ecoil, 2006), Crete is the largest island in Greece. The island consists of four Prefectures; *Iraklio, Chania, Rethimno* and *Lasithi*. Crete is one of the leading olive farming and olive oil producing areas in Greece, with olive holdings covering approximately *25%* of total island area and annual olive oil production exceeding *150.000* tonnes (Ecoil, 2006).

The area of Voukolies is located in the northwest part of the *Chania* Prefecture, expanding in an area of about *75.000* square kilometres, at an altitude of *110* metres (Ecoil, 2006). In the 2011 Census, its population was estimated at *3.189* (Elstat, 2011). The climate is temperate with north winds during winter and autumn and weak winds during summer (Ecoil, 2006). Temperature ranges between a minimum of *12*^{0}C during winter and a maximum *27*^{0}C during summer. Besides olives, typical local cultivations include citrus, vines and vegetables (Ecoil, 2006).

Figure 4.1.: Aerial photograph of Voukolies Region (Ecoil, 2006)

4.2.2. Olive Oil Production Practices

The most common olive variety cultivated in the region is called *Koroneiki* (or *Ladolia* or *Psilolia)*, covering approximately *85%* of the olive tree cultivation area. Favourable climatic conditions, particularly excessive sunlight and dry climate, as well as, technical expertise gained by local farmers throughout the years, have established the olive oil produced in the region as a product of superior quality (Ecoil, 2006).

Planting occurs during November and December, manually, with a mattock and a spade, by digging holes of dimensions *60x40* centimetres, so that the root of the planted tree has the same depth as in the nursery bucket, Soil, is then, applied to the digged hole and the tree is irrigated to increase yield (It should be noted that in the area under study, *40%* of total olive trees are not irrigated, *30%* is irrigated by wells water and the remaining *30%* by municipal water). The most applied *Irrigation* process is that of *Drip Irrigation*. It takes three years for the planted olive tree to produce and about six to seven years for the quality production to initiate. To ensure land productivity and consistency, local farmers exercise soil *Ploughing*, once a year (Ecoil, 2006).

Depending on growing conditions, olive trees may reach a height of ten meters, but typically, olive trees are pruned. *Pruning* occurs once a year and the adopted method adopted in the region is that of *Rejuvenation*, which involves very old and tall trees being cut, with a use of hand-held petrol chainsaw, at approximately 80-100 centimetres to improve their productivity. It is important to note, that as part of the *Pruning* process, considerable quantities of *Residues* (*Branches*) are being produced. In *Voukolies*, these *Residues* are not treated. They are burnt by farmers in controlled areas, free of vegetation near their plantations. The generated ash is manually disposed to the agricultural land (Ecoil, 2006).

Figure 4.2.: Olive Tree Pruning in Voukolies (Ecoil, 2006)

Tree productivity can, also, be enhanced by the use of fertilisers. In the area of *Voukolies* Nitrogen (N)-based fertilisers, namely of *NPK 20-10-10 type*, are being used, in the majority of the cases. *Fertilisation*, is performed, once a year, manually, by redepositing the chemical around the tree root. Regarding *Pest Control*, only a minority (30%) of local farmers uses chemicals, with the remaining 70% preferring herb cutting. Those who do use chemical *Pesticides,* apply them three times a year by adjusting a sprayer to their tractors (Ecoil, 2006). *Weed Control* via the use of *Herbicides*, is, also applied in the area. *Herbicide* application is assisted by sprayers.

Generation of olive oil occurs during the summer, when it is, gradually, being stored inside the olive fruit and continues until winter, when the olive oil is ready to be collected. *Collection* takes place from the middle of November until late February. The typical method followed is called *Thwacking* and involves the olive fruit being collected in nets, sack clothes or plastic and, then, put into bags, with the assistance of ranks and sieves, so as to separate the fruit from any *Leaves* and *Branches*, before being transferred to the *Olive Mill (OM)* for further processing and, finally, olive oil *Extraction* (Ecoil, 2006).

Figure 4.3: Olive Collection in Voukolies (Ecoil, 2006)

The *Polemarchi Olive Mill (OM)* is located at a close range (approximately one kilometre) from olive plantations and is supplied with water through the *Voukolies* municipal public network. Olives are transferred to the *Olive Mill (OM)* with tractors, in fabric bags of 50 kilograms capacity. There, the collected olives, having being stored in pallets for two days, are, firstly, washed, with the use of machinery, from soil, dust and other material and separated, with the use of leaf separators, from the remaining leaves. This *Purification* process requires about 20% of total *Olive Mill (OM)* water consumption. The olive fruit is, then grinded into smaller parts (olive paste), using metal grinders, which rotate it in high speed within a lame drum and, subsequently, the *Olive Paste* is massaged through the use of round or elongate massage equipment. The final step of the *Olive Mill (OM)* process is the *Extraction* of *Olive Oil* from *Olive Paste.* In Voukolies, this task is performed by *three-phase centrifugation systems* (Ecoil, 2006). As explained in previous sections, within these systems *Water* and *Paste* are inserted into a horizontal centrifugal machine so as to be separated. Any unpurified oils are, in turn, inserted into a vertical centrifugal machine, where oil is separated from *Wastewate*r (vegetable water). At the end of the process three fractions are generated: *Oil, Olive Pomace or Husk* and *Wastewater*, known as *Olive Mill Wastewater (OMWW*) (Prosodol, 2012). Wastewater is treated at the local Water Treatment facilities in Voukolies, through *Chlorination. Pomace*, is not treated and is considered as *Solid Waste*. The produced olive oil is stored into indoor tanks (for an average period of six months), before being transferred to the selling point in dark glass bottles (Ecoil 2006).

4.3. OLIVE OIL PRODUCTION IN SPAIN: THE CASE STUDY OF RIBERA BAJA, NAVARRA

4.3.1. Description of the Geographic Area

With a population of approximately *640.000* and expanding in an area of *10.391* square kilometres, the autonomous *Comunidad Foral de Navarra (Navarra*) consists of three Regions: a. the *Mountains (Montaña*), b. the *Middle Area (Zona Media)* and c. the *Ribera*, on the banks of the Ebro River. These three Regions are further separated into *Districts (Comarcas).* The *Mountains* consist of: a. *Navarre Húmeda*, b. the *Valles Pirenaicos* and c. the *River Basins of the Cuencas Prepirenaicas*, the *Middle Area* consists of a. *Tierra Estella* and b. *Navarre Media Oriental* and the Ribera consists of: a.

Ribera Estellesa and b. *Ribera Tudelana* (Gobierno de Navarra, 2018). Navarra is separated into seven agricultural Regions. Olive plantations can be met in six of them, most notably in the areas of Arróniz, in the centre of the *Comunidad* and Ribera Baja in the south (Ecoil, 2006)

Navarra expands in an area of 10.391 square kilometres and Rivera Baja is situated in the south part of the region. Its climate is of Mediterranean continental nature, with dry summers, temperatures with large annual variations, limited and irregular rainfall and north winds. Besides olives, typical local cultivations include almonds and vines. Although Ribera Baja is the most productive area, within the Navarra Region, figures demonstrate that olive growing in the area is marginal and is, most likely, used for private consumption. In 2006, it was estimated that only *2.5%* of total agricultural land was dedicated to olive farming, due to the fact that the olive oil sector has struggled in the region, as a result of industrialisation and liberalisation. However, in recent years there has been a gradual interest in reviving the local olive oil industry (Ecoil, 2006).

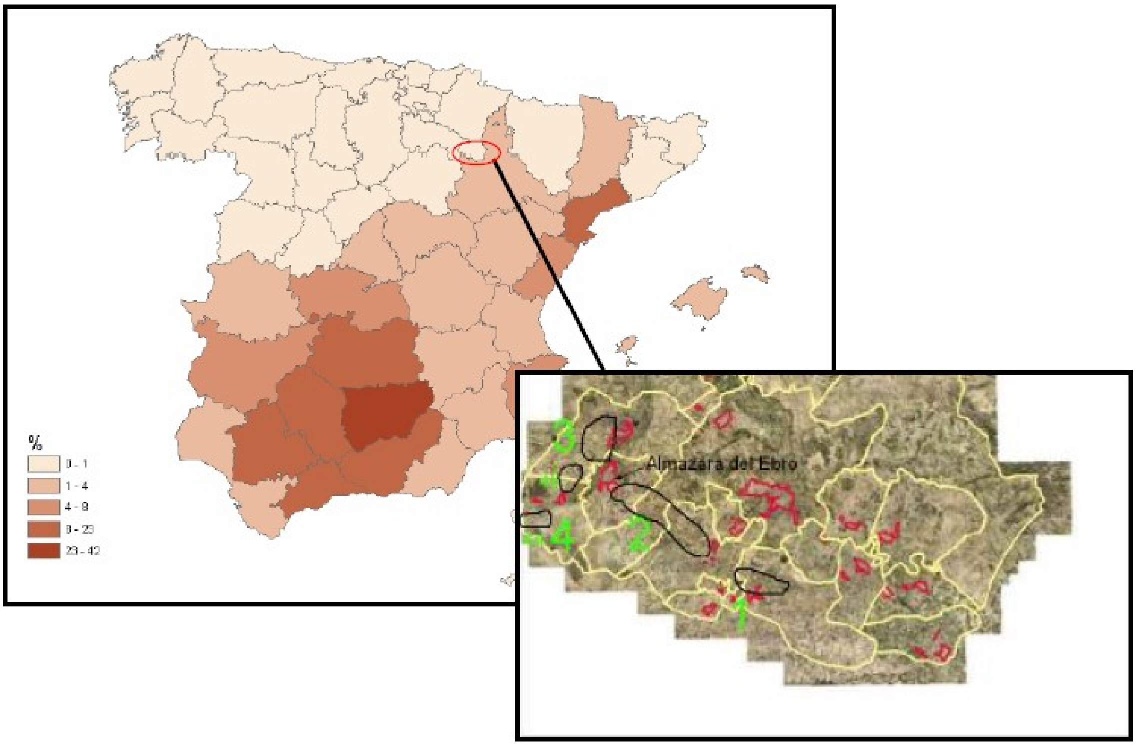


Figure 4.4.: Olive Oil areas in Ribera Baja (Ecoil, 2006)

4.3.2. Olive Oil Production Practices

The most common olive variety cultivated in the region is called *Arróniz,* which can only be met in Navarra and *Empeltre*, which is the main variety met in the Ebro River Basin (Ecoil, 2006).

Planting occurs during the end of winter, where no severe weather conditions are expected and water for *Irrigation* (after winter rains) is sufficient. Almost all olive plantations in Ribera Baja are irrigated (approximately 96%). The irrigation system comes from superficial waters. Typically, “excess” water from local rivers, accumulated from October until April, is used to water olive groves. During the remaining months where water is scarce, a few groves are irrigated by drip system (Ecoil, 2006).

To improve productivity, local farmers, contrary to common practice in Spain, prune trees every year, at a high to medium intensity. Pruning should be completed by the end of winter, when there is no risk of trees being frozen. In Ribera Baja, *Pruning* is considered a manual activity, with local farmers using chainsaws, small and big pruning scissors and handsaws. The *Pruning* process generates two by-products, *Branches* and *Leaves.* Although they, both, can have alternative uses, such as row material for heat and livestock feeding, respectively, local farms, merely burn them (Ecoil, 2006). Tree productivity can, also, be enhanced by the use of fertilisers. In the area of Ribera Baja two types of fertilisers are being used. During winter Nitrogen (N)-based fertilisers, namely of *NPK 12-12-24* type, while during summer of *Ammonium Nitrate*. Depending on olive grove size fertiliser application is either performed manually, around the olive canopy, in case of small trees, or mechanically, by using a spinning fertiliser spreader. *Pest Control,* in the majority of cases is performed by applying chemicals through the of tank sprayer chemicals. Similarly, for *Weed Control*, most farmers resort to the use of *Herbicides*, at an average 3-4 times per year. *Ploughing* by crossing till, 3-4 a years is another common practice (Ecoil, 2006).

Collection period of olives differs, depending on variety, but in general occurs from November to December. The method adopted is that of use long sticks and limb vibrators. Plastic nets are placed on the ground, under the trees to collect the fallen olive fruit. It must be noted that olives that have fallen to the ground, outside the collection process, are neglected, since they are subject to pest diseases. Finally, collected olives are placed into plastic fruit boxes of approximately 300 kilograms capacity, before being transferred to the *Olive Mill (OM)* for further processing and, finally, olive oil *Extraction* (Ecoil, 2006).

Only one *Olive Mill (OM)* is operational throughout the year in the region, thus total olive production is processed through it. There, the collected olives are, firstly, cleaned from impurities, such as *Leaves, Branches* and *Dirt*, with the use of an olive winnower. These products are used for feeding sheep livestock in a radium of approximately 2 kilometres. The next step in the *OM* process is the *Crushing* of the clean olives, until a *Paste* is formed and, then, their further milling. The final step of the *Olive Mill (OM)* process is the *Extraction* of *Olive Oil* from *Olive Paste*. In Ribera Baja, this task is performed by *two-phase centrifugation systems* (Ecoil, 2006). As explained in previous sections, within these systems, *Water* and *Paste* are inserted into a horizontal centrifugal machine so as to be separated, with water use being minimal and used water being recycled. Any unpurified oils are, in turn, inserted into a vertical centrifugal machine, where *Oil* is separated from *Wastewater* (vegetable water). The output produced is *Oil* and *Humid Pomace*, also, known as *Two-Phase Olive Mill Wastewater (TPOMWW).* The adverse effect of *TPOMWW* generation is that, it is dried on site, with the drying process being expensive and produces *Greenhouse Gases (GHGs)* and fumes (Prosodol, 2012). *Pomace* is stored in an outdoor hopper (Ecoil, 2006), before being sold to an olive oil industry in *Borges Blanques* (Lleida), approximately *278* kilometres from the *Olive Mill (OM)* location. Sold *Pomace* is delivered in trailers of *25-30* tonnes capacity. Separated *Vegetable Water* is stored in a cess pit and then distributed over the fields, almost every two days. Finally, the produced *Olive Oil* is stored into stainless steel tanks, until it is bottled in glass bottles or sold (Ecoil 2006).

4.4. APPLICATION OF THE LIFE CYCLE ASSESSMENT (LCA) METHODOLOGY TO THE CASE STUDIES

4.4.1. Goal and Scope Definition

The *Goal* of the study is to analyse the practices applied throughout the *Life Cycle* of olive oil production in Greece and Spain and compare the derived environmental impacts. The *Life Cycle Assessment (LCA)* methodology will be used in order to choose the optimal olive oil production system. The methodology will be applied with the use of the *SimaPro* software, which enables the evaluation of *Environmental Impacts*, by using specific *Environmental Impact Indicators*, to be further analysed in subsequent sections.

4.4.2. Functional Unit

The *Functional Unit* is defined as "production of one litre of extra virgin olive oil".

4.4.3. System Boundaries

The *System Boundaries,* set for the analysis are:
- *Agricultural* phase: referring to *Soil Management, Irrigation, Application of Fertilisers, Application of Pesticides, Application of Herbicides, Pruning, Olive Collection* and *Transportation* to the *Olive Mill (OM).*
- *Processing* phase: referring to *Olive Purification, Olive Grinding and Olive Oil Extraction. Bottling* is not included in the *System Boundaries,* since the vast majority of *Olive Mills (OM)* in both countries*,* as mentioned in previous sections does not engage into such activities.
- *Distribution* phase: referring to transportation activities. For *Voukolies*, since no data are available regarding the location of the end user, we, only, consider transportation to the port of *Souda, Chania*. The distance from *Voukolies* to *Souda* is *32.5* kilometres (Google Maps, 20018). For *Navarra*, since the olive oil production quantity is low, we assume that it will be consumed locally, therefore we, only, consider regional transportation activities. We assume an average distance from the *Olive Mill (OM)* of *14.35* kilometres (Ecoil, 2006).
- *Disposal* phase: referring to treatment options. Three types of waste are identified: *Pruning Residues*, *Pomace* and *Wastewater*. *Pruning Residues* in *Voukolies* and *Ribera Baja* are not treated, merely, burnt, therefore they are considered as a final waste flow. *Pomace* in *Voukolies* is again, not treated and is simply disposed of in evaporation ponds for drying. Its treatment from the evaporation pond onwards is not considered in this report. On the other hand, in *Ribera Baja*, *Pomace* is sold as a by-product. Finally, in both regions *Wastewater* is treated in designated facilities (Ecoil, 2006).

The *Use* phase (cooking, salad dressing, deep frying is not included in the analysis, since it is not considered to severely affect the supply chain (Salomone, et al., 2015) and data are unavailable within the literature.

The *System Boundaries* are depicted as per below graph:

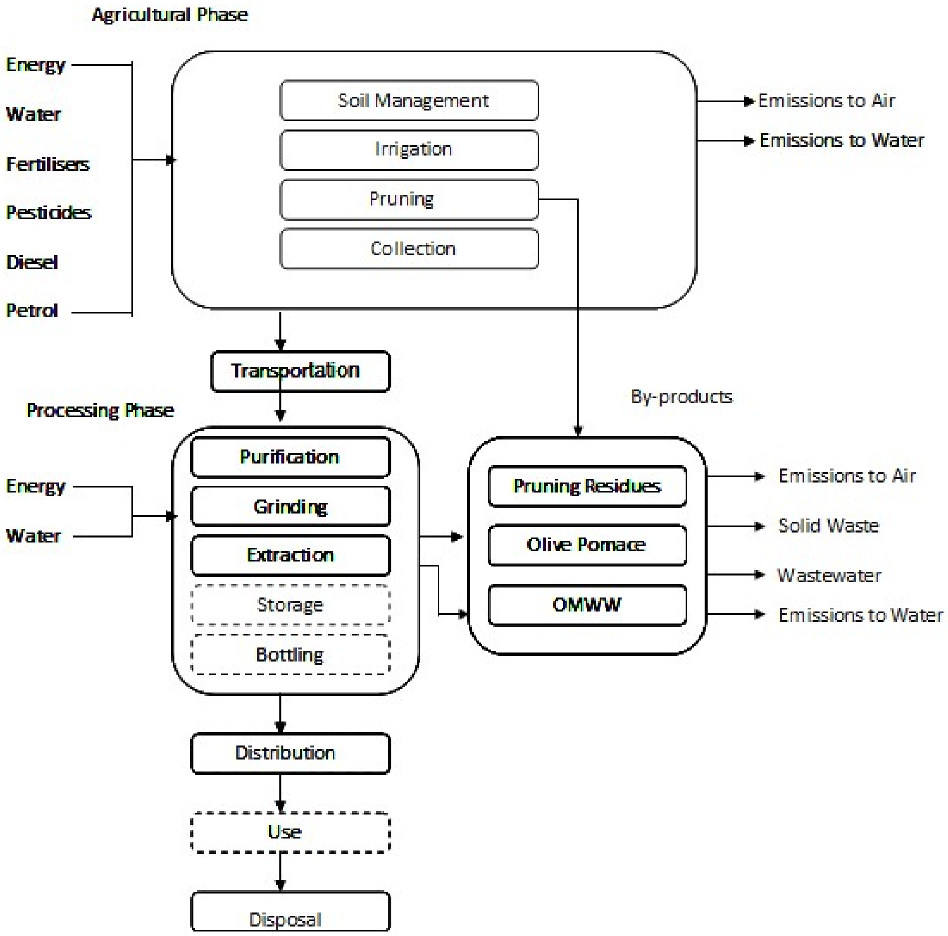


Figure 4.5.: System Boundaries

4.4.4. Life Cycle Inventory (LCI)

For each of the two *Production Systems* an *Inventory* was created based on real data regarding the applied processes. For processes, where real data were not available, *Inventory* was based on the *Ecoinvent v2.2* database.

4.4.4.1. Assumptions

Due to the complexity of the introduced *Production System*, the need to simplify calculations and overcome possible lack of data and the demand to build comparable systems, the following assumptions have been introduced:

- 1 litre of olive oil equals 0.912 kilograms.
- for Greece: 1 litre of olive oil derives from 4.29 kilograms of olives. For Spain: 1 litre of olive oil derives from 5.2 kilograms of olives.
- production and maintenance of capital infrastructure and machinery in all *Life Cycle* stages is not included in the analysis.
- manufacture and installation of industrial equipment is excluded from the analysis.
- production, packaging and transportation of agricultural inputs, such as *Fertilisers*, *Pesticides* and *Herbicides* is not included in the analysis.

- disposal of packaging agricultural inputs, such as *Fertilisers*, *Pesticides* and *Herbicides* is not included in the analysis.
- production of diesel is excluded from the analysis.
- transportation of farmers to and from farms is excluded from the analysis.
- production, transportation and disposal of plastic boxes, nets and mesh bags is not included in the analysis.
- plantations are irrigated in both *Systems*
- *fertilisation* is performed manually in the case of *Voukolies*, while in the case of *Ribera Baja* is performed mechanically, via spray tanks.
- transportation to the *Olive Mill (OM)* from farm takes place by means of 3.5 tonnes vans (Ecoil, 2016). Agricultural machinery, such as tractors, chainsaws, etc, stay within plantation limits.
- we assume that, upon extraction, olive oil is immediately distributed for consumption.
- in Greece, distributed olive oil is transported by means of 16-32 tonnes lorries, while in Spain, olive is distributed by means of 3.5 tonnes vans.

4.4.4.2. Life Cycle Impact Assessment (LCIA)

The study has been conducted by data obtained from the *Case Studies* developed as part of the *Ecoil* project and the *SimaPro Ecoinven*t database. To calculate the *Impact Assessment* results the *CML 2001* and *Eco-Indicator 99* methods were used.
Below, a brief presentation of the two methods key features is provided.

4.4.4.2.1. CML 2001

The method was created in 2001 by the *University of Leiden*, Netherlands and contains more than *1.700* different flows. It is divided into *Baseline* and *non-Baseline Impact Categories*, the *Baseline* being the most commonly used in *Life Cycle Assessment (LCA)* analyses. In particular, the *Baseline Impact* Categories include:
- *Acidification:* refers to the impacts of acidifying substances on soil, groundwater, surface water, organisms, ecosystems and materials. An *Acidification Potential (AP)* factor describes the fate and deposition of acidifying substances to air. It is expressed as kg. SO_2 equivalent.
- *Global Warming Potential:* refers to the adverse affects of *Climate Change* on ecosystem, human health and material welfare. This *Impact Category Indicator* relates to the emissions of greenhouse gases to air. A *Global Warming Potential (GWP)* factor is determined for a time period 100 years (GWP100). It is expressed as kg. carbon dioxide/kg. emission.
- *Depletion of Abiotic Resources:* refers to the protection of human welfare, human and ecosystem health. This *Impact Category Indicator* relates to the extraction of minerals and fossil fuels due to inputs in the system. An *Abiotic Depletion Factor (ADF)* is determined for each extraction of minerals and fossil fuels, based on concentration reserves and rate of de-accumulation. It is expressed as kg. antimony equivalents/kg. extraction.
- *Ecotoxicity:* refers to the impact of toxic substances emissions to air, water and soil on fresh water ecosystems. An *Eco-toxicity Potential (FAETP)* factor describes the fate,

exposure and effects of toxic substances. It is expressed as 1.4-dichlorobenzene equivalents/kg emission.
- *Marine Toxicity:* refers to impacts of toxic substances on marine ecosystems.
- *Terrestrial Toxicity*: refers to impacts of toxic substances on terrestrial ecosystems.
- *Eutrophication:* refers to all impacts caused by emissions of nutrients to air, water and soil. A *Nutrification Potential (NP)* factor is determined and expressed as kg. PO_4 equivalents per kg. emission.
- *Human Toxicity:* refers to *the* effects of toxic substances on the human environment. A *Human Toxicity Potential (HTP),* factor describes the fate, exposure and effects of toxic substances for an infinite time horizon. It is expressed as 1.4-dichlorobenzene equivalents/ kg. emission.
- *Ozone Layer Depletion*: refers to the harmful effects of *UV-B Radiation* on human and animal health, terrestrial and aquatic ecosystems, biochemical cycles and materials. An *Ozone Depletion Potential (ADP)* factor defines the ozone depletion potential of different gasses. It is expressed as gr. CFC-11 equivalent/ kg. emission.
- *Photo-oxidant Formation:* refers to the formation of reactive substances (mainly ozone) which are injurious to human health and ecosystems and which may damage crops, also known as *"Summer Smog".* A *Photochemical Ozone Creation Potential (POCP)* factor is determined for the emission of substances to air. It is expressed as kg. ethylene equivalents/kg. emission (Sima Pro, 2018).
At this point, it should be stated that the results of this study were analysed based on the *CML 2001 Baseline* approach.

4.4.4.2.2. Eco-indicator 99

Eco-indicator 99 is a damage-oriented method for *Life Cycle Assessment*. In particular, the methodology identifies three damage categories, based on which *Impact Categories* are classified:
- damage to *Human Health:* expresses the number of *Years Lost* and number of years *Lived Disabled*, combined as *Disability Adjusted Life Years (DALYs)*
- damage to *Ecosystem Quality*: express the loss of species over a specific area, under a given period of time
- damage to *Resources*: expresses the additional energy that is required for future extractions of fossil fuels and minerals (SimaPro, 2018).

CHAPTER 5

RESULTS AND DISCUSSION

5.1. RESULTS

After having developed the two distinct supply chain models referring to the olive oil production in Greece and Spain in the *SimaPro* software, this section provides the analysis of the results. More specifically, each *Production System* is presented as a separate *Unit* (or *Assembly* in *Sima Pro* terminology). Each *Unit* includes a set of *Processes,* which explain the different activities performed within each *Unit* and which are built, by using several *Inputs*. The *Units (Assemblies)* examined in this analysis are *Agricultural, Processing* and *Distribution* phases. Finally, a *Disposal* scenario compliments the model.

A graphical representation of the model is available through the *Network Results* of the software. A *Network* structure includes all *Inputs*, but if one is met multiple times, it only appears once. As there is a limit in the number of *Processes* presented in the *Network* structure, only the top ones are graphically available. For this reason, a number of *Units* and *Processes* of this analysis are not portrayed in the *Network Results*, however they are included in all relevant calculations (SimaPro, 2018).

Inventory Data of each *Production System* were tested by using the *Baseline CML 2001* and *Eco-Indicator 99* methodologies. In the former, *Inventory Data* were tested against *Abiotic Depletion (ADP), Acidification (AP), Eutrophication (EP), Global Warming (GWP100), Ozone Layer Depletion (ODP), Human Toxicity (HTP), Fresh Water Aquatic Ecotoxicity, Marine Aquatic Ecotoxicity, Terrestrial Ecotoxicity* and *Photochemical Oxidation (POCP) Impact Categories*. In the latter, they were tested against *Carcinogens, Respiratory Organics, Respiratory Inorganics, Climate Change, Radiation, Ozone Layer, Ecotoxicity, Acidification/Eutrophication, Land Use, Minerals* and *Fossil Fuels Impact Categories*. A graphical and numerical representation of data is provided

In *CML 2001 Baseline* methodology, to quantify the environmental impact of olive oil to each of these *Impact Categories*, the *Characterisation* method was used. *Characterisation* expresses the relative contribution of a substance to an environmental impact. Substances are multiplied by a *Characterisation Factor (CF)*. Additionally, for an easier understanding of the environmental impact of olive oil, the *Normalisation* method may be used. *Normalisation*, is an optional step in *Life Cycle Assessment (LCA)* studies, in which, the quantified impact is compared to a certain reference value (PRé Consultants, 2014). In this section, graphical results based only on the *Characterisation* methodology are analysed. Graphical results based on the *Normalisation* methodology are provided in Appendix A.

Analysis-specific results are presented as follows: each *Phase* of each *Production System* is graphically depicted in terms of *Network* structure and tested against the above mentioned *Impact Categories*, through the application of the two previously stated methodologies. Then, each distinct *Unit* of the two country models is compared. The same applies for the complete *Life Cycle* of the Greek and Spanish olive oil product. At the end of this Chapter, results are briefly discussed.

5.2 NETWORK RESULTS

5.2.1. Greece

The graphical representation of the *Network* structure of the Greek *Production System* for each *Phase*, as well as for the complete *Life Cycle* is as per below figures. As mentioned before, only the Phases with the highest contribution are graphically depicted.

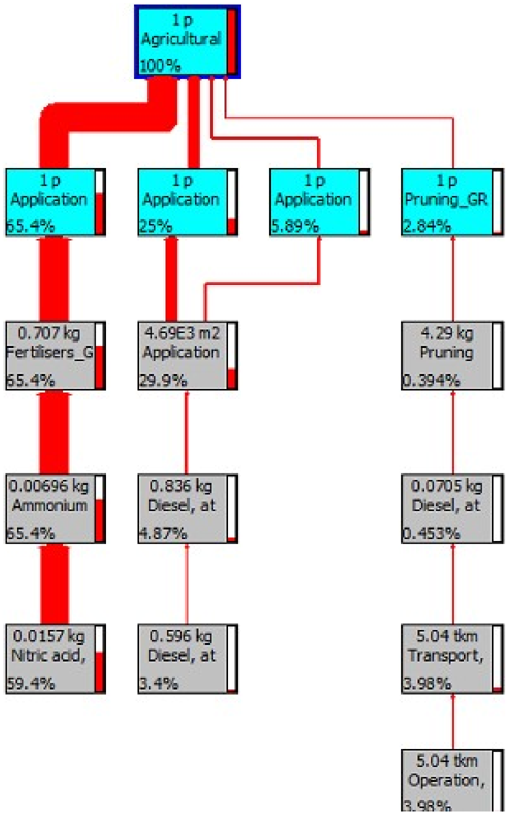


Figure 5.1.: Network Results, Agricultural Phase, Greece (SimaPro Software)

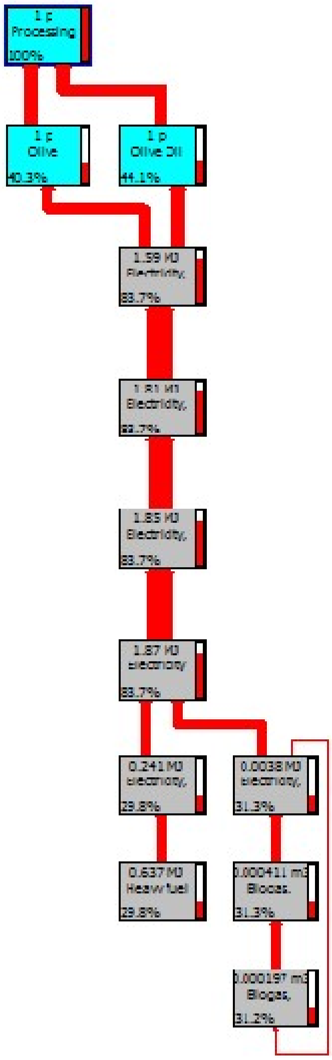


Figure 5.2.: Network Results, Processing Phase, Greece (SimaPro Software)

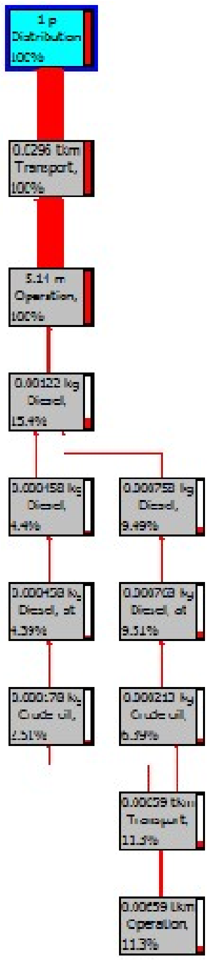


Figure 5.3.: Network Results, Distribution Phase, Greece (SimaPro Software)

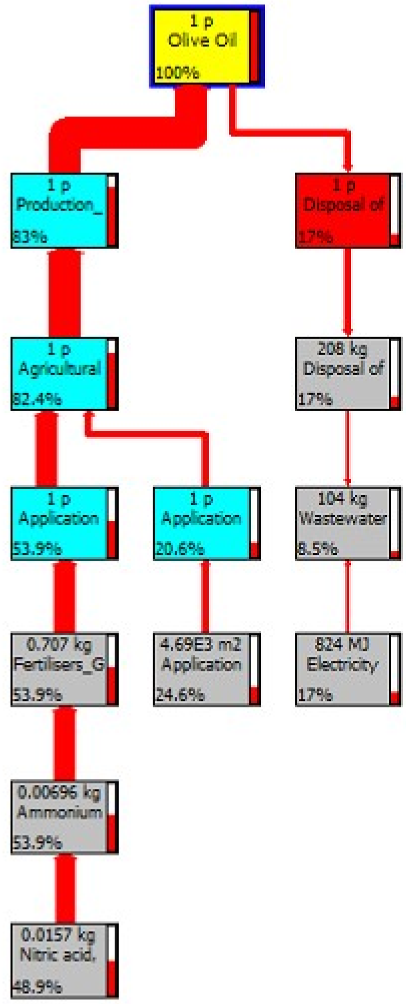


Figure 5.4.: Network Results, Life Cycle, Greece (SimaPro Software)

5.2.2. Spain

The graphical representation of the *Network* structure of the Spanish *Production System* for each *Phase*, as well as for the complete *Life Cycle* is as per below figures. As mentioned before, only the Phases with the highest contribution are graphically depicted.

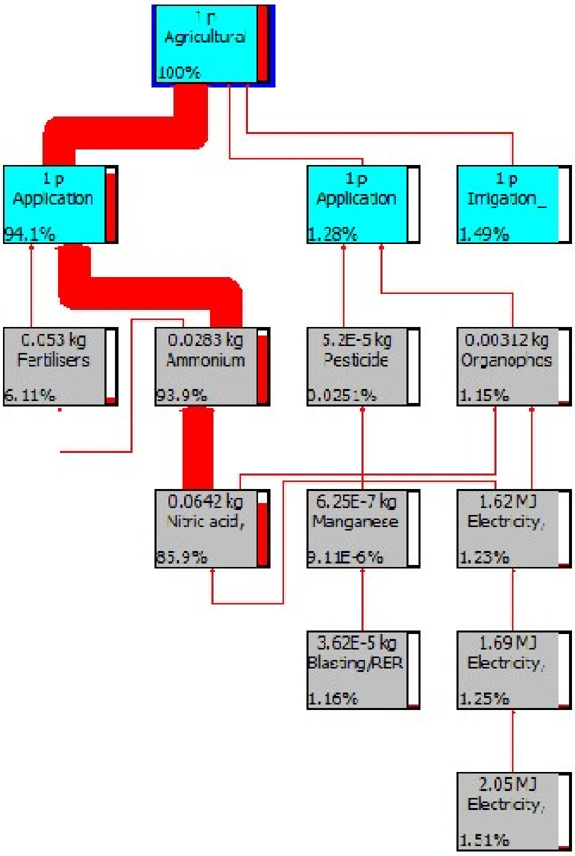


Figure 5.5.: Network Results, Agricultural Phase, Spain (SimaPro Software)

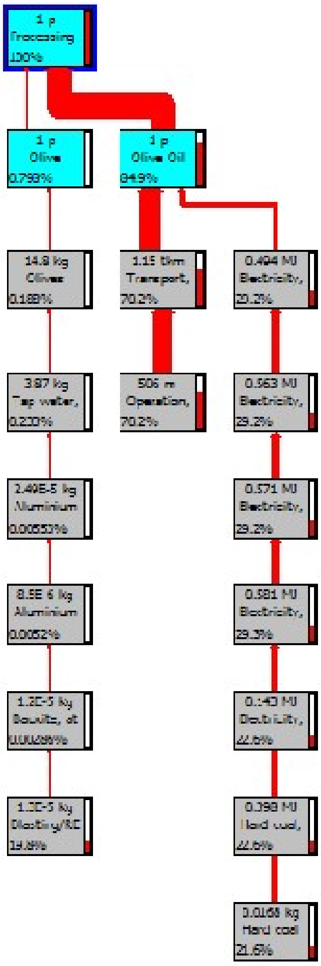


Figure 5.6.: Network Results Processing Phase (SimaPro Software)

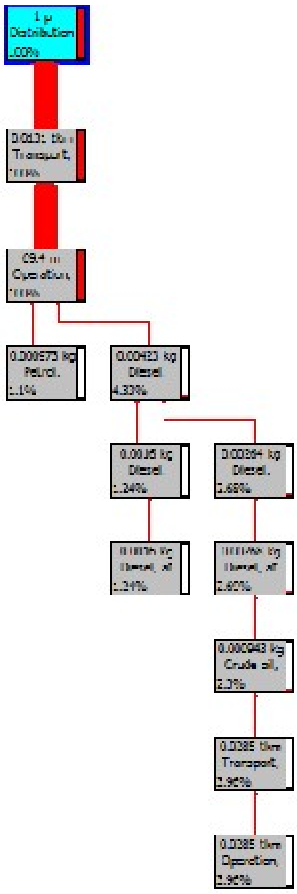


Figure 5.7.: Network Results, Distribution Phase, Spain (SimaPro Software)

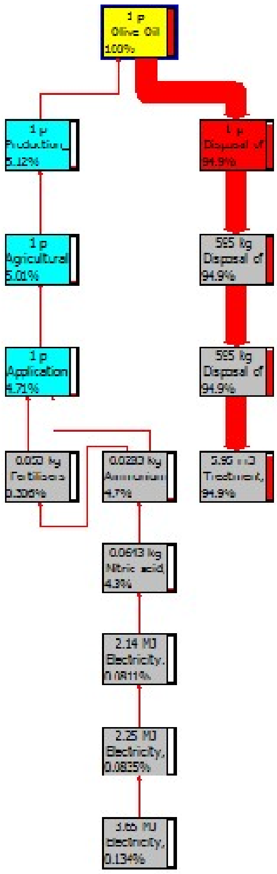


Figure 5.8.: Network Results, Life Cycle, Spain (SimaPro Software)

5.3. IMPACT ASSESSMENT

5.3.1. Results of Impact Indicators according to the CML 2001 Baseline Method

5.3.1.1. Greece

5.3.1.1.1. Graphical Representation

The results of the *Impact Indicators* according to *CML 2001 Baseline* method, for the Greek *Production System,* for each *Phase,* as well as for the complete *Life Cycle*, are presented below. The *Distribution* phase is not presented separately, since it comprises from only one *Transportation Process,* thus, it is the only one with an environmental impact.

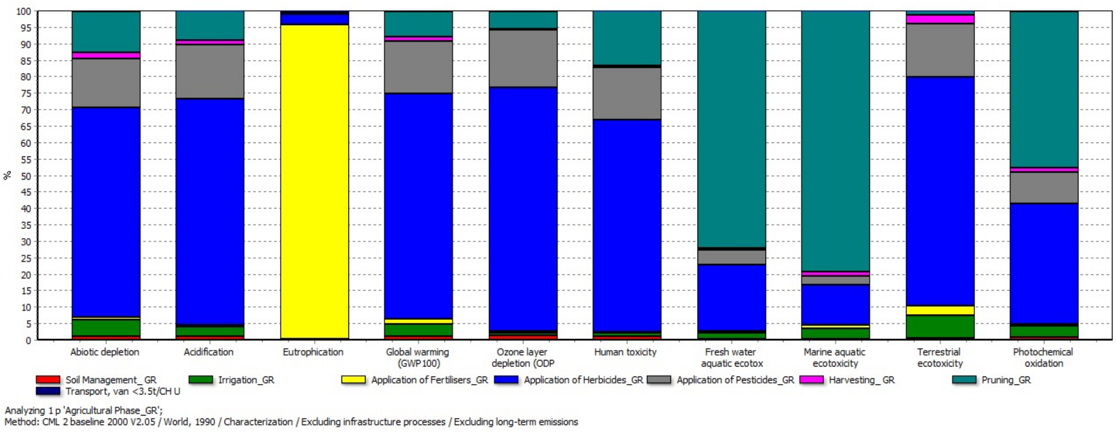


Figure 5.9.: Agricultural Phase Greece, Results per Impact Category, CML 2001 Baseline, Characterisation (SimaPro Software)

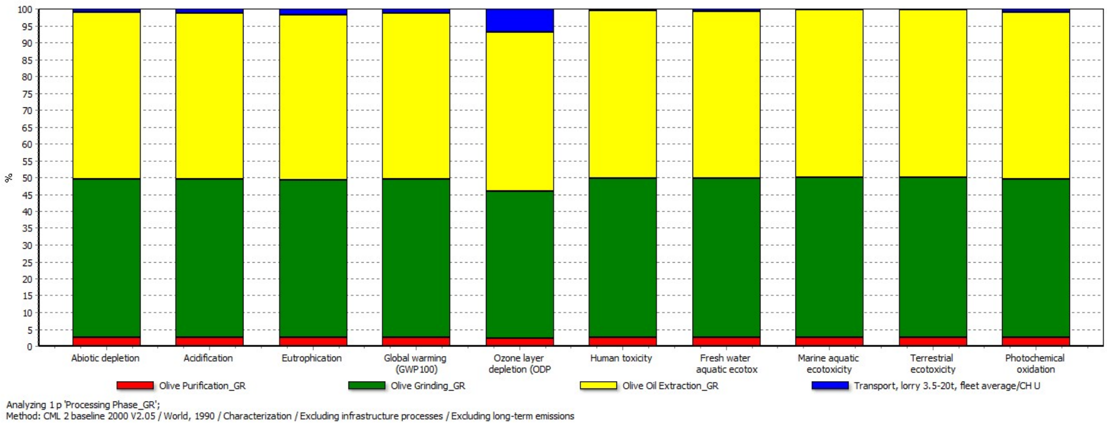


Figure 5.10.: Processing Phase Greece, Results per Impact Category, CML 2001 Baseline, Characterisation (SimaPro Software)

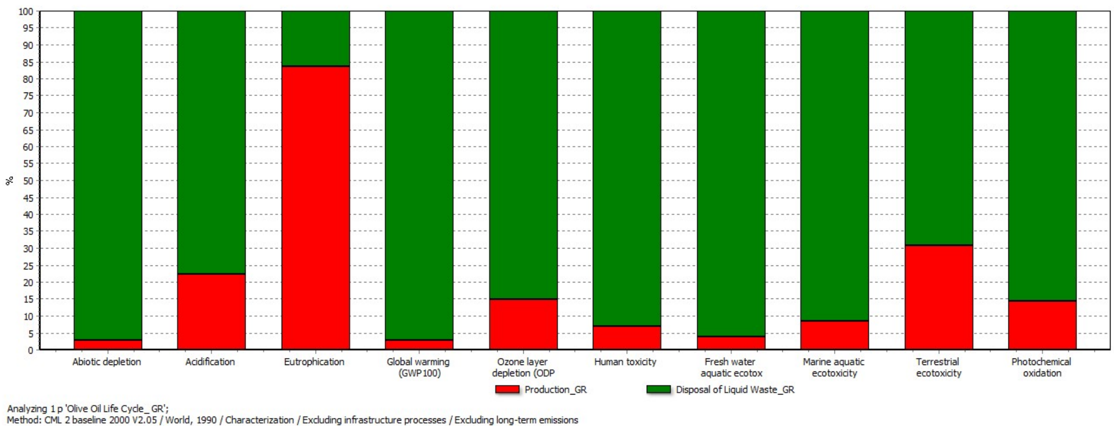


Figure 5.11.: Life Cycle Greece, Results per Impact Category, CML 2001 Baseline, Characterisation (SimaPro Software)

5.3.1.1.2. Numerical Representation

The *Characterised* and *Normalised* values per each *Impact Indicator,* for the Greek *Production System*, for each *Phase*, as well as for the complete *Life Cycle* are presented in the two tables below:

Table 5.1.: Characterised Values of Impact Categories, Greece, CML 2001 Baseline (SimaPro Software)

Impact Category	Unit	Agricultural Phase	Processing Phase	Distribution Phase	Disposal of Liquid Waste	Life Cycle
Abiotic Depletion	kg Sb eq	0.025018284	0.0047995099	2,85E+02	10.428.997	1.072.746
Acidificatio n	kg SO2 eq	0.027564305	0.0031940834	2,21E+02	0.10782731	0.13860779
Eutrophicat ion	kg PO4--- eq	0.13306203	0.00052147018	4,91E+00	0.026234511	0.15982292
Global Warming (GWP100)	kg CO2 eq	36.306.386	0.50697804	0.0045466956	14.962.526	15.376.742
Ozone Layer Depletion (ODP)	kg CFC-11 eq	5,17E+00	1,49E-01	6,83E-03	3,04E+01	3,57E+01
Human Toxicity	kg 1,4-DB eq	22.530.495	0.096217287	0.00031060536	31.553.308	33.902.886
Fresh Water Aquatic Ecotoxicity	kg 1,4-DB eq	0.11335815	0.0077156631	3,09E+02	29.499.303	3.071.035
Marine Aquatic Ecotoxicity	kg 1,4-DB eq	37.678.187	46.193.909	0.08943202	46.198.228	5.042.888
Terrestrial Ecotoxicity	kg 1,4-DB eq	0.0075258608	0.0020571797	2,30E+01	0.021635999	0.031221339
Photochem ical Oxidation	kg C2H4 eq	0.00089267846	0.00012622207	5,34E+00	0.0060522375	0.0070716724

Table 5.2.: Normalised Values of Impact Categories, Greece, CML 2001 Baseline (SimaPro Software)

Impact Category	Agricultural Phase	Processing Phase	Distribution Phase	Disposal of Liquid Waste	Life Cycle
Abiotic Depletion	1,58E-06	3,03E-07	1,80E-09	6,59E-05	6,78E-05
Acidification	8,52E-07	9,87E-08	6,83E-10	3,33E-06	4,28E-06
Eutrophication	1,00E-05	3,93E-08	3,70E-10	1,98E-06	1,20E-05
Global Warming (GWP100)	8,24E-07	1,15E-07	1,03E-09	3,40E-05	3,49E-05
Ozone Layer Depletion (ODP)	4,53E-09	1,30E-10	5,98E-12	2,66E-08	3,13E-09
Human Toxicity	3,76E-07	1,61E-08	5,19E-11	5,27E-06	5,66E-06
Fresh Water Aquatic Ecotoxicity	5,48E-07	3,73E-08	1,49E-11	1,42E-05	1,48E-05
Marine Aquatic Ecotoxicity	4,97E-06	6,10E-08	1,18E-09	6,10E-05	6,66E-05
Terrestrial Ecotoxicity	2,85E-07	7,80E-08	8,71E-11	8,20E-07	1,18E-06
Photochemical Oxidation	8,56E-08	1,21E-08	5,12E-11	5,80E-07	6,78E-07

5.3.1.2. Spain

5.3.1.2.1. Graphical Representation

The results of the *Impact Indicators* according to *CML 2001 Baseline* method, for the Spanish *Production System,* for each *Phase,* as well as for the complete *Life Cycle*, are presented below. The *Distribution* phase is not presented separately, since it comprises from only one *Transportation Process,* thus, it is the only one with an environmental impact.

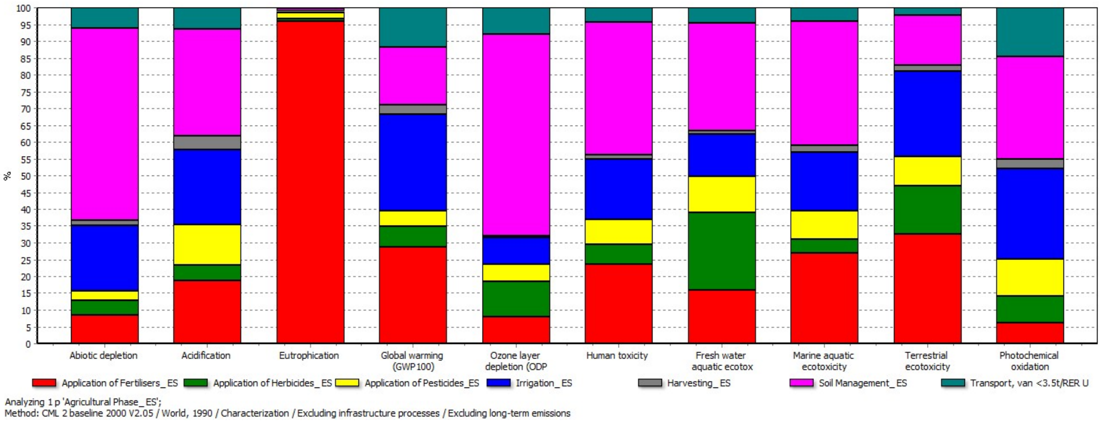


Figure 5.12.: Agricultural Phase, Greece, Results per Impact Category, CML 2001 Baseline, Characterisation (SimaPro Software)

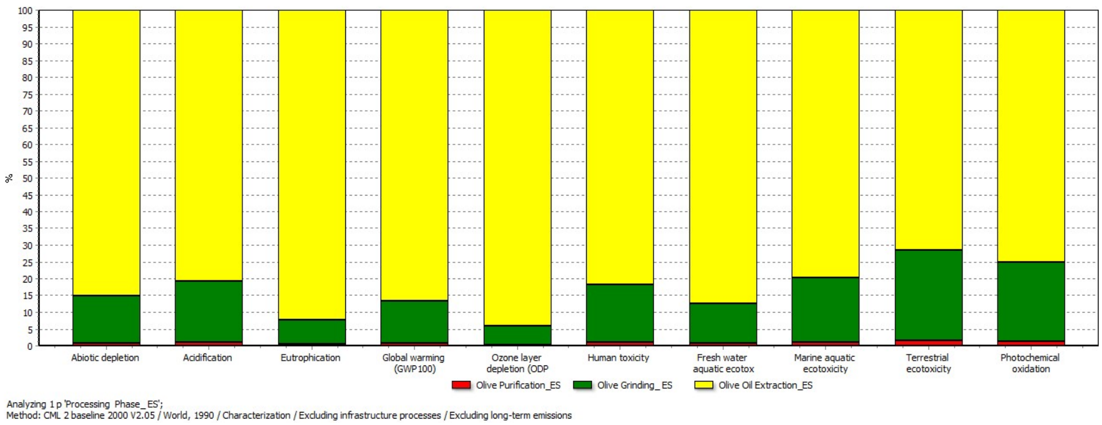


Figure 5.13.: Processing Phase, Spain, Results per Impact Category, CML 2001 Baseline, Characterisation (SimaPro Software)

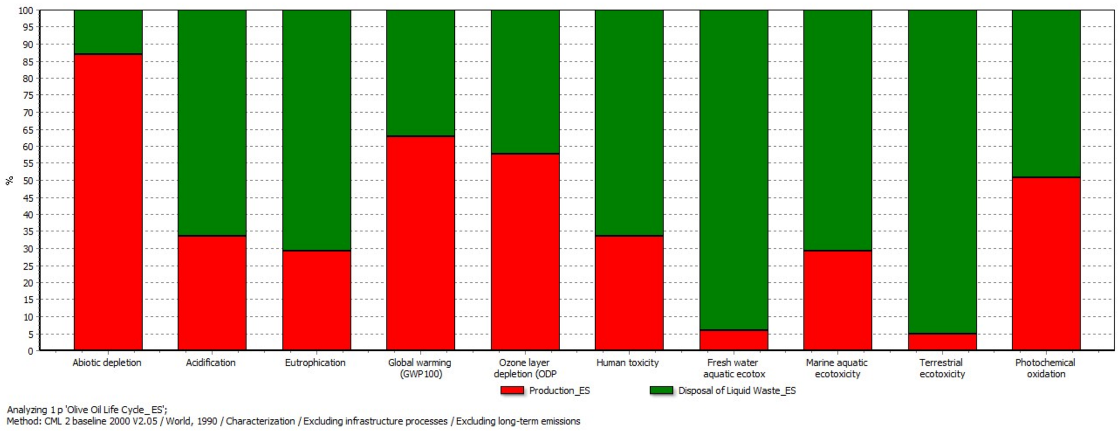


Figure 5.14.: Life Cycle, Spain, Results per Impact Category, CML 2001 Baseline, Characterisation (SimaPro Software)

5.3.1.2.2. Numerical Representation

The *Characterised* and *Normalised* values per each *Impact Indicator,* for the Spanish *Production System*, for each *Phase*, as well as for the complete *Life Cycle* are presented in the two tables below:

Table 5.3.: Characterised Values of Impact Categories, Spain, CML 2001 Baseline (SimaPro Software)

Impact Category	Unit	Agricultural Phase	Processing Phase	Distribution	Disposal of Liquid Waste	Total
Abiotic Depletion	kg Sb eq	0.011238501	0.0020287823	0.00012323815	0.0019924839	0.015383005
Acidification	kg SO2 eq	0.0057588762	0.0020222833	6,53E+02	0.015515386	0.023361841
Eutrophication	kg PO4--- eq	0.030211063	0.00033323372	1,29E+02	0.074377225	0.10493445
Global Warming (GWP100)	kg CO2 eq	0.94287796	0.31313992	0.019493532	0.75306987	20.285.813
Ozone Layer Depletion (ODP)	kg CFC-11 eq	2,11E-01	3,87E-01	2,90E-02	1,86E+00	4,38E+00
Human Toxicity	kg 1,4-DB eq	0.20323449	0.028127139	0.0015524318	0.46023914	0.6931532
Fresh Water Aquatic Ecotoxicity	kg 1,4-DB eq	0.016710334	0.0021433751	0.00013322367	0.29975142	0.31873835
Marine Aquatic Ecotoxicity	kg 1,4-DB eq	55.312.716	81.551.486	0.39534742	15.368.111	21.754.433
Terrestrial Ecotoxicity	kg 1,4-DB eq	0.0023968089	0.00026849414	9,78E+01	0.052365105	0.05504019
Photochemical Oxidation	kg C2H4 eq	0.00030029484	5,82E+01	7,70E+01	0.00035354935	0.00071972314

Table 5.4.: Normalised Values of Impact Categories, Spain, CML 2001 Baseline (SimaPro Software)

Impact Category	Agricultural Phase	Processing Phase	Distribution	Disposal of Liquid Waste	Total
Abiotic Depletion	7,10E-07	1,28E-07	7,79E-09	1,26E-07	9,72E-07

Acidification	1,78E-07	6,25E-08	2,02E-09	4,79E-07	7,22E-07
Eutrophication	2,27E-07	2,51E-08	9,74E-11	5,60E-07	7,90E-06
Global Warming (GWP100)	2,14E-08	7,11E-08	4,43E-09	1,71E-07	4,60E-07
Ozone Layer Depletion (ODP)	1,85E-09	3,39E-10	2,54E-11	1,63E-09	3,84E-09
Human Toxicity	3,39E-08	4,70E-09	2,59E-11	7,69E-08	1,16E-07
Fresh Water Aquatic Ecotoxicity	8,07E-08	1,04E-08	6,43E-10	1,45E-06	1,54E-06
Marine Aquatic Ecotoxicity	7,30E-07	1,08E-07	5,22E-10	2,03E-06	2,87E-06
Terrestrial Ecotoxicity	9,08E-08	1,02E-08	3,71E-12	1,98E-06	2,09E-06
Photochemical Oxidation	2,88E-08	5,58E-09	7,38E-10	3,39E-08	6,90E-08

5.3.1.3. Greece-Spain Comparison

5.3.1.3.1. Graphical Representation

The comparison of the results of the *Impact Indicators* according to the *CML 2001 Baseline* method, for the Greek and Spanish *Production Systems,* for each *Phase,* as well as for the complete *Life Cycle*, are presented below.

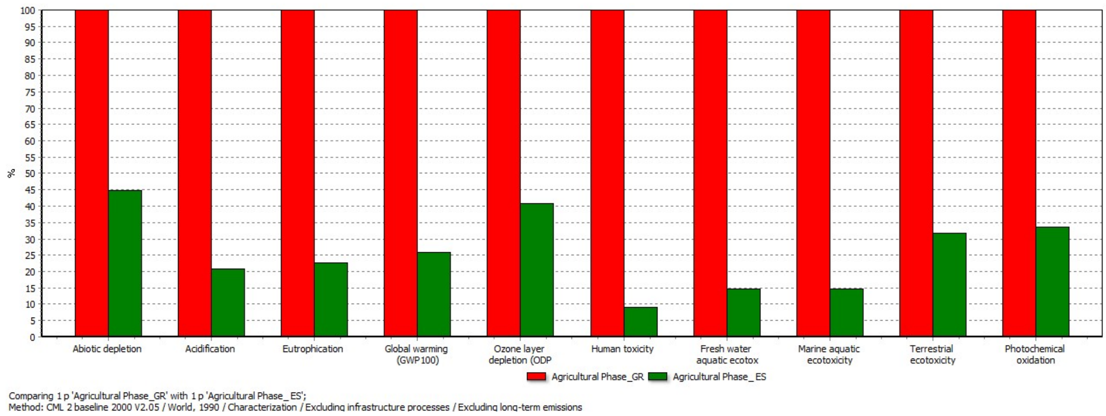


Figure 5.15.: Agricultural Phase, Greece, Spain, Results per Impact Category, CML 2001 Baseline, Characterisation (Sima Pro Software)

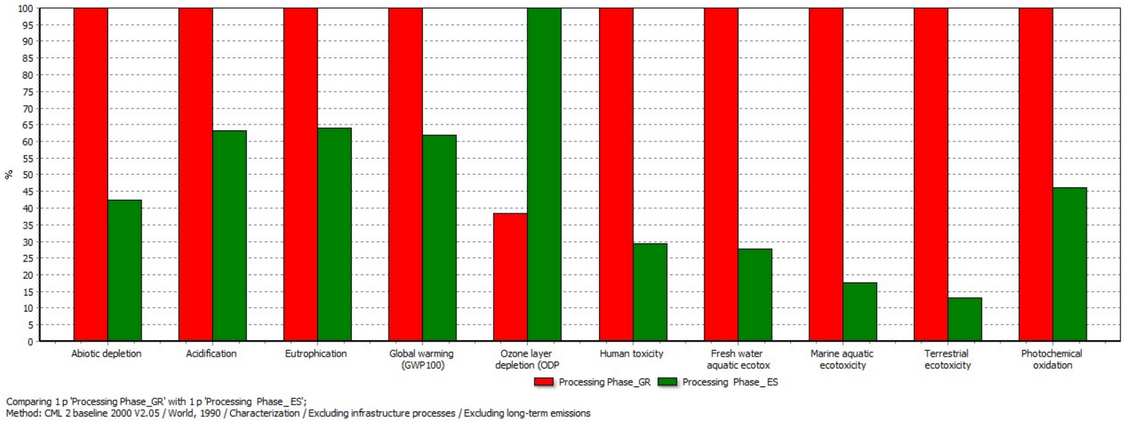


Figure 5.16.: Processing Phase, Greece, Spain, Results per Impact Category, CML 2001 Baseline, Characterisation (SimaPro Software)

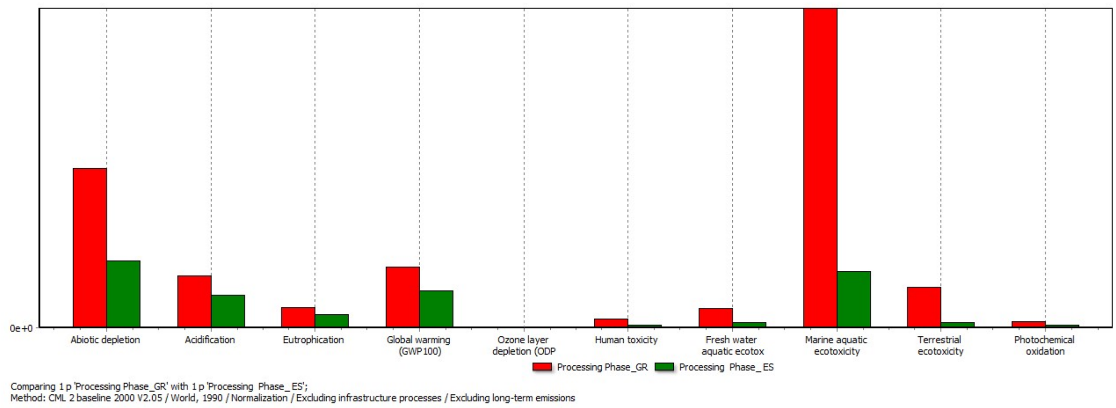


Figure 5.17.: Distribution Phase, Greece, Spain, Results per Impact Category, CML 2001 Baseline, Characterisation (SimaPro Software)

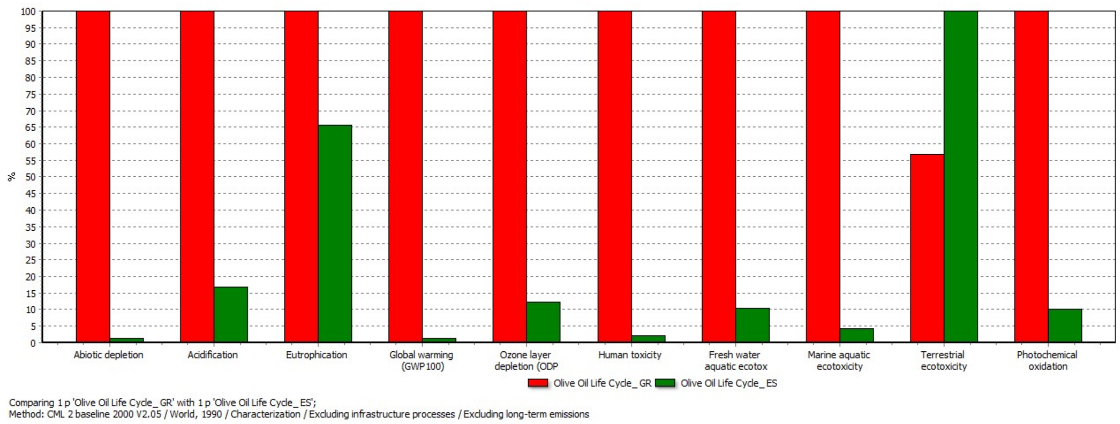


Figure 5.18.: Life Cycle, Greece, Spain, Results per Impact Category, CML 2001 Baseline, Characterisation (SimaPro Software)

5.3.1.3.2. Numerical Representation

The comparison of the *Characterised* and *Normalised* values, per *Impact Category*, for the *Agricultural* phase, for the Greek and Spanish *Production Systems* are presented in the two tables below:

Table 5.6.: Characterised Values of Impact Categories, Greece, Spain, Agricultural Phase, CML 2001 Baseline (SimaPro Software)

Impact category	Unit	Agricultural Phase_GR	Agricultural Phase_ ES
Abiotic Depletion	kg Sb eq	0.025018284	0.011238501
Acidification	kg SO2 eq	0.027564305	0.0057588762
Eutrophication	kg PO4--- eq	0.13306203	0.030211063
Global Warming (GWP100)	kg CO2 eq	36.306.386	0.94287796
Ozone Layer Depletion (ODP)	kg CFC-11 eq	5,17E+00	2,11E-01
Human Toxicity	kg 1,4-DB eq	22.530.495	0.20323449
Fresh Water Aquatic Ecotoxicity	kg 1,4-DB eq	0.11335815	0.016710334
Marine Aquatic Ecotoxicity	kg 1,4-DB eq	37.678.187	55.312.716
Terrestrial Ecotoxicity	kg 1,4-DB eq	0.0075258608	0.0023968089
Photochemical Oxidation	kg C2H4 eq	0.00089267846	0.00030029484

Table 5.7.: Normalised Values of Impact Categories, Greece, Spain, Agricultural Phase, CML 2001 Baseline (SimaPro Software)

Impact category	Agricultural Phase_GR	Agricultural Phase_ ES
Abiotic Depletion	1,58E-06	7,10E-07
Acidification	8,52E-07	1,78E-07
Eutrophication	1,00E-05	2,27E-07
Global Warming (GWP100)	8,24E-07	2,14E-08
Ozone Layer Depletion (ODP)	4,53E-09	1,85E-09
Human Toxicity	3,76E-07	3,39E-08
Fresh Water Aquatic Ecotoxicity	5,48E-07	8,07E-08
Marine Aquatic Ecotoxicity	4,97E-06	7,30E-07
Terrestrial Ecotoxicity	2,85E-07	9,08E-08
Photochemical Oxidation	8,56E-08	2,88E-08

The comparison of the *Characterised* and *Normalised* values, per *Impact Category,* for the *Processing* phase, for the Greek and Spanish *Production Systems* are presented in two the tables below:

Table 5.8.: Characterised Values of Impact Categories, Greece, Spain, Processing Phase, CML 2001 Baseline (SimaPro Software)

Impact category	Unit	Processing Phase_GR	Processing Phase_ ES
Abiotic Depletion	kg Sb eq	0.0047995099	0.0020287823
Acidification	kg SO2 eq	0.0031940834	0.0020222833
Eutrophication	kg PO4--- eq	0.00052147018	0.00033323372
Global Warming (GWP100)	kg CO2 eq	0.50697804	0.31313992
Ozone Layer Depletion (ODP)	kg CFC-11 eq	1,49E-01	3,87E-01
Human Toxicity	kg 1,4-DB eq	0.096217287	0.028127139
Fresh Water Aquatic Ecotoxicity	kg 1,4-DB eq	0.0077156631	0.0021433751
Marine Aquatic Ecotoxicity	kg 1,4-DB eq	46.193.909	81.551.486
Terrestrial Ecotoxicity	kg 1,4-DB eq	0.0020571797	0.00026849414
Photochemical Oxidation	kg C2H4 eq	0.00012622207	58,17905

Table 5.9.: Normalised Values of Impact Categories, Greece, Spain, Processing Phase, CML 2001 Baseline (SimaPro Software)

Impact category	Processing Phase_GR	Processing Phase_ ES
Abiotic Depletion	3,03E-07	1,28E-07
Acidification	9,87E-08	6,25E-08
Eutrophication	3,93E-08	2,51E-08
Global Warming (GWP100)	1,15E-07	7,11E-08
Ozone Layer Depletion (ODP)	1,30E-10	3,39E-10
Human Toxicity	1,61E-08	4,70E-09
Fresh Water Aquatic Ecotoxicity	3,73E-08	1,04E-08
Marine Aquatic Ecotoxicity	6,10E-08	1,08E-07
Terrestrial Ecotoxicity	7,80E-08	1,02E-08
Photochemical Oxidation	1,21E-08	5,58E-09

The comparison of the *Characterised* and *Normalised* values, per *Impact Category,* for the *Distribution* phase, for the Greek and Spanish *Production Systems* are presented in the two tables below:

Table 5.10.: Characterised Values of Impact Categories, Greece, Spain, Distribution Phase, CML 2001 Baseline (SimaPro Software)

Impact category	Unit	Distribution_GR	Distribution_ES
Abiotic Depletion	kg Sb eq	2,50E+02	0.00012323815
Acidification	kg SO2 eq	1,05E+00	6,53E+02
Eutrophication	kg PO4--- eq	1,99E+01	1,29E+02
Global Warming (GWP100)	kg CO2 eq	0.0039757376	0.019493532
Ozone Layer Depletion (ODP)	kg CFC-11 eq	5,98E-03	2,90E-02
Human Toxicity	kg 1,4-DB eq	0.00025535916	0.0015524318
Fresh Water Aquatic Ecotoxicity	kg 1,4-DB eq	2,79E+02	0.00013322367
Marine Aquatic Ecotoxicity	kg 1,4-DB eq	0.079356473	0.39534742
Terrestrial Ecotoxicity	kg 1,4-DB eq	2,10E+01	9,78E+01
Photochemical Oxidation	kg C2H4 eq	3,0841045	76,998977

Table 5.11.: Normalised Values of Impact Categories, Greece, Spain, Distribution Phase, CML 2001 Baseline (SimaPro Software)

Impact category	Distribution Phase _GR	Distribution Phase _ES
Abiotic Depletion	1,58E-09	7,79E-09
Acidification	3,24E-10	2,02E-09
Eutrophication	1,50E-10	9,74E-11
Global Warming (GWP100)	9,02E-10	4,43E-09
Ozone Layer Depletion (ODP)	5,24E-13	2,54E-11
Human Toxicity	4,26E-12	2,59E-11
Fresh Water Aquatic Ecotoxicity	1,35E-10	6,43E-10
Marine Aquatic Ecotoxicity	1,05E-09	5,22E-10
Terrestrial Ecotoxicity	7,96E-11	3,71E-12
Photochemical Oxidation	2,96E-11	7,38E-10

The comparison of the *Characterised* and *Normalised* values*,* per *Impact Category,* for the *Life Cycle* for the Greek and Spanish *Production Systems* are presented in the two tables below:

Table 5.12.: Characterised Values of Impact Categories, Greece, Spain, Life Cycle, CML 2001 Baseline (SimaPro Software)

Impact category	Unit	Olive Oil Life Cycle_ GR	Olive Oil Life Cycle_ ES
Abiotic Depletion	kg Sb eq	1.072.746	0.015383005
Acidification	kg SO2 eq	0.13860779	0.023361841
Eutrophication	kg PO4--- eq	0.15982292	0.10493445
Global Warming (GWP100)	kg CO2 eq	15.376.742	20.285.813
Ozone Layer Depletion (ODP)	kg CFC-11 eq	3,57E+01	4,38E+00
Human Toxicity	kg 1,4-DB eq	33.902.886	0.6931532
Fresh Water Aquatic Ecotoxicity	kg 1,4-DB eq	3.071.035	0.31873835
Marine Aquatic Ecotoxicity	kg 1,4-DB eq	5.042.888	21.754.433
Terrestrial Ecotoxicity	kg 1,4-DB eq	0.031221339	0.05504019
Photochemical Oxidation	kg C2H4 eq	0.0070716724	0.00071972314

Table 5.13.: Normalised Values of Impact Categories, Greece, Spain, Life Cycle CML 2001 Baseline (SimaPro Software)

Impact category	Olive Oil Life Cycle_ GR	Olive Oil Life Cycle_ ES
Abiotic Depletion	6,78E-05	9,72E-07
Acidification	4,28E-06	7,22E-07
Eutrophication	1,20E-05	7,90E-06
Global Warming (GWP100)	3,49E-05	4,60E-07
Ozone Layer Depletion (ODP)	3,13E-09	3,84E-09
Human Toxicity	5,66E-06	1,16E-07
Fresh Water Aquatic Ecotoxicity	1,48E-05	1,54E-06
Marine Aquatic Ecotoxicity	6,66E-05	2,87E-06
Terrestrial Ecotoxicity	1,18E-06	2,09E-06
Photochemical Oxidation	6,78E-07	6,90E-08

5.3.2. Results of Impact Indicators according to the Eco-Indicator 99 Method

5.3.2.1. Greece

5.3.2.1.1. Graphical Representation

The results of the *Impact Indicators* according to *Eco-Indicator 99* method, for the Greek *Production System,* for each *Phase,* as well as for the complete *Life Cycle*, are presented below. The *Distribution* phase is not presented separately, since it comprises from only one *Transportation Process,* thus, it is the only one with an environmental impact.

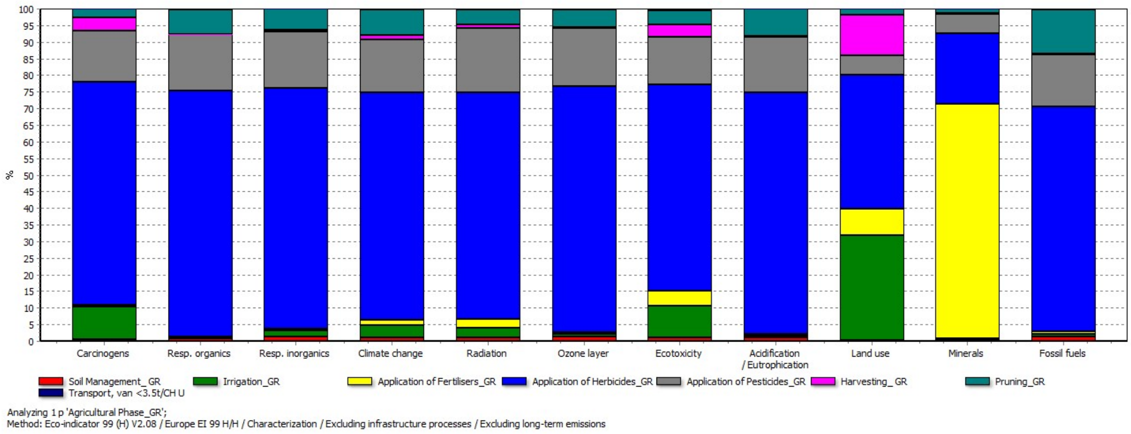


Figure 5.19.: Agricultural Phase, Greece, Results per Impact Category, Eco-Indicator 99, Damage Assessment (SimaPro Software)

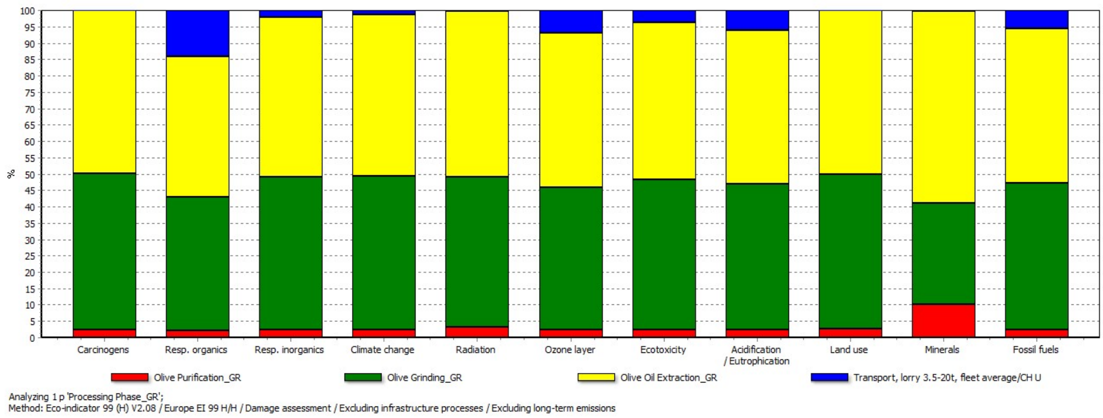


Figure 5.20.: Processing Phase, Greece, Results per Impact Category, Eco-Indicator 99, Damage Assessment (SimaPro Software)

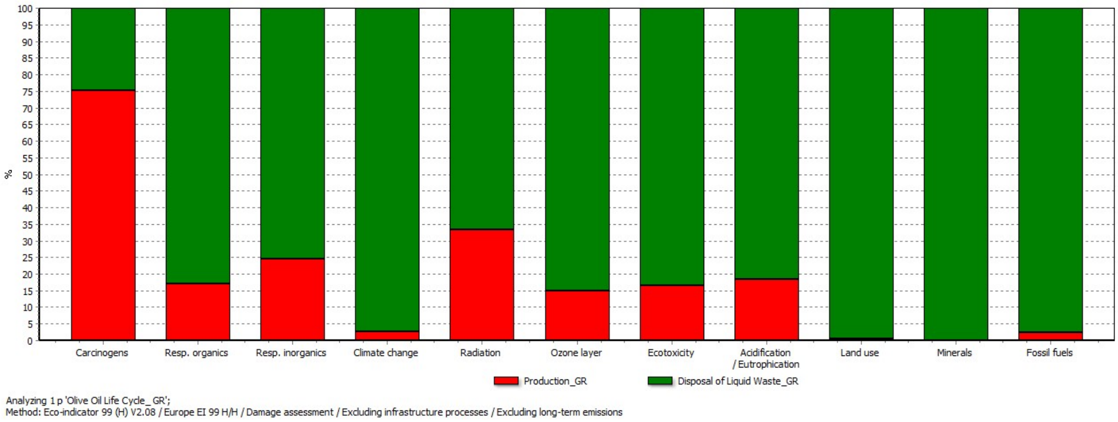


Figure 5.21.: Life Cycle, Greece, Results per Impact Category, Eco-Indicator 99, Damage Assessment (SimaPro Software)

5.3.2.1.2. Numerical Representation

The *Damaged Assessment* values per each *Impact Indicator,* for the Greek *Production System*, for each *Phase*, as well as for the complete *Life Cycle* are presented in the table below:

Table 5.14.: Life Cycle, Greece, Damage Assessment, Eco-Indicator 99 (SimaPro Software)

Impact Category	Unit	Agricultural Phase	Processing Phase	Distribution Phase	Disposal of Liquid Waste	Life Cycle
Carcinogens	DALY	2,57E+00	9,52E-01	2,25E-04	1,17E+00	4,68E+00
Resp. Organics	DALY	6,91E-02	7,41E-05	3,78E-05	3,37E-01	4,07E-02
Resp.Inorganics	DALY	5,83E-01	3,99E+00	3,97E-02	1,92E+02	2,55E+02
Climate Change	DALY	7,62E+00	1,06E+00	9,53E-03	3,14E+02	3,23E+02
Radiation	DALY	3,77E-03	1,58E-03	3,94E-07	1,07E-02	1,61E-02
Ozone Layer	DALY	5,43E-04	1,57E-04	7,17E-06	3,21E-02	3,77E-02
Ecotoxicity	PDF*m2yr	0.013535444	0.0051492529	0.00011773424	0.095701005	0.11450344
Acidification/ Eutrophication	PDF*m2yr	0.25140852	0.0061692645	0.00020655717	11.529.254	14.107.098
Land Use	PDF*m2yr	0.00057218013	0.0007161575	1,86E+00	0.19298335	0.19427187
Minerals	MJ surplus	0.0001218391	1,50E+02	3,15E-01	0.14599572	0.14613264
Fossil Fuels	MJ surplus	71.376.915	0.24085913	0.0086865322	2.916.165	29.900.374

The *Normalised* values per *Damage Category,* for the Greek *Production System*, for each *Phase*, as well as for the complete *Life Cycle* are presented in the table below:

Table 5.15.: Life Cycle, Greece, Normalisation, Eco-Indicator 99 (SimaPro Software

Damage Category	Agricultural Phase	Processing Phase	Distribution Phase	Disposal of Liquid Waste	Life Cycle
Human Health	1,17E+03	6,85E+02	5,65E+00	5,87E+02	5,87E+02
Ecosystem Quality	6,86E+01	2,10E+01	5,67E-01	5,40E+02	5,40E+02
Resources	1,62E-01	3,19E+02	1,15E+01	1,94E+02	1,94E+02

5.3.2.2. Spain

5.3.2.2.1. Graphical Representation

The results of the *Impact Indicators* according to *Eco-Indicator 99* method, for the Spanish *Production System,* for each *Phase,* as well as for the complete *Life Cycle*, are presented below. The *Distribution* phase is not presented separately, since it comprises from only one *Transportation Process,* thus, it is the only one with an environmental impact.

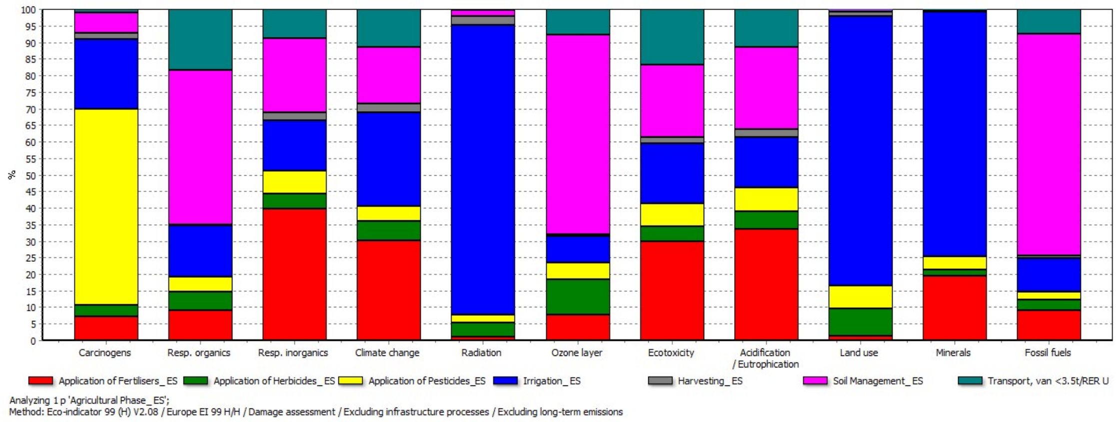


Figure 5.22.: Agricultural Phase, Spain, Results per Impact Category, Eco-Indicator 99, Damage Assessment (SimaPro Software)

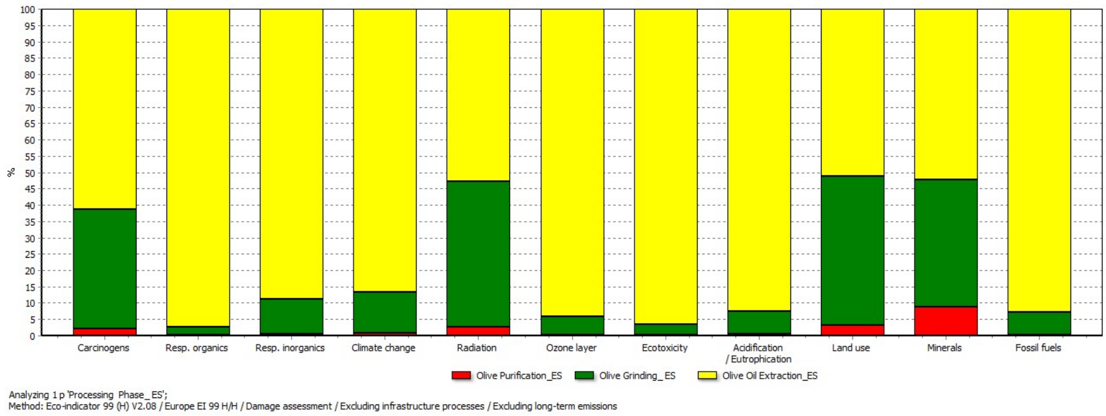


Figure 5.23.: Processing Phase, Spain, Results per Impact Category, Eco-Indicator 99, Damage Assessment (SimaPro Software)

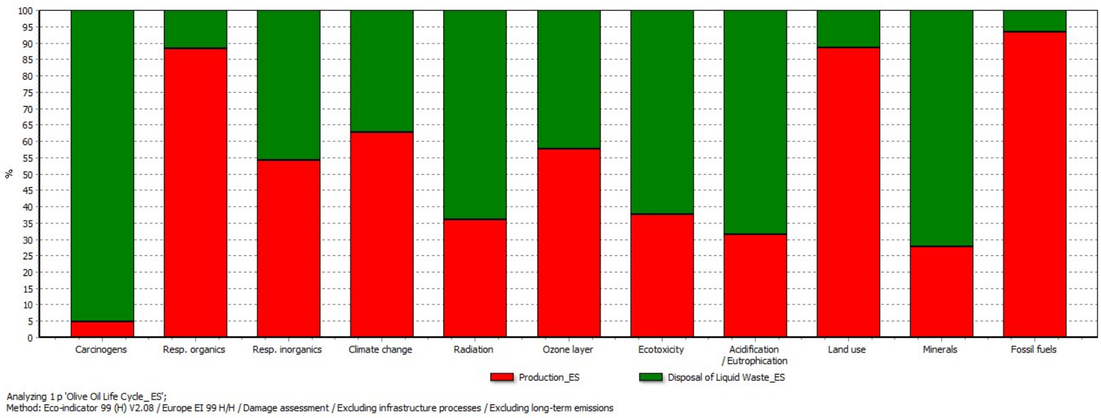


Figure 5.24.: Life Cycle, Spain, Results per Impact Category, Eco-Indicator 99, Damage Assessment (SimaPro Software)

5.3.2.2.2. Numerical Representation

The *Damaged Assessment* values per each *Impact Indicator,* for the Spanish *Production System*, for each *Phase*, as well as for the complete *Life Cycle* are presented in the table below:

Table 5.16.: Life Cycle, Damage Assessment, Eco-Indicator 99 (SimaPro Software)

Impact Category	Unit	Agricultural Phase	Processing Phase	Distribution Phase	Disposal of Liquid Waste	Life Cycle
Carcinogens	DALY	8,69E-01	6,92E-02	1,52E-03	1,86E+01	1,95E+01
Resp. Organics	DALY	1,10E-02	3,67E-03	3,54E-04	2,02E-03	1,71E-02
Resp.Inorganics	DALY	9,84E+00	3,37E+00	1,50E-01	1,13E+01	2,47E+01
Climate Change	DALY	2,01E+00	6,57E-01	4,09E-02	1,61E+00	4,32E+00
Radiation	DALY	3,94E-02	3,39E-04	1,79E-05	7,61E-02	1,19E-01
Ozone Layer	DALY	2,22E-03	4,07E-04	3,04E-05	1,95E-03	4,61E-03
Ecotoxicity	PDF*m2yr	0.0078636397	0.0070133256	0.00023214936	0.02510359	0.040212705
Acidification/ Eutrophication	PDF*m2yr	0.026371857	0.014112417	0.00052917554	0.089426345	0.13043979
Land Use	PDF*m2yr	0.0063151525	0.00031200228	8,46E+00	0.00086349368	0.0074914947
Minerals	MJ surplus	0.0018047878	2,28E+02	2,14E+00	0.0047527013	0.0065804713
Fossil Fuels	MJ surplus	29.110.616	0.50829787	0.037487642	0.25082409	37.076.712

The *Normalised* values per *Damage Category,* for the Spanish *Production System*, for each *Phase*, as well as for the complete *Life Cycle* are presented in the table below:

Table 5.17.: Life Cycle, Spain, Normalisation, Eco-Indicator 99 (SimaPro Software)

Damage Category	Agricultural Phase	Processing Phase	Distribution Phase	Disposal of Liquid Waste	Life Cycle
Human Health	334,4733	468,3186	21,98966	193,1621	64,88938
Ecosystem Quality	70,88254	37,47318	1,332275	200,3493	311,3957
Resources	2,391344	673,5248	49,67141	338,6392	8,719125

5.3.3. Greece- Spain Comparison

5.3.3.1. Graphical Representation

The comparison of the results of the *Impact Indicators* according to *Eco-Indicator 99* method, for the Greek and Spanish *Production Systems,* for each *Phase,* as well as for the complete *Life Cycle*, are presented below.

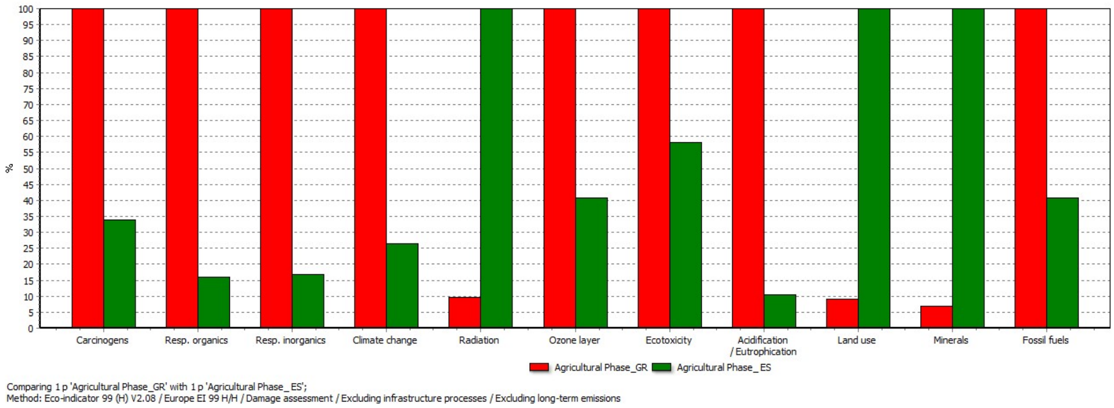


Figure 5.25.: Agricultural Phase, Greece, Spain, Results per Impact Category, Eco-Indicator 99, Damage Assessment (SimaPro Software)

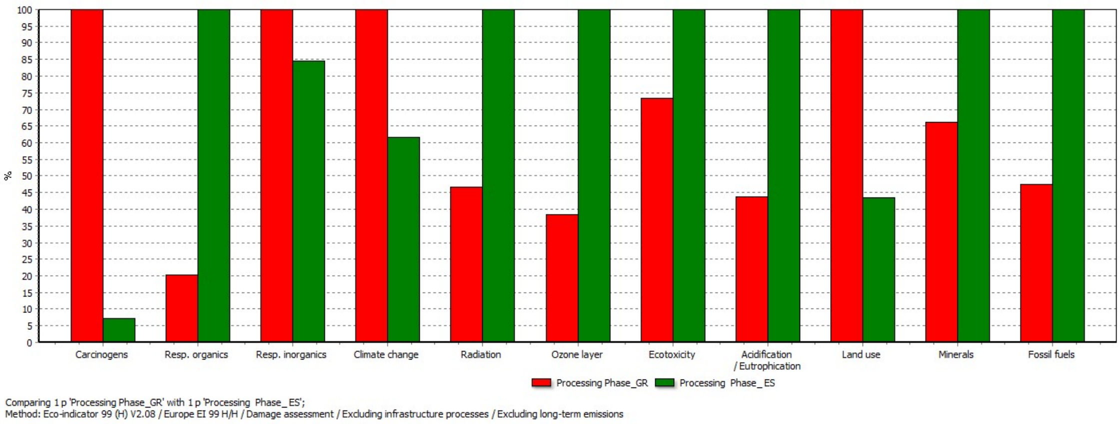


Figure 5.26.: Processing Phase, Greece, Spain, Results per Impact Category, Eco-Indicator 99, Damage Assessment (SimaPro Software)

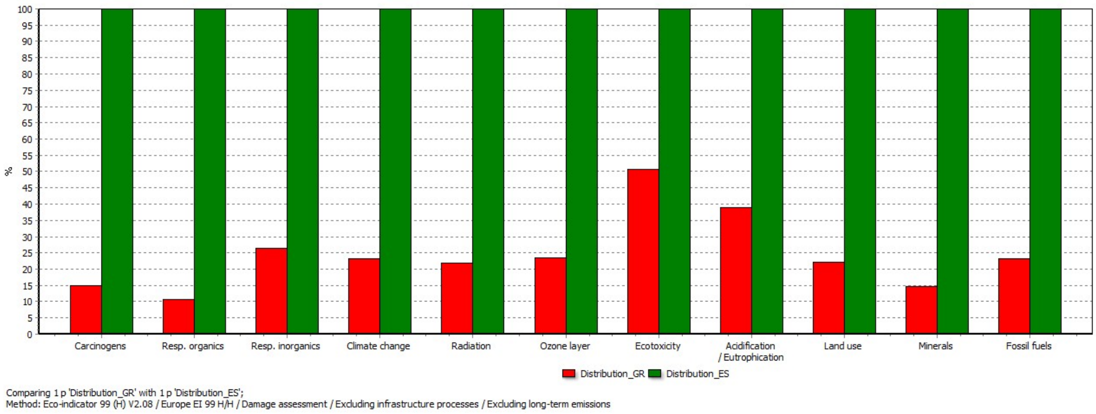


Figure 5.27.: Distribution Phase, Greece, Spain, Results per Impact Category, Eco-Indicator 99, Damage Assessment (SimaPro Software)

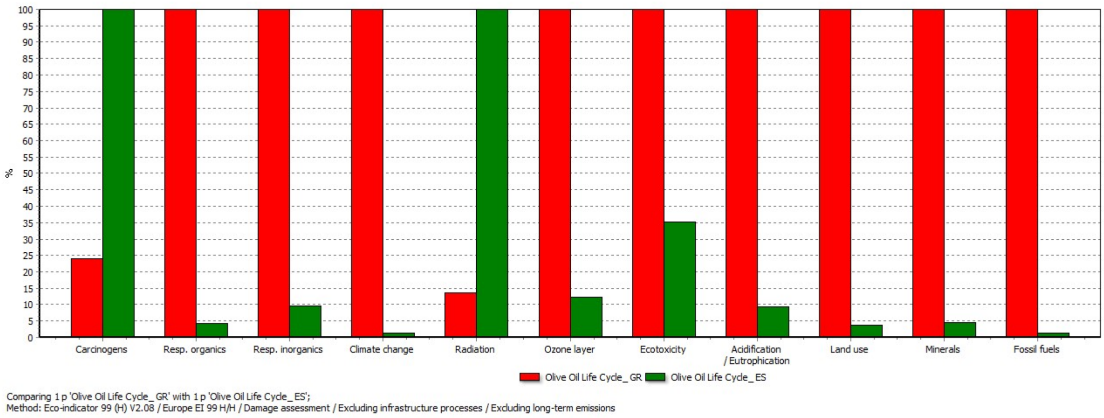


Figure 5.28.: Life Cycle, Greece, Spain, Results per Impact Category, Eco-Indicator 99, Damage Assessment (SimaPro Software)

5.3.3.2. Numerical Representation

The comparison of the *Damaged Assessment* values, per *Impact Category*, for the *Agricultural* phase, for the Greek and Spanish *Production Systems* are presented in the table below:

Table 5.18.: Agricultural Phase, Greece, Spain, Damage Assessment, Eco-Indicator 99 (SimaPro Software)

Impact Category	Unit	Agricultural Phase_ GR	Agricultural Phase_ ES
Carcinogens	DALY	2,57E+00	8,69E-01
Resp. Organics	DALY	6,91E-02	1,10E-02
Resp.Inorganics	DALY	5,86E+01	7,76E+00
Climate Change	DALY	7,62E+00	2,01E+00
Radiation	DALY	3,77E-03	3,93E-02
Ozone Layer	DALY	5,43E-04	2,22E-03
Ecotoxicity	PDF*m2yr	0.013535444	0.0078636397
Acidification/	PDF*m2yr	0.25140852	0.026371857

Eutrophication			
Land Use	PDF*m2yr	0.00057218013	0.0063151525
Minerals	MJ surplus	0.0001218391	0.0018047878
Fossil Fuels	MJ surplus	42.740.724	18.334.477

The comparison of the *Normalised* values, per *Damage Category,* for the *Agricultural* phase, for the Greek and Spanish *Production Systems* are presented in the table below:

Table 5.19.: Agricultural Phase, Greece, Spain, Normalisation, Eco-Indicator 99 (SimaPro Software)

Damage Category	Agricultural Phase_ GR	Agricultural Phase_ ES
Human Health	1,17E+03	334,4733
Ecosystem Quality	6,86E+01	70,88254
Resources	1,62E-01	2,391344

The comparison of the *Damaged Assessment* values, per *Impact Category*, for the *Processing* phase, for the Greek and Spanish *Production Systems* are presented in the table below:

Table 5.20.: Processing Phase, Greece, Spain, Damage Assessment, Eco-Indicator 99 (SimaPro Software)

Impact Category	Unit	Processing Phase_GR	Processing Phase_ ES
Carcinogens	DALY	9,52E-01	6,92E-02
Resp. Organics	DALY	7,41E-05	3,67E-03
Resp.Inorganics	DALY	3,99E+00	3,38E+00
Climate Change	DALY	1,06E+00	6,57E-01
Radiation	DALY	1,58E-03	3,39E-04
Ozone Layer	DALY	1,57E-04	4,07E-04
Ecotoxicity	PDF*m2yr	0.0051492529	0.0070133256
Acidification/ Eutrophication	PDF*m2yr	0.0061692645	0.014112417
Land Use	PDF*m2yr	0.0007161575	0.00031200228
Minerals	MJ surplus	1,50E+02	2,28E+02
Fossil Fuels	MJ surplus	0.46064325	0.3280141

The comparison of the *Normalised* values, per Damage Category, for the *Processing* phase, for the Greek and Spanish *Production Systems* are presented in the table below:

Table 5.21.: Processing Phase, Greece, Spain, Normalisation, Eco-Indicator 99 (SimaPro Software)

Damage Category	Processing Phase_GR	Processing Phase_ ES
Human Health	6,85E+02	468,3186
Ecosystem Quality	2,10E+01	37,47318
Resources	3,19E+02	673,5248

The comparison of the *Damaged Assessment* values, per *Impact Category*, for the *Distribution* phase, for the Greek and Spanish *Production Systems* are presented in the table below:

Table 5.22.: Distribution Phase, Greece, Spain, Damage Assessment, Eco-Indicator 99 (SimaPro Software)

Impact Category	Unit	Distribution Phase_GR	Distribution Phase_ES
Carcinogens	DALY	2,25E-04	1,52E-03
Resp. Organics	DALY	3,78E-05	3,54E-04
Resp.Inorganics	DALY	3,99E-02	1,51E-01
Climate Change	DALY	9,53E-03	4,09E-02
Radiation	DALY	3,94E-06	1,79E-05
Ozone Layer	DALY	7,17E-06	3,04E-05
Ecotoxicity	PDF*m2yr	0.00011773424	0.00023214936
Acidification/ Eutrophication	PDF*m2yr	0.00020655717	0.00052917554
Land Use	PDF*m2yr	1,86E+00	8,46E+00
Minerals	MJ surplus	3,15E-01	2,14E+00
Fossil Fuels	MJ surplus	0.0050453262	0.021780975

The comparison of the *Normalised* values, per *Damage Category*, for the *Distribution* phase, for the Greek and Spanish *Production Systems* are presented in the table below:

Table 5.23.: Distribution Phase, Greece, Spain, Normalisation, Eco-Indicator 99 (SimaPro Software)

Damage Category	Distribution Phase _GR	Distribution Phase_ ES
Human Health	5,65E+00	21,98966
Ecosystem Quality	5,67E-01	1,332275
Resources	1,15E+01	49,67141

The comparison of the *Damaged Assessment* values, per *Impact Category*, for the *Life Cycle* phase, for the Greek and Spanish *Production Systems* are presented in the table below:

Table 5.24.: Life Cycle, Greece, Spain, Damage Assessment, Eco-Indicator 99 (SimaPro Software)

Impact Category	Unit	Life Cycle_ GR	Life Cycle_ ES
Carcinogens	DALY	4,68E+00	1,95E+01
Resp. Organics	DALY	4,07E-02	1,71E-02
Resp.Inorganics	DALY	2,56E+02	2,26E+01
Climate Change	DALY	3,23E+02	4,32E-01
Radiation	DALY	1,61E-02	1,19E-01
Ozone Layer	DALY	3,77E-02	4,61E-03
Ecotoxicity	PDF*m2yr	0.11450344	0.040212705
Acidification/ Eutrophication	PDF*m2yr	14.107.098	0.13043979

Land Use	PDF*m2yr	0.19427187	0.0074914947
Minerals	MJ surplus	0.14613264	0.0065804713
Fossil Fuels	MJ surplus	17.837.342	24.293.677

The comparison of the *Normalised* values, per Impact Category, for the *Life Cycle*, for the Greek and Spanish *Production Systems* are presented in the table below:

Table 5.25.: Life Cycle, Greece, Spain, Normalisation, Eco-Indicator 99 (SimaPro Software)

Damage Category	Life Cycle_ GR	Life Cycle_ ES
Human Health	5,87E+02	64,88938
Ecosystem Quality	5,40E+02	311,3957
Resources	1,94E+02	8,719125

5.4. DISCUSSION OF RESULTS

5.4.1 Discussion of Results of Impact Indicators according to the CML 2001 Baseline Method

Analysed data suggest that the overall impact of the Greek olive oil *Production System* is more severe, compared to the Spanish one. However, attention must be paid to the *Impact Indicator*s of *Terrestrial Ecotoxicity* and *Eutrophication* that rank high and can be attributed, the former, to *Fertilisation* and, the latter, to the excessive use of water, mainly for *Irrigation* purposes. Two types of *Fertilisers* are applied in *Ribera Baja*, *NPK 12-12-24* and *Nitrate*-based. Moreover, *Fertilisation* is a mechanical process, compared to their manual application in *Voukolies.* Regarding *Irrigation,* almost all olive plantations are irrigated from superficial waters which are free, therefore *Water Consumption* is neither controlled nor monitored (Ecoil, 2006). Finally, *Waste Treatment*, as depicted in the *Disposal* scenarios contribute to the lower overall environmental impact of the Spanish olive oil *Life Cycle*. *Wastewater* is treated in designated facilities, *Pomace* is re-used. The difference with the Greek *Waste Treatment* option is that, *Wastewater* is treated through *Chlorination,* a process that generates emissions to water and *Pomace* is considered a final waste flow.
As a second-level analysis, conclusions on the *Impact Indicators* that rank the highest per each *Phase* of the two *Production Systems* may be drawn. Overall, the Greek *Agriculture* phase has a higher environmental impact compared to the Spanish one. The impact categories that rank the highest are *Abiotic and Ozone Layer Depletion*, This can be, mainly attributed to the type of *Herbicides* used in Greece, having *Glyphosate* as the main compound. According to some studies *Glyphosate* may persist in the ground for up to six months (National Pesticide Information Centre, 2018).
The Greek *Processing* phase, generally, holds a higher environmental burden. However, the Spanish *Production System* scores high regarding the *Ozone Layer Depletion Impact Indicator.* This can be attributed to the olive oil *Extraction* process and, in particular, the stage of *Pomace* separation and transportation of the By-product to the location of buyer. Three more *Impact Indicators* of the Spanish *Production System* that we may focus on are *Acidification, Eutrophication* and *Global*

Warming (GWP100). Acidification and *Eutrophication* can, again, be attributed to the olive oil *Extraction* process and, in particular, the stage of *Pomace* separation and transportation of the By-product to the location of the *Buyer*. The high score of the *Global Warming (GWP100) Impact Indicator* can be attributed on the levels of *Energy Consumption.* One considerable energy consuming factor is the *Olive Mill (OM)* processes and particularly the olive oil *Extraction* process, which takes place by using *two-phase systems.* Although, such systems are efficient, they demand greater energy resources, compared to *three-phase* ones used in Greece.

Finally, the phase where the Greek *Production System* has less environmental impact is that of *Distribution*. This is due to the fact, that though the distance considered in the Greek *Production System* is greater, it is performed by more efficient means.

5.4.2 Discussion of Results of Impact Indicators according to the Eco-indicator 99 Method

Analysed data suggest that, overall, the Spanish *Production System* causes less damage to all *Damage Categories* compared to the Greek one. However, at a closer look per each *Phase,* some useful conclusions may be drawn. In the *Agricultural* phase, the Spanish *Production System* ranks higher at the *Ecosystem Quality Damage Category*, mainly due to the *Acidification/Eutrophication Impact Indicator*. As in the case of the *CML 2001 Baseline* analysis, this can be attributed to the excessive use of free and uncontrolled water resources that occurs in the *Ribera Baja* case.

Similarly, in the *Processing* phase, the Spanish *Production System* has a greater impact regarding the *Damage to Resources Damage Category.* One cause may be the energy consumed, throughout the *Olive Mill (OM)* processes, especially the energy consumed by the *two-phase system* used for the separation of olive oil during the *Extraction* process.

Finally, we notice that the *Distribution* phase is the only one that the Greek production System has less impact compared to the Spanish one. Again, this is due to the use of more efficient means of transportation.

CHAPTER 6

CONCLUSIONS

6.1. CONCLUSIONS-RECOMMENDATIONS

Olive oil production is a significant global business sector, as an increasing number of States engages into the activity. The industry is, particularly, significant for the European Union (EU), where considerable areas of farming land is devoted into olive cultivation and numerous businesses operate within the olive oil supply chain, from olive oil processing, to packaging, to distribution, to marketing of the final product. Even more significant, it is to states across the Mediterranean, as olives and olive oil have traditionally been a source of employment and income. Moreover, olives and olive oil have, historically, been affiliated with the Mediterranean culture, tradition and lifestyle.

However, the production of olive oil can be the cause of several adverse environmental effects. These effects may differ, based on the practices and methods applied within the various steps of the olive oil *Life Cycle*. This paper focused on the identification of those effects and the evaluation of their impact, by examining two distinct *Production Systems* applied in Greece and Spain, two of the major international olive oil producers with the use of the *Life Cycle Assessment (LCA)* methodology, with a special focus on the *Agricultural, Processing* and *Distribution* phases, with the first two, being, according to the *Literature Review* the highest contributors to the environmental impacts identified. The differences identified refer to the different practices adopted within the supply chain, such as, the level of *Irrigation* applied, the type of *Fertilisers* used, the *Processing Systems*, the management of *By-products* and *Waste*, the methods of *Disposal*.

Even though, the environmental impacts caused by the two *Production Systems* examined differ, it becomes evident that certain stages of the olive oil supply chain are responsible for these adverse environmental effects, the most important of which being:

- *Water Consumption*: during the *Agricultural* phase water is, mainly, consumed because of *Irrigation*. Although *Irrigation* improves olive production, it should be applied in moderation, following a specific plan, given, also, that the olive tree is particularly resistant to dry conditions. The selection of soil type is another crucial factor regarding *Water Consumption* rationalisation.

In the *Production* phase, the amount of water used depends on the extraction method used (*Pressure* or *Centrifiguration*) and the engineering processes applied. *Two-phase systems* require less use of water, since an amount of water used is recycled, thus they are more efficient compared to *three-phase* ones. However, water consumption, within the *Olives Purification*, must be closely monitored and controlled, in both types of systems. Additionally, the installation of *Closed Recycling Cleaning Systems,* not only lead to decreases in *Water Consumption,* but can lead to *Energy Efficiencies* (Ecoil, 2006).

- *Application of Chemicals*: agricultural yield and productivity can be improved by the application of chemical *Fertilisers*, *Pesticides* and *Herbicides*. However, these chemicals produce emissions that pollute the air and groundwater. Chemicals must not, only be used in moderation, but should be applied under a specific plan and with methods suggested by authorities.
- *Waste Management:* in the *Agricultural* phase, waste generated is solid in the form of *Pruning Residues*. These *Residues* may be either burnt, which result in air emissions, or can have alternative uses, such as row material for heat and livestock feeding. In the *Production* phase, waste generated can be classified as solid (*Olive Pomace*) and liquid (*Olive Mill Wastewater-OMWW*) waste. Their final treatment depends on the practice adopted. For example, *Olive Pomace* may be either landfilled, or sold as a by-product. The amount of *OMWW* depends on the extraction system applied: *two-phase systems* generate less wastewater, as an amount of water used is recycled, compared to *three-phase systems.* As generated *Solid Waste* can have alternative uses, the most efficient approach is to be treated as a by-product rather than be considered as a final waste flow. As mentioned before, *Pruning Residues* may be used as row material for heat and livestock feeding, while *Olive Pomace* may be the base of an alternative and renewable source of energy in the form of *Pomace Wood.* On the other hand, *Wastewater* may be re-used for *Irrigation* purposes, after undergoing treatment.

Finally, although it has not been identified as the most severe environmental effect, measures have been proposed regarding the rationalisation of *Energy Consumption*, such as the adaptation of an *Energy Management Plan* (*Demand Analysis, Combustion Improvement, Insulation of Thermal surfaces, Use of Energy Saving Equipment, Processes Automation, or Improvement in Exploiting Thermal Content of Exhaust Gases*) that may not only achieve lower energy requirements, but, also lead to reduced emissions of exhausted gases (Ecoil, 2006).

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Appendix A

IMPACT ASSESSMENT

A. Results of Impact Indicators according to CML 2001 Baseline Method

A.1. Greece

A.1.1. Graphical Representation

The results of the *Impact Indicators* according to *CML 2001 Baseline* method, for the Greek *Production System,* for each *Phase,* as well as for the complete *Life Cycle*, are presented below. The *Distribution* phase is not presented separately, since it comprises from only one *Transportation Process,* thus, it is the only one with an environmental impact.

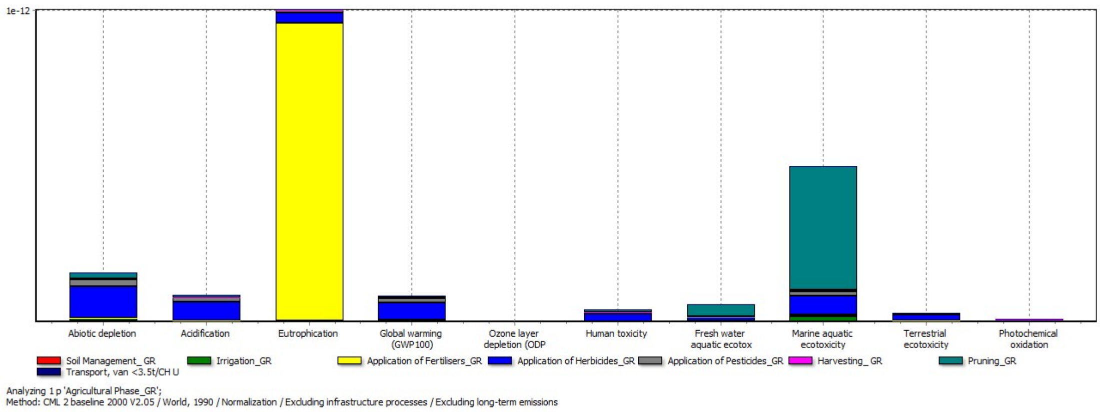

Figure A.1.: Agricultural Phase, Greece, Results per Impact Category, CML 2001 Baseline, Normalisation (SimaPro Software)

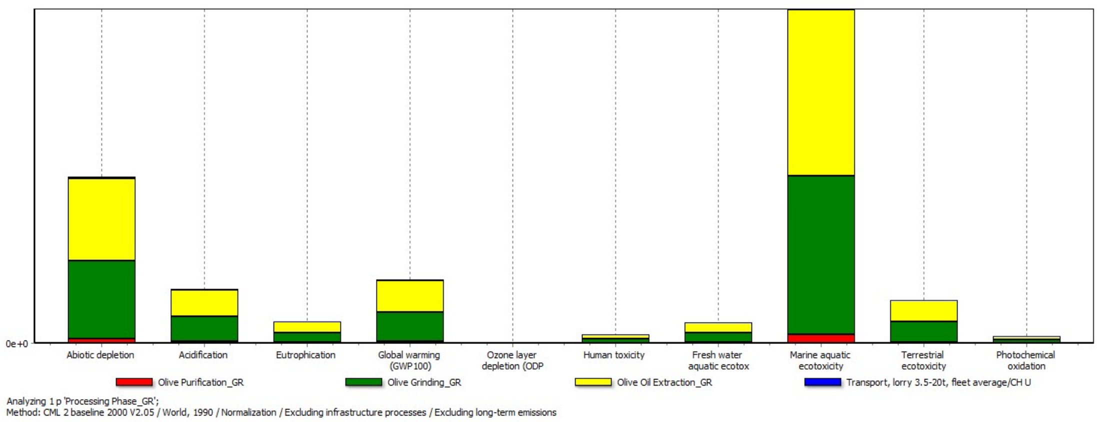

Figure A.2.: Processing Phase, Greece, Results per Impact Category, CML 2001 Baseline, Normalisation (SimaPro Software)

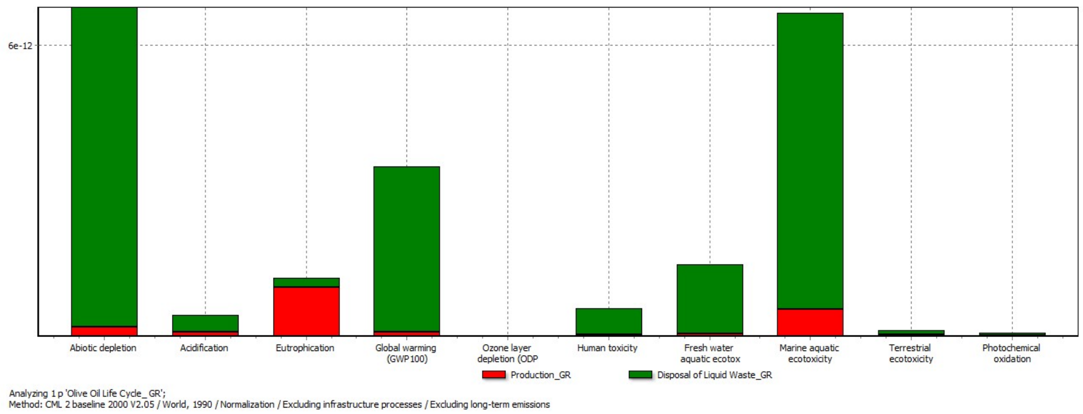

Figure A.3.: Life Cycle, Greece, Results per Impact Category, CML 2001 Baseline, Normalisation (SimaPro Software)

A.2. Spain

A.2.1. Graphical Representation

The results of the *Impact Indicators* according to *CML 2001 Baseline* method, for the Spanish *Production System,* for each *Phase,* as well as for the complete *Life Cycle*, are presented below. The *Distribution* phase is not presented separately, since it comprises from only one *Transportation Process,* thus, it is the only one with an environmental impact.

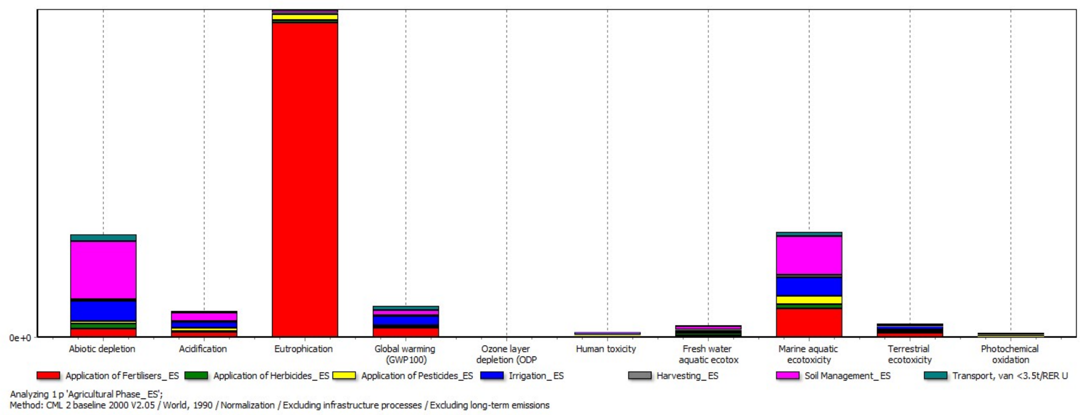

Figure A.4.: Agricultural Phase, Spain, Results per Impact Category, CML 2001 Baseline, Normalisation (SimaPro Software)

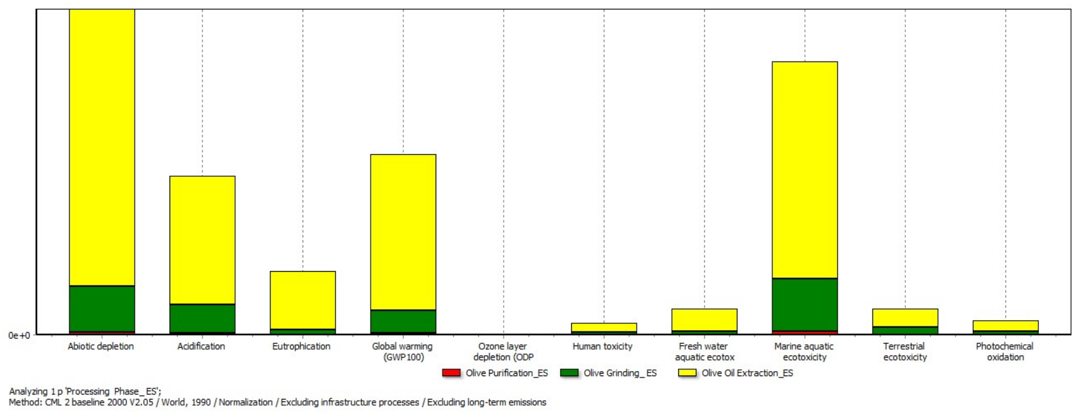

Figure A.4.: Processing Phase, Spain, Results per Impact Category, CML 2001 Baseline, Normalisation (SimaPro Software)

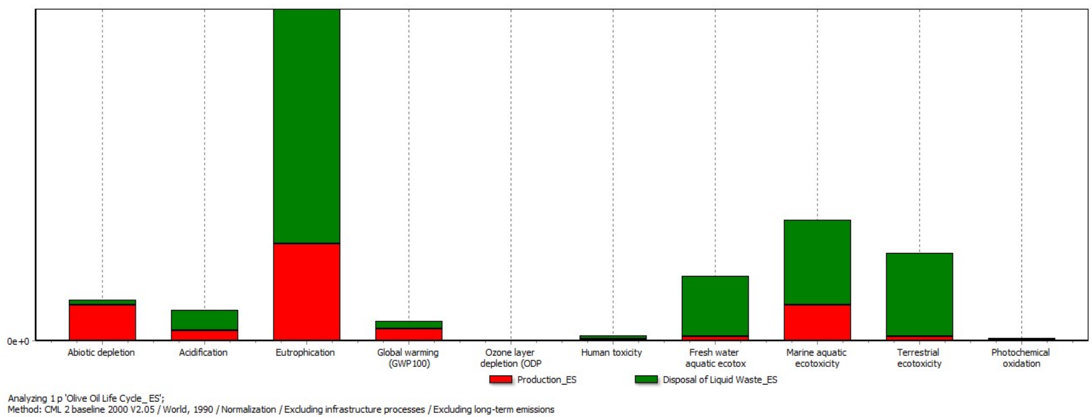

Figure A.6.: Life Cycle, Spain, Results per Impact Category (CML 2001 Baseline, Normalisation (SimaPro Software)

A.3. Greece- Spain Comparison

A.3.1. Graphical Representation

The comparison of the results of the *Impact Indicators* according to the *CML 2001 Baseline* method, for the Greek and Spanish *Production Systems,* for each *Phase,* as well as for the complete *Life Cycle*, are presented below.

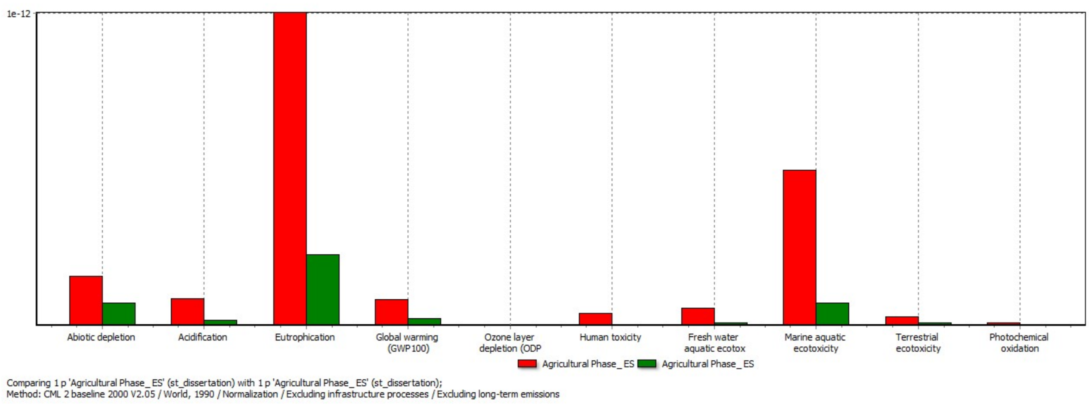

Figure A.7.: Agricultural Phase, Greece, Spain, Results per Impact Category, CML 2001 Baseline, Normalisation (SimaPro Software)

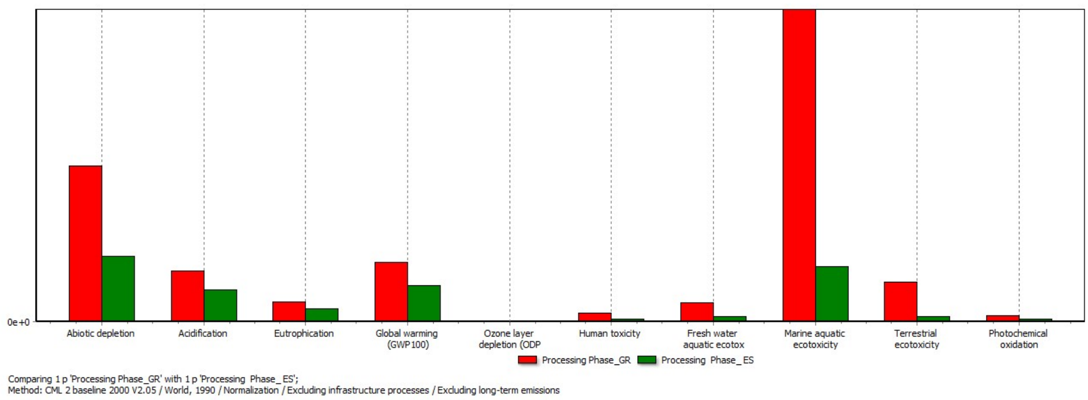

Figure A.8.: Processing Phase, Greece, Spain, Results per Impact Category, CML 2001 Baseline, Normalisation (SimaPro Software)

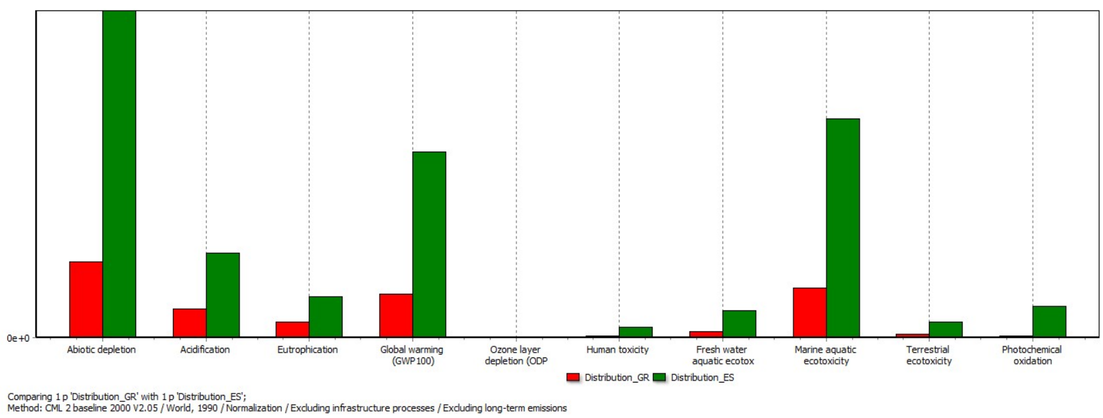

Figure A.9.: Distribution Phase, Greece, Spain, Results per Impact Category, CML 2001 Baseline, Normalisation (SimaPro Software)

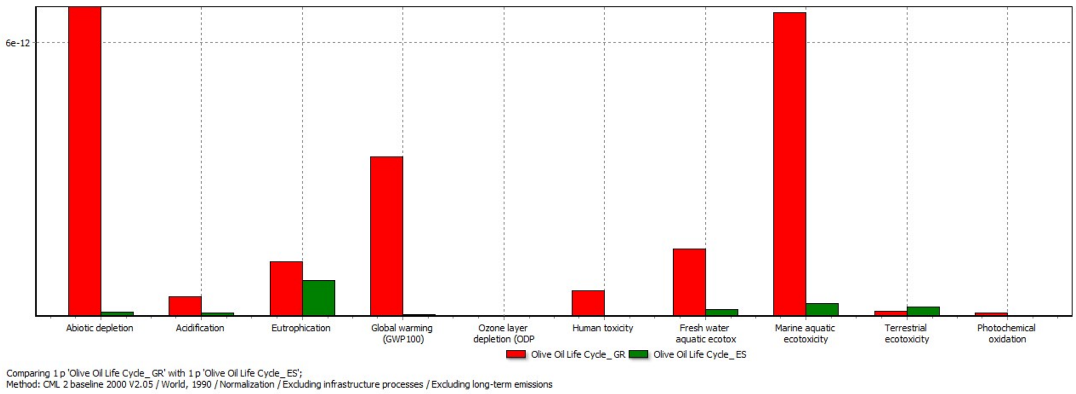

Figure A.10.: Life Cycle, Greece, Spain, Results per Impact Category, CML 2001 Baseline, Normalisation (SimaPro Software)