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# Life Cycle Assessment of olive oil production in Greece

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Agricultural production is a sector with high socio-economic significance and key implications on employment and nutritional security. However, the impacts of agrifood production and consumption patterns on the environment are considerable, mainly due to the demand of large inputs of resources. This paper presents a case study of olive oil production in Greece, an important agri-product especially for countries in the Mediterranean basin. *Life Cycle Assessment* has been used to quantify the environmental performance of olive oil production. Fourteen sub-systems of the overall olive oil production are investigated. All key parameters that are associated with the life cycle of olive oil production are studied and environmental "hotspots" are diagnosed. Cultivation of olive trees and production of olive oil are the sub-systems that are responsible for the majority of the environmental impacts and thus any effort to minimize the overall life cycle impact from olive oil production should include them.



## 1. Introduction

Agrifood is considered as one of the industrial sectors with a major political and economic significance and as such it is highly regulated and protected within Europe (Iakovou et al., 2014). Moreover, it is one of the sectors with key implications on human capital employment, nutritional security, but also on environmental sustainability due to the demand of large inputs of resources (Tukker et al., 2006; Koroneos et al., 2005). Solely, the food and drink sector is responsible for nearly one third of the overall environmental impacts in Europe (Bakas, 2012).

In the last decade, the increased alertness of consumers on the impacts of agrifood production and consumption patterns on the environment urged the industry within the sector to give emphasis on the environmental issues related to their products (Matos and Hall, 2007; Maloni and Brown, 2006; Vachon and Klassen, 2006; Welford and Frost, 2006; Ilbery and Maye, 2005; Courville, 2003; Weatherell and Allinson, 2003). However, in practice there are major obstacles in conducting studies that deal with impacts of food products from "farm to fork". This is mainly attributed to the lack of public databases with suitable data for such a large and complex system as the one of the agrifood industrial sector (Koroneos et al., 2005). Moreover, the required data involves a large number of stakeholders (production, manufacturing, storage, distribution, packaging, consumption and disposal) and scientific disciplines who often do not share data. In this light, scientific work usually focuses either on primary agri-production or on industrial processing of agrifood and does not cover agrifood production from cradle to grave.

In this work, the emphasis is given in the life cycle of olive oil, which is considered as a key agrifood product for countries in the Mediterranean basin both due to its considerable share in the local economy, but also due to its role in the Mediterranean diet. Olive oil production involves the consumption of significant quantities of resources (e.g. energy, fuel, water, chemical products) and the generation of emissions that are emitted to the natural environment. The tool that is chosen for the calculation of the environmental burden is Life Cycle Assessment (LCA), one of the most commonly used environmental tools for environmental management and decision-making (Iakovou et al., 2009). Following to the ISO 14040 and 14044 standards (ISO, 2006a, 2006b), LCA targets to quantify the effects from the use of energy and material processing throughout all phases in a product's life cycle (e.g. Winkler and Bilitewski, 2007; Finnveden, 1999; Craighill and Powell, 1996).

In the literature there are a number of studies that have used LCA for various stages of the olive oil production. Indicatively,

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Notarnicola et al. (2004) compared the production systems of the conventional and organic extra-virgin olive oil in order to measure cost and environmental profiles. The work resulted into the fact that the organic system has a better environmental profile. However, its cost profile is significantly worse when the external costs are not taken into account. Similarly, De Gennaro et al. (2012) integrated LCA and LCC methods in order to assess whether high trees density olive-growing, which allows a higher level of mechanization, can reduce production costs without jeopardizing the environmental sustainability. The LCA has proved that such innovative olive-growing models show better environmental performance for all impact categories that were investigated. Moreover, they were proven also to be more cost efficient compared to traditional practices. Avraamides and Fatta (2008) investigated the processes that result to the most significant environmental burdens in olive oil production in Cyprus. The study provided evidence that the production of the inorganic fertilizers, along with the disposal of liquid effluent from olive mills to evaporation ponds were major contributors to the olive oil life cycle environmental impact. Intini et al. (2011) used LCA in order to assess the environmental performance of a power plant that is fed with olive oil industries' waste. Michalopoulos and Christodoulopoulou (2011) conducted a comprehensive LCA study on extra virgin olive oil produced by 68 olive growers in 487 olive groves in southern Greece. The authors resulted that the cultivation of olive trees is responsible for the vast majority of the life cycle environmental impacts. Moreover, Salomone and Ioppolo (2012) used LCA in order to determine the environmental impacts of activities related to the production of olive oil in the province of Messina, Italy and design an eco-friendlier and more efficient local supply chain. Results show that the phase of agri-production is the main contributor to the overall environmental impact, even in the scenarios that pest treatments are limited. Cossu et al. (2013) used LCA in order to study the wet husk and improve the recovery and upgrade the solid wastes of the olive oil extraction process. From the study, it becomes evident that wastewater management produced from husk during the oil extraction should be optimized in order to minimize the overall environmental burden. Iraldo et al. (2014) used LCA in order to define the environmental requirements for compliance with a product qualification scheme. According to the authors, the LCA study can provide critical insights towards process and product redesign.

Although a number of relevant papers have been already published in conference proceedings and technical reports, up to the authors' knowledge this is the first attempt to demonstrate the environmental impact of olive oil production in Greece and validate it through its publication in a well acknowledged peer reviewed journal. Moreover, the olive oil production system that is herein studied is analyzed into fourteen (14) sub-systems in an effort both to increase the detail of the analysis and at the same time provide useful insights concerning the processes that are most responsible for the overall burden. The main objective of this paper is to recognize all key parameters that are associated with the life cycle of olive oil production in Greece. More specifically, through the presented case study focus is given on the identification of the phases within the product's life cycle which is responsible for the majority of the environmental inputs and outputs with the aim to diagnose environmental "hotspots". Furthermore, the present work aims to propose improvements towards overall optimization of the system. The rest of the paper is organized as follows: In Section 2 the product and the system under study are determined, while also the assumptions of the work and the Life Cycle Inventory are presented. Results of the LCA study are illustrated in Section 3 and the paper wraps up with the conclusions in Section 4.

## 2. Product and system definition

The manufacturer under study is based in Gerakini, Chalkidiki, Greece. The company uses olives locally produced and produces bottled olive oil that is mainly exported to Europe. The product studied in this work is extra virgin olive oil and is marketed in 1 lt plastic bottles. The system investigated takes into consideration the following fourteen (14) sub-systems; (i) fertilizer production, transport and use, (ii) pesticides production, transport and use, (iii) manufacture of agricultural equipment, (iv) cultivation of olives, (v) transportation of olives from the field to the manufacturer, (vi) production of olive oil, (vii) bottles' production and transportation, (viii) lids' production, (ix) bottling of olive oil, (x) packaging production and transportation, (xi) adhesive tape, (xii) palettes, (xiii) stretch film, (xiv) palletizing of olive oil bottles. The system is analytically illustrated in Fig. 1.

The functional unit is one bottle of extra virgin olive oil with a volume of 1 lt. The association of the functional unit, which is comprised of the product itself and the packaging materials, with the system's parameters is analytically described in Table 1. The system boundaries include the processes that have been identified and related to production and transportation of chemicals, cultivation of olives, transfer of olives to the mill and all the processes taking place there for the extraction of oil and packaging. Although the system boundaries include all phases of the olive oil production, the following are not included in the present study; (i) consumption of olive oil, (ii) planting of olive trees, (iii) construction of infrastructure and facilities of the mill, (iv) maintenance of plant and agricultural machinery, (v) manufacture and installation of industrial equipment, (vi) packing of raw materials, (vii) the production of diesel, (viii) ink and printing, (ix) storage of waste, (x) raw materials, emissions and waste for the production of pesticides.

The assumptions that are taken into consideration are the following:

a. The production of 1 lt of extra virgin olive oil requires 4 kg of olives.
b. Olives are transported from the farm to the manufacturer with the use of a 2.4 diesel pickup truck. The vehicle's payload weight is 1100 kg consumption of the truck is assumed at 7.5 lt of diesel per 100 km. Such a vehicle is representative of the majority of agricultural machinery used in the wider area under study.
c. Transportations towards and from the farm are materialized with the use of the aforementioned pickup truck, while the tractor remains at the farm.
d. Transportations are calculated based on the place of residence of people involved in the farming process (either owners or seasonal workers). Primarily the place of residence is a village close to the farm. The distance from the farmers' residence to the farms is 4 km on average, while farms are located 5 km on average from the manufacturer. Transportations are calculated on the condition that all the work that is carried out outside of the farm involves only one farmer. For the harvesting of olives in a 25-acres farm, we assume that there are 6 people involved who work 8 h per day. Those six farmers need eight days for harvesting.
e. Farmers use tractors with an average engine of 80 HP, which is typical for farmers in Greece. The consumption of the tractor is assumed at 5 lt of diesel per 100 km for light tasks (spraying, fertilizing, etc.) and 6.5 lt of diesel per 100 km for heavy tasks (plowing, transportation, etc.).
f. Two different hypotheses have been taken into account in our study concerning fuel consumption; (a) low consumption of 5 lt per hour for low-consuming activities such as spraying,