World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:8, No:4, 2014

An Analysis of Eco-efficiency and GHG Emission of Olive Oil Production in Northeast of Portugal

M. Feliciano, F. Maia, A. Gonçalves

Abstract**—**Olive oil production sector plays an important role in Portuguese economy. It had a major growth over the last decade, increasing its weight in the overall national exports. International market penetration for Mediterranean traditional products is increasingly more demanding, especially in the Northern European markets, where consumers are looking for more sustainable products. Trying to support this growing demand this study addresses olive oil production under the environmental and eco-efficiency perspectives. The analysis considers two consecutive product life cycle stages: olive trees farming; and olive oil extraction in mills. Addressing olive farming, data collection covered two different organizations: a middle-size farm (~12ha) (F1) and a large-size farm (~100ha) (F2). Results from both farms show that olive collection activities are responsible for the largest amounts of Green House Gases (GHG) emissions. In this activities, estimate for the Carbon Footprint per olive was higher in F2 (188g CO_2e/kg_{olive}) than in F1 (148g CO_2e/kg_{olive}). Considering olive oil extraction, two different mills were considered: one using a two-phase system (2P) and other with a three-phase system (3P). Results from the study of two mills show that there is a much higher use of water in 3P. Energy intensity (EI) is similar in both mills. When evaluating the GHG generated, two conditions are evaluated: a biomass neutral condition resulting on a carbon footprint higher in 3P (184g $CO_2e/L_{olive\ oil}$) than in 2P (92g $CO_2e/L_{olive\ oil}$); and a non-neutral biomass condition in which 2P increase its carbon footprint to 273g $CO_2e/L_{olive\ oil}$. When addressing the carbon footprint of possible combinations among studied subsystems, results suggest that olive harvesting is the major source for GHG.

Keywords**—**Carbon footprint, environmental indicators, farming subsystem, industrial subsystem, olive oil.

I. INTRODUCTION

OVER the last decades there has been a growing interest for pollution prevention in the agro-industrial sector. Among the relevant drivers for such change are consumers' choices concerning food products [1] and product packaging [2], along with tight legislation that is applied in most countries. Trying to address legislation and market demands, several studies have been developed to address the most significant environmental aspects of some agro-industries such as wine (e.g. [3]), fruit (e.g. [4]) and olive oil production (e.g. [5]).

Olive oil production takes place mainly on five European countries: Spain, Italy, Greece, Portugal and France. Over the last decade these countries were responsible for 76% of the global production [6]. Such production is translated into internal consumption as this product plays an essential role in the so called "Mediterranean diet" [7], recently classified as a World's Intangible Cultural Heritage by UNESCO.

Portugal accounts for 2-3% of the global olive oil production coming from over 336.000 hectares of olive groves. Among European Union nations, Portuguese contribution has been growing over the recent years (Fig. 1). This activity takes place in most of the Portuguese regions, although Alentejo and Trás-os-Montes are the most olive productive locations (Fig. 2).

Recently, Trás-os-Montes saw its status grow as one of the best olive oil production regions in the world, providing a major added value to the local economy. Olive oil system combines many stages and normally has a vertical structure within the regional scale, which includes local olive farms, olive oil mills and distribution structures. Despite this economic value, local producers have struggled over time to deal with the environmental impact from Olive Oil production, because it is complex and multidimensional, including often significant aspects such as waste water, energy consumption or gaseous emissions [8].

This study presents some of the preliminary results from a larger research aiming to address the olive oil life cycle as a whole, under the framework of the EcoDeep project. This larger project aims to address eco-efficiency in agro-industrial activities. This paper focuses on two complementary subsystems, here called the farming and the industrial subsystems.

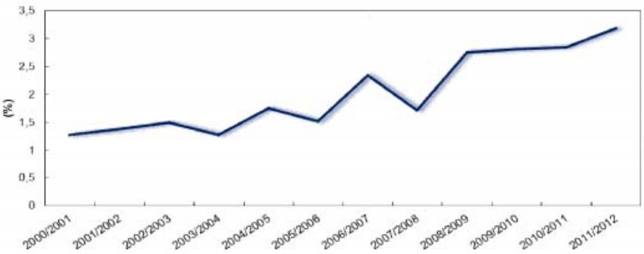

Fig. 1 Portuguese contribution (percentage) to the European Union olive oil production from 2001-2012

M. Feliciano is with CIMO Research Center, Escola Superior Agrária do Instituto Politécnico de Bragança, Campus de Santa Apolónia, Apartado 1172, 5301-855 Bragança, Portugal (corresponding author to provide phone: +351273303339; e-mail: msabenca@ipb.pt).

F. Maia and A. Gonçalves are with CIMO Research Center, Escola Superior Agrária do Instituto Politécnico de Bragança, Campus de Santa Apolónia, Apartado 1172, 5301-855 Bragança, Portugal (e-mail: filipemaia@hotmail.com, ajg@ipb.pt).

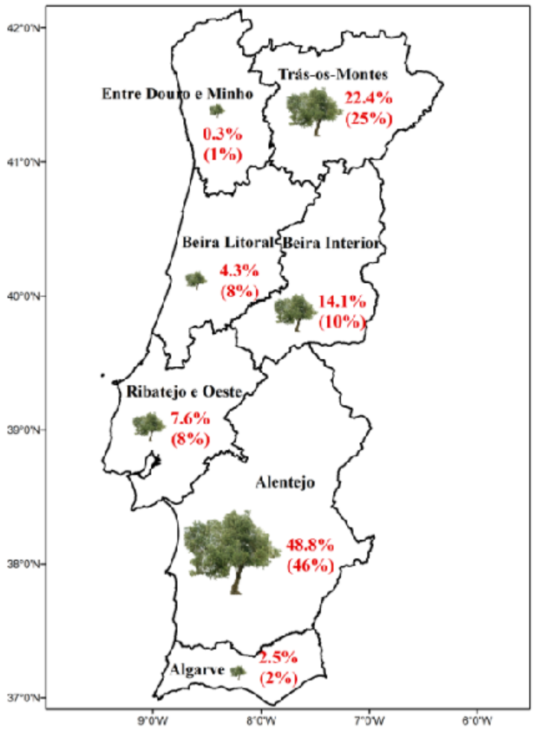

Fig. 2 Olive plantations from census 2009 [9] and (between brackets) olive oil production from 2004 to 2012 [6]

II. Methods

A. Gold Definition and Indicators

This study can be divided into three different stages. Firstly, it addresses two fundamental processes from the farming subsystem, investigating some of its most relevant impacts using environmental and eco-efficiency indicators. Secondly, moving onwards in the product life cycle, the same indicators are applied to two industrial subsystems, using different technologies. Finally, the overall carbon footprint was calculated combining the two subsystems. Using these approaches, this study addresses some of the most relevant impacts in the olive oil sector, from olive to olive oil or from olive tree farms to the olive oil extraction mills.

Indicators used in this study include: Energy intensity, GHG emission intensity, GHG intensity and Water withdrawn intensity [10].

Energy intensity:

$$EI = \frac{\sum_S Q_S}{P} \tag{1}$$

GHG emission intensity:

$$GEI = \frac{\sum_j M_j}{P} \tag{2}$$

GHG intensity:

$$GHGI = \frac{\sum_j M_j}{\sum_S Q_S} \tag{3}$$

Water withdrawn intensity:

$$WWI = \frac{\sum_O V_O}{P} \tag{4}$$

where: Q_s – energy amount (toe) from different sources; P – production volume (physical unit); M_j – greenhouse gas mass j (t CO_2e); V_o – water volume withdrawn from source o.

GEI was considered to be equivalent to GHG footprint (kg CO_2e/P). Considering the diverse nature of the two types of subsystems evaluated, two different functional units are used. In the case of the farming subsystem, the study considers the importance of raw materials and therefore uses one kilogram of olives as the functional unit. In the case of the industrial subsystem, the study takes into account the product, therefore having one Liter of olive oil as the functional unit. Finally, looking at the combined effect of both subsystems, and addressing the need for a common benchmark, on Liter of olive oil is used as the functional unit. Data was collected for the calendar year of 2011.

B. Boundaries and Data Collection

This study evaluates activities developed in the Trás-os-Montes region, second largest production region in Portugal. The two complementary subsystems addressed in this study can be described as interconnected and highly interdependent, mostly related within a close geographical proximity. Fig. 3 presents the most relevant activities and flows considered in this study.

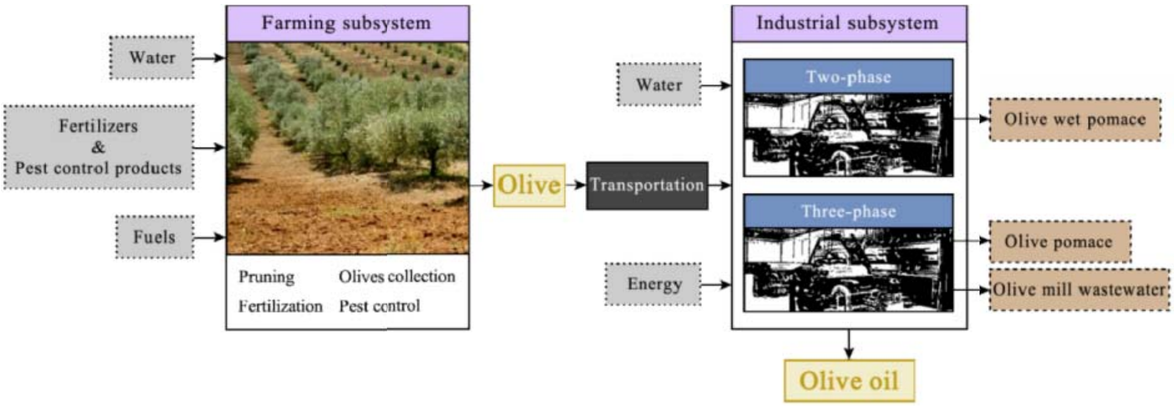

Fig. 3 Olive processing from olive farming to olive oil extraction

The activities presented inside the farming subsystem box in Fig. 3 are the most commonly performed in the region, including: cultivation, pruning, fertilization, olive collection and pest control. Transport activity was considered as part of the farming subsystem as it’s mostly performed by olive farmers.

Concerning the processing subsystem, two of the three prevailing production processes were considered, namely [9]: the two-phase centrifugation process (2P), present in 60% of the local facilities, and growing in relevance; and the three-phase centrifugation process (3P), accountable for 32.5% of the facilities and loosing relevance in the Trás-os-Montes region. A third one, more traditional process, using a press mechanism, is losing relevance in the region, and was not considered in this study.

Data describing the farming subsystem was collected from two olive trees farmers both follow the specific regulations for integrated production of olive cultivation. Although the mean size of olive groves is around two hectares, including mostly small productions, this study focused on larger producers with steady organized businesses, addressing: a farm with 12 ha, with 170 olive trees per hectare, a medium-size producer (F1); and a farm with 100 ha, with 204 olive trees per hectare, a large-size producer (F2). Most relevant information from these two Farms is presented in Table I.

TABLE I
PRIMARY DATA FOR THE OLIVE FARM STAGE

Olive farm information	**Producer**		**Units**
	F1	F2	
Olives	22	155	t
Area	11.92	100	ha
Inputs		*Per 1000 kg of olives*	
Water	5.45	2.2	m^3
Diesel	53.2	72.9	L
N	29	154	Kg
P	0.1	0.5	Kg
K	0.01	1.0	Kg
CaO	8	121	Kg
MgO	8	44	Kg
Boron	0.3	0.2	Kg
SO_3	--	0.4	Kg
Copper	--	1.1	Kg
lambda-cyhalothrin	--	0.01	Kg
Glyphosate	1.3	0.3	Kg
Dimethoate	--	0.03	Kg

Results presented in Table II show there were higher inputs in both energy and chemical compounds in F2, despite there was no equivalent increase in productivity, as this farm produced less olives per hectare (1.55 t/ha) than F1 (1.85 t/ha). However, there are relevant fluctuations in productivity in different years as these values cannot be seen as permanent.

Data collection on the industrial subsystem addressed two different olive oil production facilities: a two-phase processing unit (2P) and a three-phase processing unit (3P). Among the most elementary differences between these two mills, 2P uses far less water than 3P and as a consequence generates smaller amounts of waste water. Other elementary data from these units is presented in Table II.

The 3P mil had higher electricity consumption around 30% higher than 2P. Despite this difference, olive oil yield (in liters) per Kg of olive was smaller in 3P.

TABLE II
PRIMARY DATA FOR THE OLIVE OIL PROCESSING, PER 1 L OF OLIVE OIL

Inputs	**Olive Mill**		Units / $L_{olive\ oil}^{-1}$
	2F	3F	
Olive	6.34	5.98	Kg
Leaves	0.19	0.31	Kg
Water	0.21	5.9	L
Electricity	0.195	0.28	kWh
Olive Stones	0.12	--	Kg
Gas propane	--	0.02	Kg
Outputs			
Olive Oil	256349	188250	L
Olive Wet Pomace	4.41	--	kg/$L_{olive\ oil}$
Pomace	--	3.5	kg/$L_{olive\ oil}$
Wastewater	0.18	1	L/$L_{olive\ oil}$

III. RESULTS

A. Farming Subsystem

Energy use in farming may assume multiple sources but it is mostly provided by fuel burning, either gasoline or diesel. All energy sources can be normalized by ton of oil equivalent (toe), therefore allowing cross-evaluation.

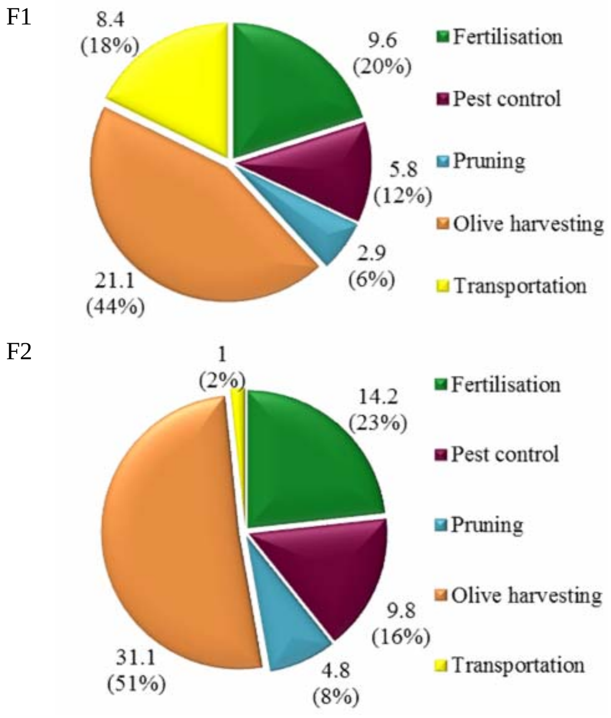

Fig. 4 Energy Intensity (kgoe/kgolive) distribution by processes above and its relative distribution (%), in each farming stage for both olive farms

Energy use by each farmer was evaluated through EI analysis. The production reference considers kilograms of oil equivalent units per Kg of collected olives. As expected, F2 had a higher EI (60.8 kgoe/kg_{olive}) than F1 (47.7 kgoe/kg_{olive}).

Results show (Fig. 4) that the most energy demanding process in both farms is olive harvesting using fuel-powered machinery (umbrella type), accountable for 44% of EI in F1 and 51% in F2. Fertilization is also responsible for a significant EI, 20% in F1 and 23% in F2. The most relevant relative differences between farms can be identified in the final olive transportation, as F1 spend far more fuel than F2; differences are mostly caused by the logistics taking olives to the mills. Farmer F1 travels around 40 km using a tractor, a vehicle with higher fuel consumption, while Farmer F2 uses a much fuel-efficient vehicle, a pick-up truck, to carry the olives to a mill located only 17 km from the farm.

To evaluate carbon footprint (GEI), GHG was calculated (gCO_2e), taking into account the emission factor (EF) proposed by the IPCC [11]. As GHG generated in both activities are mostly related to fuel consumption (Fig. 4.), there is a clear relation between energy use and GHG emissions. Considering this induced environmental impact, F2 generated 188g CO_2e/kg_{olive}, equivalent to a global CO_2e production of 29 tones, nine times higher than F1 results, which had a smaller per olive GHG emission (148g CO_2e/kg_{olive}).

Water consumption is quite small in both farms as olive groves are mostly rain fed. Additional water is only provided for fertilization and pest control purposes (Fig. 5).

As expected, F2 had higher global water consumption; however when considering normalized data (Fig. 5) F1 had higher values in relation with the amount of olives collected (5.5 L/kg_{olive}). Among the different process stages, pest control stands-out as the most water demanding in this subsystem.

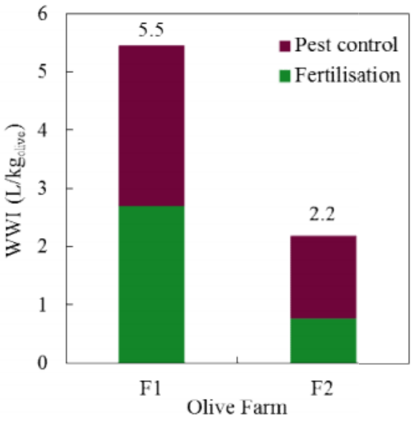

Fig. 5 WWI for each olive farm and for the two consuming processes

B. Industrial Subsystem

Water usage is quite different when considering the two studied processes, as the three-phase process, much older, consumes far more water than the two phase process [8]. This well-known fact is recognizable in this study as 3P had an WWI of 6L/$L_{olive\ oil}$, much higher than 0.2L/$L_{olive\ oil}$ consumed by the 2P (Table III).

While consuming more water, 3P generates far more waste-water, treated by using evaporation ponds, producing a waste that is later used as soil fertilizer. 2P system produces close to zero waste-water because the aqueous solution extracted at the end of the process is usually mixed with the pomace (a by-product resulting from oil extraction).

Olive pomace, present in both processes, is managed differently depending on the two types of processes: 2P generates a more humid pomace, and olive stones within it are sorted and used to heat the boiler; 3P generates a pomace, lower in moisture content that is sold to a different factory that uses it to extract Pomace Olive Oil.

TABLE III
INDICATORS RESULTS FOR EACH OLIVE OIL MILL

Indicators	**Olive Mill**		**Units**
	2F	3F	
EI	0,09	0,08	kgoe/$L_{olive\ oil}$
GEI	92 (273)*	184	gCO_2e/ $L_{olive\ oil}$
GHGI	1026 (3056)*	2305	$kgCO_2e$/toe
WWI	0,2	6	L/$L_{olive\ oil}$

* In between brackets ( ) - values represent GHG emissions from olive stone burning assuming a non-neutral carbon condition

Energy use in both processes was evaluated using kg of oil equivalent (kgoe). Fig. 6 presents the contribution of individual energy sources in both mills. As energy use was quite similar, results show that the main difference between both mills consists on the fuel used in the furnaces for heating water. 2P mill uses olive stones while the 3P uses propane gas. Differences could also be found in the use of electricity between the two mills, mostly used in buildings (lights, air heating systems and electronics) and process machinery, as 2P uses 0.2kWh/$L_{olive\ oil}$, while 3P has a more intense use with 0.28kWh/$L_{olive\ oil}$ (Table II).

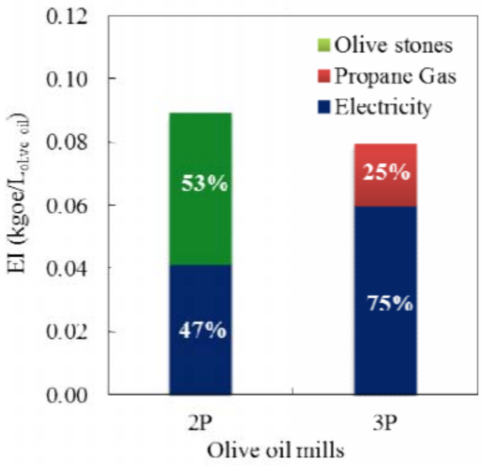

Fig. 6 Energy consumption per activity for each olive oil mill

Despite the higher use of olive stones as a fuel in 2P, EI is similar in both mills, with 0.09kgoe/$L_{olive\ oil}$ in 2P and 0.08kgoe/$L_{olive\ oil}$ in 3P. Although biomass is frequently seen as a carbon neutral source [12], [13] this study considers two conditions: a neutral GHG generated by olive stones burning and a non-neutral condition. When using a normalized indicator related to GHG, the GHGI, differences are found and can be identified depending on those two calculation principles: when considering the combustion of olive stones as a carbon neutral, 2P can be seen as the most eco-efficient process as it has lower GHGI (1026kg CO_2e/toe against 2305kg CO_2e/toe in 3P) (Table III). However when considering a non-neutral carbon emission in 2P, this process can be seen as the least eco-efficient as GHGI value increases up to 3056kg CO_2e/toe (Table III). Therefore there is a significant difference resulting from biomass GHG neutrality interpretation.

Finally, Carbon Footprint (GEI) was estimated taking into account the different combinations between farms and mills data, using a liter of olive oil as the functional unit. For these scenarios, a mean distance of 25km was assumed for the olives transportation between farms and mills. Results from these different combinations (four) are represented in Fig. 7.

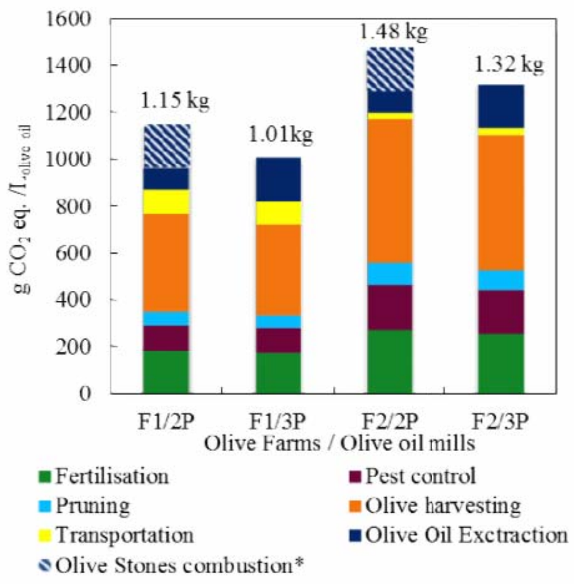

Fig. 7 Carbon footprint from different processes within the olive oil production cycle

Taking into account GHG emissions from olive stones burning, results show that the combination between F2 and 2P clearly generates the largest amount of greenhouse gas emission, with 1.47kgCO_2e/$L_{\text{olive oil}}$, while being responsible for the most relevant carbon footprint (just higher than the combination between F2 and 3P). Conversely, considering biomass neutral GHG emissions, combinations with 2P mills can be seen as having lower GHG emissions, with 0.97kg CO_2e/L_{oliveoil} when associated with F1 and 1.30kgCO_2e/$L_{\text{olive oil}}$ when associated with F2. Nonetheless, results suggest that there is a larger impact on this indicator coming from the characteristics of the two types of farming subsystem, as the industrial subsystem was only accountable for (an average) of 18%, of the emission from all processes, ranging from 14% in the F2/3P combination up to 23% in the F1/2P. Olive harvesting is clearly responsible for the highest GHG emissions.

IV. CONCLUSIONS

Focusing on two life subsystems, this study shows some insight on the complexity of the olive oil life cycle through the evaluation of two pairs of complementary organizations.

Addressing the farming system, two different organizations were evaluated including a medium and a large size farm. Normalized results show that F2 farm was the most energy demanding, using an additional 28% in toe for each kg of olives harvested. When evaluating the relative distribution in energy use among activities, it was quite similar in both farms, as differences were mainly found related to the requirements in the transportation of olives after harvesting, which was dependent on vehicles used and distance travelled to mills by both farmers. When evaluating the most energy demanding activities in both farms, mechanical collection was responsible for around half of the global amount of this input, as it can be seen as the consequence of the generalization of such processes across the region, replacing traditional manual, labor-intensive processes. Energy use in different processes then translates into GHG emissions, as burning fuel is the major contributor to such gases. Under this circumstances, carbon footprint was accordingly higher in F2 (188g CO_2e/kg_{olive}) than in F1 (148g CO_2e/kg_{olive}).

The evaluation of olive oil mills focused on assessing the differences between the two most commonly used production methods, in two contrasting organizations. Among the differences between such processes, the use of water is generally seen as a major factor and is related with the amount of waste water generated [8]. These known differences were also found between case studies, as P3 uses almost thirty times more water than P2, thus generating a much larger amount of an organically charged waste water. Differences between mills were also found concerning energy use. Electricity use is similar in both processes, though higher in 3P, with an average of 0.24kWh/$L_{\text{olive oil}}$ among mills, this value is similar to others found in other case study [14]. Relevant differences can be found in the sources for local energy generation through fuel combustion, as 2P uses olive stones to fuel its furnaces while 3P uses propane gas. Despite the differences in the use of secondary sources of energy, they have little impact on EI.

Despite the financial benefits of burning olive stones in furnaces, as it is a cheap and easily available source of energy, when considering burning such by-products as being a non-carbon neutral activity, results show that there is a clear effect in GHG emissions. This energy source generated higher GHG in the 2P farm than in 3P farm, despite the fact that the second uses a fossil fuel (propane gas). Although results can only suggest this hypothesis, there is a sense that financial benefits from olive stones burning by 2P may have influenced the intensive burning of this byproduct, and so removing some eco-efficiency in the use of this biomass as fuel.

Finally, carbon footprint from multiple subsystems was evaluated by combination of different scenarios, using data from both olive farming and extraction case studies. An additional variation was introduced to consider both neutral and non-neutral biomass burning effect on GHG. From the analysis of all combinations tested there is clear evidence that olive harvesting is the major source for carbon footprint within the two evaluated subsystems from the olive oil life cycle. These results are consistent with existent studies [11], [6] and suggest that there is a significant negative impact when moving from manual intensive to machine intensive olive harvesting. Concerning the industrial subsystem it is clear that there is a clear reduction in GHG emissions when considering a neutral effect from olive stones burning in 2P, as this condition changes the evaluation of the impact of such system, moving from the highest GHG source to the least GHG emitter. These results show that when addressing such indicators as EI and GHG, in these two complementary subsystems, olive harvest should be seen as the main cause of concern, as more efficient methods should be developed and implemented.

ACKNOWLEDGMENT

This research was co-funded by the project ECODEEP (Eco-efficiency and Eco-management in the Agro Industrial sector, FCOMP-05-0128-FEDER-018643).

The authors gratefully acknowledge the involved farms and oil mills for providing relevant data for this study.

REFERENCES

[1] F. Iraldo, F. Testa, and I. Bartolozzi, "An application of Life Cycle Assessment (LCA) as a green marketing tool for agricultural products: the case of extra-virgin olive oil in Val di Cornia, Italy," Journal of Environmental Planning and Management, vol. 57, pp. 78-103, 2013.

[2] S. W. McDaniel and D. H. Rylander, "Strategic green marketing," Journal of consumer marketing, vol. 10, pp. 4–10, 1993.

[3] B. Rugani, I. Vázquez-Rowe, G. Benedetto, and E. Benetto, "A comprehensive review of carbon footprint analysis as an extended environmental indicator in the wine sector," Journal of Cleaner Production, vol. 54, pp. 61-77, 2013.

[4] W. W. Ingwersen, "Life cycle assessment of fresh pineapple from Costa Rica," Journal of Cleaner Production, vol. 35, pp. 152-163, 2012.

[5] R. Salomone and G. Ioppolo, "Environmental impacts of olive oil production: A Life Cycle Assessment case study in the province of Messina (Sicily)," Journal of Cleaner Production, vol. 28, pp. 88-100, 2012.

[6] IOOC, International Olive Oil Council. Available from: www.internationaloliveoil.org. Accessed February 2013.

[7] V. Uylaşer and G. Yildiz, "The Historical Development and Nutritional Importance of Olive and Olive Oil Constituted an Important Part of the Mediterranean Diet," Critical Reviews in Food Science and Nutrition, 2013.

[8] I. E. Kapellakis, K. P. Tsagarakis, and J. C. Crowther, "Olive oil history, production and by-product management," Reviews in Environmental Science and Bio/Technology, vol. 7, pp. 1-26, 2008.

[9] INE - Instituto Nacional de Estatística, I. P., "Recenseamento Agrícola 2009 - Análise dos principiais resultados", Lisboa, Portugal, 2011.

[10] D. Maxime, M. Marcotte, and Y. Arcand, "Development of eco-efficiency indicators for the Canadian food and beverage industry," Journal of Cleaner Production, vol. 14, pp. 636-648, 2006.

[11] IPCC – Intergovernmental Panel on Climate Change, "2006 IPCC Guidelines for National Greenhouse Gas Inventories", Japan, 2006.

[12] A. K. Petersen Raymer, "A comparison of avoided greenhouse gas emissions when using different kinds of wood energy," Biomass and Bioenergy, vol. 30, pp. 605-617, 2006.

[13] H. K. Sjølie and B. Solberg, "Greenhouse gas emission impacts of use of Norwegian wood pellets: A sensitivity analysis," Environmental Science and Policy, vol. 14, pp. 1028-1040, 2011.

[14] M. Avraamides and D. Fatta, "Resource consumption and emissions from olive oil production: a life cycle inventory case study in Cyprus," Journal of Cleaner Production, vol. 16, pp. 809-821, 2008.

Open Science Index, Environmental and Ecological Engineering Vol:8, No:4, 2014 publications.waset.org/9997989.pdf