Greenhouse gas assessment of olive oil in Portugal addressing the valorization of olive mill waste

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Abstract

This article presents a comparative life-cycle Greenhouse Gas (GHG) assessment of olive oil produced from two alternative extraction processes (three-phase and two-phase extraction). A life-cycle model and inventory was implemented for the entire olive oil chain, including olive cultivation, oil extraction and olive pomace oil extraction. The valorization of olive pomace (produced with olive oil) to produce olive pomace oil and extracted pomace is assessed. Two approaches for dealing with multifunctionality in the oil extraction were analyzed: i) allocation based on economic criteria (market prices) to partition impacts and ii) substitution ("avoided burden approach") of extracted pomace (displacing conventional fuel in energy intensive processes) and olive pomace oil (used for biodiesel production in Portugal, displacing the current mix of virgin oils). The results showed that the GHG intensity of olive oil greatly depends on the type of extraction process. In addition, the multifunctionality approach adopted significantly influences the results and even reverses the rank order of the extraction process that led to the lowest olive oil GHG intensity. The GHG intensity of olive oil produced from three-phase extraction vary from 0.24 kg CO_2 eq L^{-1} (substitution) to 1.86 kg CO_2 eq L^{-1} (allocation) and, for two-phase extraction, from 0.94 kg CO_2 eq L^{-1} (substitution) to 1.69 kg CO_2 eq L^{-1} (allocation). Olive cultivation was the life-cycle phase that contributes most to the total GHG intensity of olive oil production.

Keywords

Pomace, olive pomace oil, GHG assessment, allocation, substitution.

1. Introduction

Olive cultivation and olive oil extraction are important activities in many Mediterranean countries. In Portugal, the production of olive oil represented in 2013 revenues of 343 million euro [1]. Olive oil is produced in Portugal in units of three or two-phase extraction. The most remarkable difference between both types of systems is related to the co-products and residues produced. The three-phase centrifugation process results in three fractions: olive oil, a solid fraction (olive pomace) and olive mill wastewater. The two-phase centrifugation extraction (a more recent process) consumes less water and generates, together with olive oil, a suspension called 'olive mill waste' or 'olive wet pomace' (OWP). Olive pomace (OP) and OWP can be recovered to produce olive pomace oil, from a chemical extraction process using hexane. In the past decades, there has been an increase of two-phase extraction mills in order to avoid the production of olive mill wastewater. Life-Cycle Assessment (LCA) was employed to assess the environmental impacts of olive oil production in various South-European countries [e.g. 2, 3, 4, 5, 6, 7, 8]; however, only one article [3] analyzed olive pomace valorization and only considered three-phase extraction. Intini et al., 2012 [9] presented an LCA of olive pomace oil production for fuel in Italy, but did not address olive oil.

The main objective of this paper is to present a comparative life-cycle GHG assessment of olive oil produced from three and two-phase extraction mills, addressing the valorization of olive pomace (produced with olive oil) to produce olive pomace oil and extracted pomace. This study was built on a previous work [2], which investigated olive oil production without addressing the co-products and residues generated. This article is organized in four sections, including this introduction. Section 2 presents the life-cycle model, inventory and the multifunctionality approaches. Section 3 presents and discusses the main results. Section 4 draws the main conclusions together.

2. Methods

2.1 Life-Cycle Model and Inventory

LCA addresses the environmental aspects (extraction of natural resources and emissions of material and energy rejects) and its potential environmental impacts (consequences of this consumptions and releases over the surroundings) throughout a product life-cycle. The life-cycle is established according a 'cradle-to-grave' perspective comprising the anthropic transformations related to raw material acquisition, manufacture chain, use, end-of-life treatment, recycling and final disposal [10]. LCA is based on systems analysis, treating the life cycle of a product as a sequence of sub-systems that exchange inputs and outputs. According to ISO methodological framework [10] a LCA study is divided into four phases: i) Goal and scope definition; ii) Inventory analysis (LCI); iii) Impact assessment (LCIA); and iv) Interpretation.

A life-cycle (LC) model for olive oil produced in Portugal was implemented (Fig. 1), including an inventory of olive cultivation, two alternative olive oil extraction processes (three-phase and two-phase extraction), and olive pomace oil production (drying and extraction). The olive mill wastewater was treated in aerobic lagoons. It was assumed that extracted pomace is used to displace conventional fuel in energy intensive processes (i.e. ceramic industries) and that olive pomace oil is used for biodiesel production in Portugal, displacing the current mix of virgin oils. The functional unit selected was 1 L of olive oil. An average distance for the transportation of olives and pomace of 5 km from the cultivation to the olive mill, 80 km from the olive mill to olive pomace oil extraction and of 100 km from pomace oil to ceramic industries and biodiesel plants was considered.

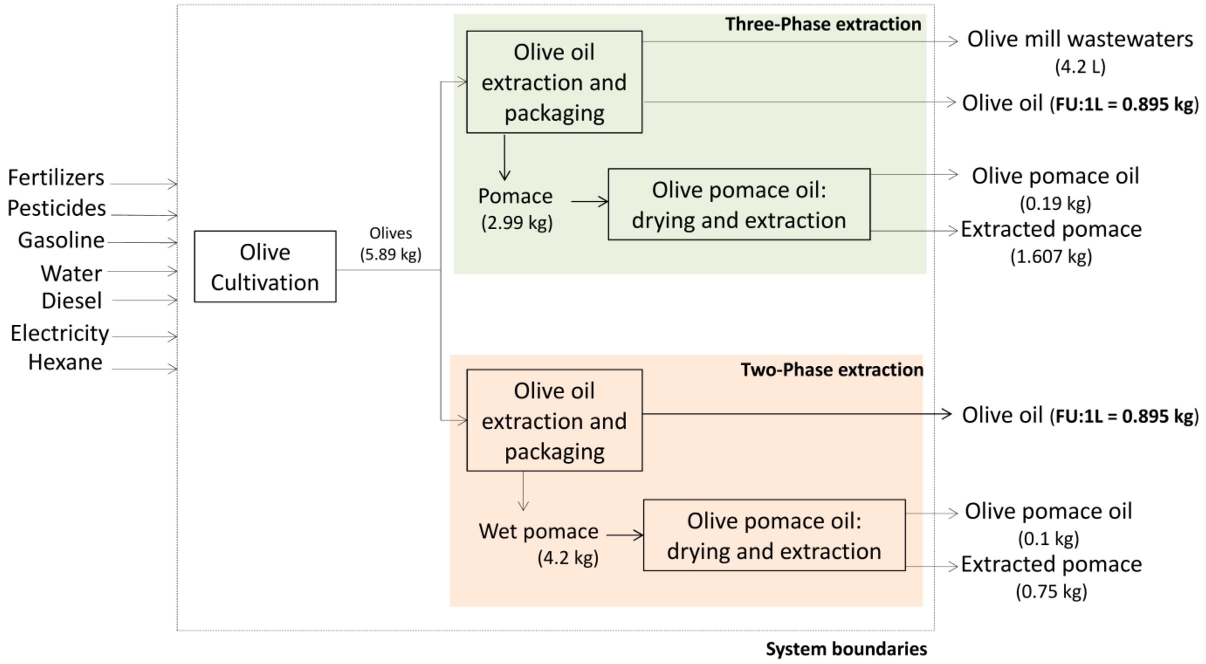


Figure 1 – System boundaries for olive oil produced in two types of extraction processes.

An intensive cultivation system (representing 71% of the total olive production in Portugal in 2013) was considered, with a productivity of about 10 tonnes per hectare [2]. The growing areas are located in Alentejo (southern of Portugal) require irrigation (2000 m^3 ha^{-1} of water) and a high level of fertilization and phytosanitary control. The calculation of GHG emissions addressed fertilization (nitrogen and urea field emissions), diesel combustion in agricultural operations [11] and agricultural inputs production [11, 12, 13]. Direct and indirect N_2O emissions and CO_2 emissions from urea application were calculated based on [14]. The main inputs for olives cultivation are presented in Table 1.

Table 1. Main Inputs of intensive olive cultivation.

Inputs		*Intensive producer*	*Units (per ha)*
Fertilizers			
	N	110	kg
	P	48.0	kg
	K	129	kg
	Urea	37.5	kg
	Borum	0.47	kg
Pesticides (a.s.)			
	Copper oxychloride	10.0	kg
	Tubeconazol	0.15	kg
	Glyphosate	2.90	kg
	Dimethoate	3.60	kg
Energy			
	Diesel	86.0	L
	Gasoline	14.0	L
	Electricity	880	kWh
Water		2000	m^3

Table 2 shows the main inputs and outputs associated with the two types of extraction systems considered (representative data from Portuguese mills [2]). The type and characteristics of olives is the determining factor for the efficiency of olive oil extraction and the efficiency was considered similar from both types of extraction. Two-phase extraction mill originates olive oil and wet pomace with 80% moisture content wet basis (mc wb), which hinders transportation. Three-phase extraction mill generate olive oil, pomace (40% mc wb) and olive mill wastewater. Olive mill wastewater was treated in aerobic lagoons (4.82 L $L^{-1}_{\text{olive oil}}$). Removal rates for the treatment reaches average values of 82.5% for chemical oxygen demand (COD), 90% for phenols and 61% for biochemical oxygen demand (BOD) [15]. An adequate operation of the system provides low or almost no methane emission. This can occur from settling basins and other pockets [16]. Methane emissions are intensified in overburdened system without control routines clearly defined. This study considered the worst scenario, with CH_4 emissions estimated based on [16] related to: i) the chemical oxygen demand (COD) of untreated wastewater (18g L^{-1}); ii) efficiency of treatment; iii) methane production capacity (0.25 kg kg^{-1} COD removed) and iii) methane correction factor (0.3). GHG emissions associated with electricity and propane production were considered based on [13, 12].

Table 2. Inventory of olive oil extraction (three and two phase system), per L of olive oil.

Inputs	*Three-phase olive mill*	*Two-phase olive mill*	*Unit (per L)*
Olives	5.89	5.89	kg
Electricity	0.269	0.269	kWh
Propane	0.01	-	kg
Water	4.82	1.24	L
Outputs			
Olive oil	1.00	1.00	L
Pomace	2.99	4.2	kg

Pomace produced from three and two-phase extraction mills was transported to the olive pomace oil mill, in which pomace was dried and attacked with hexane. As can be seen in Table 3, the drying of pomace from two-phase mill requires more energy than the three-phase and originates less extracted pomace and olive pomace oil. In this life-cycle phase, two products were co-produced: olive pomace oil and extracted pomace.

Table 3. Inputs and outputs of olive pomace oil extraction mills per tonne of olive pomace oil.

Inputs	*Three-phase olive pomace oil mill*	*Two-phase olive pomace oil mill*	*Units (per t)*
Olive pomace	16	41	t
Electricity	78	95	kWh
Diesel	20	50	L
Hexane	1.1	1.1	kg
Extracted pomace	0.6	1.85	t
Products			
Extracted pomace	8.60	7.35	t
Olive pomace oil	1	1	t

2.2. Multifunctionality: price based allocation vs. substitution

The scheme from Figure 1 stands out the multifunctional aspect of olive oil production. Dealing with multifuncionality in LCA studies is a difficult and controversial issue [17]. In order to evaluate this influence, a sensitivity analysis was performed using different approaches to deal with co-products, as recommended by ISO [10]. Two approaches for dealing with multifunctionality in the oil extraction were analyzed: i) allocation based on economic criteria (market prices) to partition impacts and ii) substitution (also called the “avoided burden approach”) of extracted pomace (displacing conventional fuel in energy intensive processes) and olive pomace oil (used for biodiesel production in Portugal, displacing the current mix of virgin oils).The allocation factors presented in Table 4 show that considering price allocation in olive oil production is approximately the same that allocating all impacts to olive oil since the price of olive oil is about 220 higher than pomace (from three-phase mill) and 1100 higher than wet pomace (from two-phase mill).

Table 4 - Allocation factors for the two olive oil production systems.

	Typology	Co-product	Mass quantities (kg/L olive oil)	Price allocation [(a)]	
				Price (€/t)	Factor
Olive oil extraction	3 phase	Olive oil	0.895	5587	98.5%
		Pomace	2.99 [(b)]	25	1.5%
	2 phase	Olive oil	0.895	5587	99.6%
		Wet Pomace	4.2 [(c)]	5	0.4%

[a)] Producers information; [b)] moisture content of 40% (wb); [c)] moisture content of 80% (wb)

Conceptually, the substitution considers that there is an alternative way of generating the exported functions, i.e. the co-products. Exported functions can be defined as functions that are generated in a system, but that are used in other system that is out of the boundaries of the first one [18]. Extracted pomace and olive pomace oil (co-produced in the olive oil system) will avoid the production of vegetable oils (for biodiesel production) and natural gas (heat process in the ceramic industry) and the corresponding credits for the avoided-burdens should be subtracted [19] from the total burdens of the olive pomace oil extraction process. The credits for vegetable oil were calculated based on the current mix of vegetable oils used for biodiesel production in Portugal (49.5% from soybean oil, 33.9% from rapeseed oil and 14.5% from palm oil) [20]. The GHG emission credits related to the vegetable oils avoided was based on [21] and [22], which calculated a range of GHG emission depending on various Land Use Change scenarios and agricultural practices. A range of credits was considered for the GHG emissions of vegetable oils as presented in Table 5 for both types of olive oil extractions.

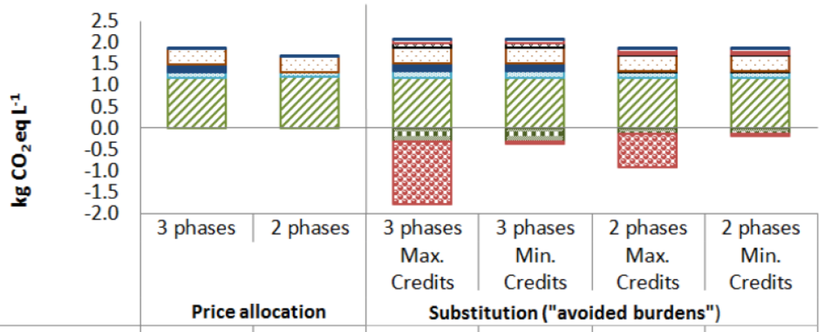
Table 5 – Credits associated with avoided production of vegetable oils and natural gas, per L of olive oil.

Extractio process	Avoided burdens		GHG credits		
			Vegetable oils		Natural Gas
	Vegetable oils (kg)	Natural Gas (MJ)	Maximum	Minimum	
Three-phase	0.19	28.3	1.48	0.07	0.32
Two-phase	0.1	13.2	0.78	0.04	0.15

Low heating value (LHV) olive pomace oil: 36.2 MJ kg^{-1}[23]; LHV extracted pomace: 17.2 MJ kg^{-1}[24])

3. Results and discussion

Fig. 2 presents the LC GHG intensity of olive oil per life-cycle phase (for the two multifunctionality approaches). It can be observed that cultivation was the life-cycle phase that contributes more to the total GHG intensity of olive oil production, followed by packing. It should be emphasized that the multifunctionality approach adopted significantly influences the results and even reverses the rank order of the extraction process that led to the lowest olive oil GHG intensity. Adopting the "avoided-burdens" approach, led to lower GHG intensity of olive oil produced with three-phase extraction relatively to two-phase extraction (74% lower for maximum credits and 1% lower for minimum credits), while using price allocation led to the opposite. In fact, for price-based allocation, the GHG intensity of olive oil produced in two-phase extraction is 9% lower than for three-phase extraction (mainly due to higher emissions in the wastewater treatment of the three-phase mill).



	3 phases	2 phases	3 phases Max. Credits	3 phases Min. Credits	2 phases Max. Credits	2 phases Min. Credits
	Price allocation		Substitution ("avoided burdens")			
▨ Avoided production of vegetable oils			-1.48	-0.07	-0.78	-0.04
▨ Avoided production of natural gas			-0.32		-0.15	
▨ Transportation (olives)	0.02	0.02	0.02		0.02	
▤ Transportation (pomace)			0.05		0.07	
▨ Transportation (extracted pomace + olive pomace oil)			0.09		0.04	
□ Packing	0.36	0.36	0.36		0.36	
▨ Olive pomace oil extraction	0.00	0.00	0.02		0.02	
■ Olive mill wastewater treatement	0.18	0.00	0.18		0	
▨ Olive oil Extraction	0.14	0.13	0.14		0.13	
▨ Cultivation	1.16	1.18	1.18		1.18	
Total (LC) GHG intensity of olive oil	**1.86**	**1.69**	**0.24**	**1.67**	**0.94**	**1.68**

Figure 2 - GHG intensity of olive oil production: per life-cycle phases and different co-product scenarios.

Cultivation was the highest contributor to GHG emissions. Fig. 3 depicts the individual contribution of each process comprised in this phase. Soil fertilization contributes with 60% for the total GHG emissions (27% from fertilizers production and 33% from soil application). Energy supply contributes to 31% of the emissions. Pesticides production completes the picture with 9%.These results shown that production and use of fertilizers are critical issues in this agro-industrial system.

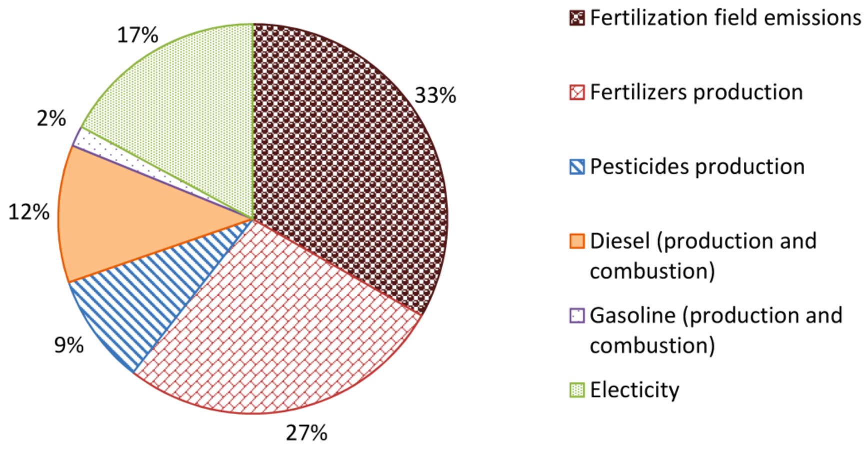


Figure 3 – Process contribution to the GHG intensity of olive cultivation.

4. Conclusions

A comparative life-cycle GHG assessment of olive oil produced from two alternative extraction processes (three-phase and two-phase extraction) addressing the valorization of olive pomace was presented. Cultivation was the life-cycle phase that contributes more to the total GHG intensity of olive oil production, followed by packing. Two approaches for dealing with multifunctionality (price-based allocation and the “avoided burdens” approach) were assessed showing that the approach adopted significantly influences the results and even reverses the rank order of the extraction process that led to the lowest olive oil GHG intensity. Furthermore, the results calculated with the “avoided burdens” approach are highly dependent on the credits associated with the virgin oil (there is a huge variation in the literature) displacing olive pomace oil.

In spite of the complexity of dealing with the multifunctionality in a LCA of olive oil, this article shows the importance of olive pomace valorization to promote an industrial ecology system associated with the olive oil chain and to reduce the life-cycle GHG intensity of olive oil. Work within the on-going project (ECODEEP) supporting this research is addressing other types of wastewater treatment systems and environmental impact categories.

Acknowledgements

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