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LIFE-CYCLE GREENHOUSE GAS EMISSIONS OF PORTUGUESE OLIVE OIL

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Abstract *The main goal of this paper was to assess the greenhouse gas (GHG) intensity of olive oil production in Portugal. A life-cycle model and inventory were implemented for the entire production process, including a comprehensive analysis of olive cultivation, olive oil extraction, packaging, and distribution. Data originates from five differently-sized Portuguese olive growers and from a total of six olive oil mills, representing the three extraction processes in use: three-phase extraction, two-phase extraction, and traditional pressing. The results show that the GHG intensity lies in the range 1.8-8.2 kg* CO_2*eq/liter and that the main contributors were fertilizers (production and field emissions). Efficient use of fertilizers thus seems to be a key factor for mitigating the GHG intensity of olive oil production.*

1. INTRODUCTION

Olive cultivation and olive oil extraction are significant activities in Portugal and other Mediterranean countries. The environmental life-cycle impact of olive oil production, however, has only been sparsely explored (e.g. [1, 2]), and there was no valuable data for Portuguese olive oil. This paper contributes at filling this gap by analyzing the life-cycle greenhouse gas (GHG) emissions of different Portuguese olive oil production systems.

Olive oil extraction can be performed through three different processes [3]. The water-intensive *three-phase* centrifugation process results in three fractions: olive oil, a solid fraction (olive pomace, OP) and olive mill wastewater (OMW). OP is typically used for a second, chemical oil extraction (which results in olive pomace oil), after which the remaining husk is used as fuel; OMW has to be treated [2]. The more recent *two-phase* centrifugation extraction uses less water and generates, together with olive oil, the so-called two-phase olive mill waste, or olive wet pomace (OWP). While using less water and generating less waste than the three-phase process, the treatment of the resulting OWP is challenging [3]. Finally, pressing systems are still in use; they are usually referred to as "*traditional* extraction".

2. LIFE CYCLE MODEL AND INVENTORY

2.1. Goal and scope definition

The GHG intensity of five olive production processes (differently-sized farms with different inputs) and six extraction processes were comparatively analyzed. The main life-cycle contributions to the overall GHG emissions were assessed. The functional unit selected was one liter of virgin olive oil. An additional functional unit – one kilogram of olives – was employed to present intermediate results. The system boundary included olive tree cultivation, olive oil extraction, packaging (0.5 liter glass bottle) and distribution (an average of 353 km by lorry).

2.2. Inventory analysis

Data were gathered primarily in collaboration with Portuguese olive farms and olive oil mills. The olive farms, for which inputs and outputs are presented in Table 1, had the following characteristics: "F1" was a mid-sized farm of 12 hectares (ha); "F2" a large 100 ha farm; "F3" a very large 250 ha farm; "F4" an organic farm. A small familiar farm "F5" of 2 ha was also included. Irrigation was only used by farm F3. Farms 1 and 2 were from northern Portugal, and farms 3-5 from the central part of the country.

Table 2 presents the data gathered from six olive oil mills: one of three phases (M1), four of two phases (M2-M5), and a traditional pressing mill (M6). Mills M1 and M2 were from the north, M3-M6 from central Portugal. The table shows substantial differences in the efficiency of olive oil extraction (1 liter from 4.60-7.35 kg of olives) and water use, depending on olive variety and extraction process. Some of the two-phase mills removed the olive stones during oil extraction and used a part of them as energy source, thus not requiring fossil fuels for heating. The remaining stones were one further output of the extraction process.

The GHG emissions associated with agricultural inputs (pesticides [4], fertilizers [4, 5], and diesel [6]), oil packaging [7] and transportation [8] were accounted for. Direct and indirect

N_2O field emissions were calculated using the IPCC Tier 1 methodology [9].

	Olive farm					
Inputs	F1	F2	F3	F4	F5	Unit ha^{-1}
	mid-sized	large	very large	organic	familiar	
Fertilizers						
Lobin (10-40-10)	3	-	-	-	-	kg
Boron	0.6	0.3	0.5	-	-	kg
Nitromagnesium 20,5 %	258.7	-	-	-	-	kg
Calcium ammonium nitrate	-	400	-	-	-	kg
Tudimag	-	267	-	-	-	kg
NPK (18-18-18)	-	2	-	-	-	kg
NPK (15-5-30)	-	3.2	-	-	-	kg
Zetaminol	-	2	-	-	-	kg
Magnesium sulphate	-	2	-	-	-	kg
Potassium chloride	-	-	25	-	-	kg
Potassium nitrate	-	-	12.5	-	-	kg
Urea (46%)	-	28	37.5	-	-	kg
NPK (12-4-6)	-	-	600	-	-	kg
NPK (6-4-12)	-	-	600	-	-	kg
Sheep manure	-	-	-	250	-	kg
Sheep pasture	-	-	-	3	-	Head
Algae extract	-	-	2.5	-	-	kg
Pesticides						
Clinic	6.5	-	-	-	-	L
Rondup supra	-	1.2	-	-	-	L
Dimethoate perfektion	-	0.8	-	-	-	L
Karate Zeon	-	0.1	-	-	-	L
Cuprocol	-	2.4	-	-	-	L
Copper oxychloride	-	-	20	-	-	L
Solution of dimethoate	-	-	9	-	-	L
Solution of tebuconazole	-	-	0.6	-	-	L
Solution of glyphosate	-	-	8	-	-	L
Irrigation						
Water	-	-	2000	-	-	m^3
Energy					-	
Gasoline	6.7	0.45	14	5	1.5	L
Diesel	118.7	118.38	86	12	10	L
Electricity	-	-	880	12	3.25	kWh
Outputs	F1	F2	F3	F4	F5	
Olives	1840	1540	10000	500	375	kg

Table 1. Inventory of olive cultivation, per hectare.

Table 2 shows the main inputs and outputs of the six extraction mills. Olive oil was the main product, but there were other outputs that can be used for different purposes and in different ways. Furthermore, the same output can be seen as co(sub)-product or residue by the market, which results in a complex multifunctional problem. This is a controversial issue among LCA practitioners, and according to ISO 14044 different approaches may be used to deal with multifunctionality. This paper presents a first assessment of the olive oil chain, and it was decided to attribute 100% of the burdens and co-product credit to olive oil (the main product). A sensitivity analysis of different methods to treat co(sub)-products is currently under investigation, as recommend by ISO 14044; however, this is beyond the scope of this short paper, and will be presented in a future publication.

Inputs	Olive oil mill						Unit L^{-1}
	Three-phase M1	Two-phase				Traditional pressing M6	
		M2	M3	M4	M5		
Olives	4.60	4.90	6.76	6.25	6.9	7.35	kg
Electricity	0.21	0.16	0.34	0.25	0.31	0.13	kWh
Propane	0.01	-	-	-	-	0.02	kg
Diesel	-	-	0.001	-	-	-	L
Water	4.61	0.24	1.35	1.2	1.24	1.84	L
Outputs							
Olive oil	1.00	1.00	1.00	1.00	1.00	1.00	L
Leaves	0.24	0.16	0.15	-	-	-	kg
Husk	2.86	3.60	5.75	3.38	3.7	3.65	kg
Olive Mill Wastewaters	4.61	0.2	-	-	-	4.31	L
Olive stones	-	0.37	0.72	-	-	-	kg

Table 2. Inventory of olive oil extraction, per liter of oil.

3. RESULTS AND DISCUSSION

The GHG intensity (expressed as CO_2 equivalent) was calculated by multiplying the various GHG emissions with their corresponding global warming potentials (100-year time horizon) [10]. Figure 1 shows the GHG emissions for the various production steps: olive production, oil extraction, packaging, and distribution. Possible combinations of olive farms and oil extraction mills were considered on a regional basis. For the north, all combinations of farms F1 and F2 with the three-phase mill M1 or the two-phase mill M2 were considered. In central Portugal, the organic farm F4 and the traditional pressing mill M6 work together. For the two-phase mills of this region (M3, M4 and M5), the mean input and output values were considered in combination with the farm F3 and the familiar farm F5.

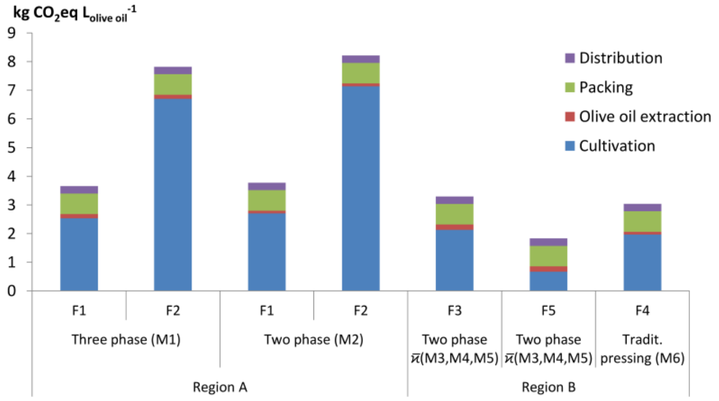

Figure 1. GHG emissions along the olive oil production steps for different olive oil extraction processes followed by several olive oil mills.

The resulting GHG intensity of virgin olive oil had a large spread, varying between 1.8-8.2 kg CO_2eq L^{-1}. Olive production dominated (0.7-7.1 kg CO_2eq L^{-1}), and is thus presented in greater detail in Figure 2.

Within the olive production step, the highest share of emissions originated from fertilizer use. About half of the emissions of synthetic fertilizers arose during their production; the remaining were field emissions. Organic fertilizers only caused field emissions. Among typical industrial farms (i.e., non-organic and non-familiar), farm F3 had the lowest GHG emissions per kg of olives despite its highest fertilizer usage per ha. The reason lies with its very high productivity (olive yield per ha more than fivefold that of farms F1 and F2). Its intensive irrigation system increased the GHG intensity of olive production only to a small extent due to process electricity. The organic farm F4, however, had even lower fertilizer emissions per kg of olives, despite its productivity being 20 times inferior to farm F3. The reason lies in its low fertilizer usage and absence of emissions during fertilizer production (as it uses only manure). The lowest emissions were calculated for the familiar farm F5, which did not use any fertilizers; however, its per-hectare yield is the lowest of all farms, and subject to large yearly variations depending on weather conditions.

A direct comparison between farms F1 and F2 demonstrates the importance of fertilizer usage and productivity. While both farms used similar amounts of fossil fuels per hectare for their agricultural operations, they applied fertilizers differently. F2 used more than twice as much fertilizer per hectare, and even more per kg of olives due to its slightly lower productivity (see Table 1). This implied more than double production-phase emissions (from the production of fertilizers) for producer F2, and also much higher fertilization field emissions (0.44 vs. 0.18 kg CO_2eq kg^{-1}). Taken together, these effects make the cultivation emissions of producer F2 more than double as high per kg of olives as those of producer F1 (1.46 and 0.55 kg CO_2eq kg^{-1}, respectively).

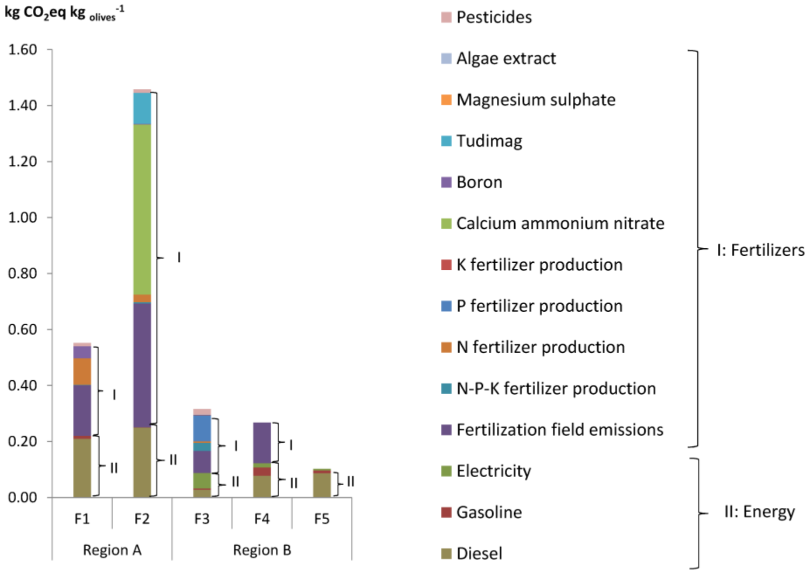

Figure 2. GHG intensity of olive cultivation.

The olive oil extraction process had a minor impact on the overall GHG intensity (due to process energy), and no noticeable difference was determined between the two- and three-phase extraction processes (Figure 3, left). The effects of OP, OMW, and OWP resulting from the extraction processes, however, were not considered in this short paper, and their inclusion in the analysis might increase the significance of the extraction step. They all induce environmental burdens but can also be used as inputs to other processes and thus avoid emissions [3]. Finally, packaging and distribution induced together an impact of about 1 kg CO_2eq per liter of olive oil (Figure 3, right).

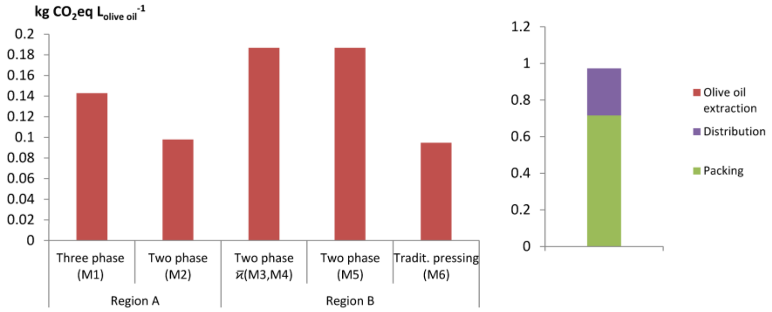

Figure 3. GHG intensity of olive oil extraction (left), and packing and distribution (right).

The GHG intensity of a kilogram of olives (as presented in Figure 2) reflects itself five- to sevenfold per liter of olive oil, corresponding to the amount of olives needed to obtain one liter of oil (see Table 1). As this item dominates the entire life-cycle impact of olive oil, enhancing the efficient use of fertilizers (i.e., large olive yields per hectare and/or reducing the amount of fertilizer) seems a key factor for mitigating the GHG intensity of olive oil.

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