LCA-based comparison of traditional and alternative scenarios in the management of wastes generated from the extra virgin olive oil production

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Abstract

The extra virgin olive oil production is one of the most important economic activity in the Mediterranean regions. The two major refuses from olive oil production, the solid-liquid OP and the liquid one OMWW, are actually disposed on the soil without control, although the existence of a national law, which limits this practice. The aim of this work is the conduction of the LCA for the production of 1 L of oil. It emerged that the production of the oil and the uncontrolled disposal on the soil of the generated wastes, have consequence on the eutrophication, photochemical oxidation and acidification of the soil, and they are also a potential source of contamination for aquifers. 1 L of Olive oil production and the wastes' release on the soil cause the emissions of 2.5 kg of CO2 equivalent and require an energetic demand for 3.0 MJ equivalent. In addition, the conventional waste scenario has been compared with the anaerobic digestion. The adoption of this technology has great advantages in all the parameters considered for the LCA study.

Keywords: olive oil, agro-food wastes, LCA, anaerobic digestion, OMWW

1. Introduction

Olive oil is one of the most used sauces all over the world, whose production is concentrated around the Mediterranean Countries, representing a very important economic sector for Spain, Italy and Greece[1]. With more than 180,000 hectares of ground cultivated to olive trees and more than 19,000 producers [2] Italy is the second Country of olive oil production in the world [3]. The two Italian regions where the olive oil production is concentrated are Toscana and Puglia, with the 61% and 19% of the national numbers of olive oil producers respectively [2].

The art of extraction oil from olive drupes dates back to 5,000 years ago, in the ancient Greece [4]. The process consisted in the extract olive oil produced in the mesocarp cells, and stored in a particular type of vacuole called a "lipo vacuole". The olive oil extraction from the other components is made possible by physical techniques exploiting the densities difference between solids, water and oil, or by chemical solvents, generally hexane [5]. The modern method of olive oil extraction uses an industrial decanter to separate all the phases by centrifugation. The olives are crushed to a fine paste by a hammer crusher, disc crusher, depitting machine or knife crusher. The paste is then left for 30 to 60 minutes in order to allow the small olive droplets to agglomerate. The aromas are created in these two steps through the action of fruit enzymes. Afterwards the paste is pumped into an industrial decanter where the phases will be separated and where water is added to facilitate the extraction process with the paste. The decanter is a large capacity horizontal centrifuge rotating approximately 3,000 rpm, the high centrifugal force created allows the phases to be readily separated according to their different densities (Olive Pomace (OP)>Olive Mill Waste Waters (OMWW)> Oil) [1]. Inside the rotating conical drum there is a coil that rotates more slowly, pushing the solid materials out of the system. Two types of decanter exist:

1) the three-phases oil decanter, in which OP, OMWW and oil are separated (Figure 1); it has the disadvantage to produce a larger quantity of OMWW than the two phase oil decanter.

2) The two-phases oil decanter has been created as an attempt to reduce the amount of OMWW generation. The olive paste is separated into only two phases: oil and wet pomace. This type of decanter, instead of having three exits (oil, water, and solids), has only two [6] ones.

The two main wastes from olive oil extraction's activity are a semi solid refuse, the OP and a liquid one, the OMWW. According a territorial survey conducted by "AgriRegioni Europa" the quantities of OP derived from olive mills in Italy and Puglia are 2,264,483 t/y and 752,642 t/y respectively [7]. Another research conducted by Bonari et al. [8] estimated the quantities of OMWW produced in Italy and Puglia, in 1,035,007 t/y and 371,269 respectively [8]OP and OMWW are rich in organic matter, have a high content of TS and of chemical substances, such as nitrogenous (TN), ammonia (TAN) and phosphorous (TP) compounds, present a low pH and high electrical conductivity and consequentially have an important environmental impact [9].

Although their chemical –physical characteristics which make OP and OMWW very polluting, in the major of the cases they are simply dispose on soil, used for irrigation or illegally discharged to the environment. The only advantage of this practice is the null cost of the operation [10]. In Italy the olive wastes amount which is possible to release on the ground is about 30 m^3/ ha year [11]. A study conducted by Sierra et al. (2007) [12] demonstrated that considering the fertility parameters studied (organic matter, N and P) it can be said that increasing the rate of OMWW on soil up to 360 m^3/ ha year, the fertility of the soil is enhanced. However, the immobilization of nitrate (rate-dependent), the increasing of the salinity and of phenolic compounds concentrations may be able to negatively affect the plants production. A part of the OP is degraded in contact with the air with the release of carbon dioxide in the atmosphere. In addition, an amplified OMWW disposition on the soil increase the chance that they can reach and pollute aquifers [10].

A promising technology to treat the olive oil production wastes is represented by Anaerobic Digestion (AD). The advantages of this technology are: high abetment of the organic substances, low need to add nutrients for the degradation of the substrates, production of stabilized sludge and the production of biogas with high methane content. Previous studies have demonstrate the good performance of biogas production by AD from olive oil wastes which in continuous mode can reach value as high as 1.4 NL/L of biogas with a methane content of 70% v/v [13].

Life Cycle Assessment (LCA) is a useful technique for analyzing the environmental footprint of products or technological processes at all stages in their life cycle – from the extraction of resources, through the production of materials, parts, and the product itself, and to the use of the product and its end of life, either by reuse, recycling, or landfilling with or without energy recovery (i.e., "from the cradle to the grave") [14].

The aim of this work is the conduction of LCA for the production of one litre of olive oil, that means to evaluate the impact of the modern technology used for the olive oil starting from the tree cultivation and fertilization phases to the bottling one. In addition, the work intends to investigate, in terms of environmental impacts, the traditional waste scenario, which consists in uncontrolled release of olive oil refuses on the ground, and compare it to the one associated to their use in AD for biogas production.

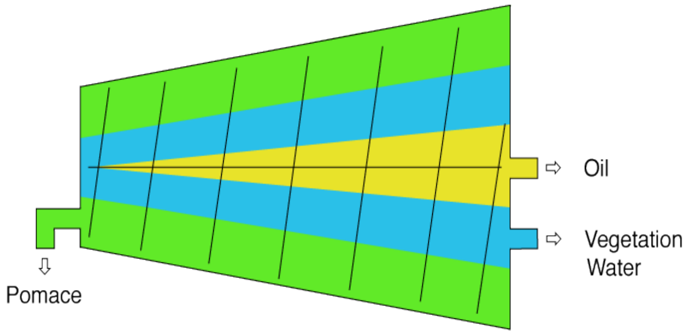

Figure 1: Mechanisms of separation by centrifugation of OP, OMWW and oil in the three-phases oil decanter

2. Materials and Methods

This research has been conducted using SimaPro v7.1.8, using its already set default databases. In particular, LCA study has been conducted according to ISO definition of LCA based on standard 14040 (2006) is the LCA Inventory. In this project, the indicators proposed by the Method of evaluation EPD 2007 of SimaPro v7.1.8, have been chosen as the main impact categories and will be evaluated in absolute terms without weighting procedures or normalizations. Specifically, the impact categories selected for this LCA study are:

- Global Warming Potential (GWP)
- Ozone Layer Depletion (OLD)
- Photochemical Oxidation
- Acidification
- Eutrophication

- Global Energy Requirement (GER), non-renewable, fossil sources

2.1 LCA of olive oil production

The functional unit correspond to 1 liter of extra virgin olive oil produced. The LCA evaluation includes all the segments from the cultivation of olive trees to the bottling of olive oil. The segments included in the LCA are: cultivation of olive trees, the machineries and the operations included in the oil production and its bottling in 1 liter glass bottles. In particular, the cultivation stage encompassed all the agricultural processes include the irrigation and fertilization of olive trees. The processing phase includes the harvesting of olives from the trees, their transport to the olive mills (where the oil is produced), the olives washing through a continuous machine, the milling operation, the malaxing and two stages of centrifugation for the extraction of oil and its separation from OP and OMWW. Lastly the bottling of olive oil into glass bottle completed the process. All the raw materials used for the realization of the machineries, the electricity consumption used during each single process and the auxiliary have been normalized taking into account the functional unit adopted for this LCA evaluation. The main characteristics related to each phase of olive oil production have been summarized in Table 1.

It is important to note that the amount of energy, gasoline, water demand and the amount of the materials for the realization of the machines involved in the different operations are already normalized taking into account the functional unit.

The assumption that are taken into considerations are the following:

- The production of 1 L of extra virgin olive oil needs of 6 kg of olives.
- Olives, fertilizers; pesticides and herbicides are transported by 2.4 gasoline pickup truck. A consumption of 7.5 L/100 km of gasoline has been considered [15]. An average distance of 20 km has been considered from the cultivation sites to the mills.
- Data of materials for the constructions of the different machines and the energy demand for the production of 1 L of extra virgin olive oil have been extracted by technical sheet from producers websites [16,17,18,19].
- Data of materials and the energy demand for the production of the necessary fertilizers and pesticides/herbicides are been calculated considering the research by Foteinis and Chatzisymeon [20].
- The production of one unit of one-liter glass bottle for the packing of the functional unit of extra virgin olive oil is already included in the software SimaPro v7.1.8.

Table 1: Main features related to each process of olive oil production

Materials (kg) **Operations and machines**	**stainless steel**	**cast iron**	**copper**	**synthetics**	**Energy (kJ)**	**Gasoline (L)**	**Water (L)**	**Manure**	**Calcium nitrate**	**Kocide Opty (30% CuOH)**	**Aliette (80% Fosetyl-Al)**	**Ridomi gold (64% Mancozebe 4% Metoxyo-M)**
Olive harvesting						4.4						
Irrigation					400		2					
Fertilizers								6	$2*10^{-4}$			
Insecticides/ herbicites										$2*10^{-4}$	$2*10^{-4}$	$2.5 * 10^{-4}$
Olive Washing Machine	1	1.32	0.4	0.6	300							
Milling machine	10	40	2	3	500							
Melaxing machine	1.5	4.5	1	5	1665							
Centrifuge	3	4	2	4	120							
Trasport of fertilizers/herbicites						2.12						
Trasport of Olives to milling sites						2.9						
Glass Bottles Production	Data already included in EcoInvent											

2.2 The waste scenarios: wastes releasing on soil vs. Anaerobic Digestion

The first waste scenario is based on the assumption that OP and OMWW are simply release on the soil. It is the scenario which really occurs in some Italian regions, especially in the south part of the Country [21]. The characteristics of OP and OMWW have been reported in Table 2. The environmental impact of this waste scenario has been normalized taking into account the OP and OMWW derived from the production of 1 liter of olive oil. It is important to underline that the concentration of the organic matter and the other parameters (e.g. phenols) of OP and OMWW excess the limits imposed by the national law [18]. The aerobic degradation of these substrates, the adsorption of chemical compounds by the soil are the major responsible of air, ground and aquifers pollution. In particular:

The CO2 emissions from the disposal of substrates on the soil by aerobic process is given by the following equation [22]:

$$ECO2 = msubstrates * TS * CC * (44/12) \qquad (4)$$

Where:

ECO2are the grams of CO2 emissions into the atmosphere; TS is the content of the TS solids of the substrates (% w/w); CC is the organic Carbon Content of the substrates (% w/w) and 44/12 is the conversion factor from carbon to carbon dioxide.

The second waste considered is the AD of a mixture of OP-OMWW having a Total Solids (TS) concentration of 10 % w/w. It is the most common TS concentration used in the digester for AD working in wet conditions. Considering the functional unit of olive oil, 3.5 kg of OP and 1.5 kg of OMWW [2] are produced for 1 Liter of oil. This waste stream make possible a production of 1.4 NL/L of biogas with a methane concentration of 70% v/v [13]. The biogas from the waste streams derived from 1 L of extra virgin olive oil production is supposed to be used into the cogeneration process for the production of 24.6 kJ of electrical energy. The digestate from AD process has a lower concentration of organic matter, which respects the limits for its releasing on the soil imposed by national law and, therefore, it is used as fertilizer. The CO2 equivalent emissions necessary for the production of the electrical energy by biogas have been calculated taking into account the functional unit and the factor extracted by the work of Cherubini et al. [23] where it is estimated a CO2 emission of about 20 g for MJ of electrical energy produced.

3. Results and discussions

3.1 Results of LCA of olive oil production

Table 3 shows the impact on the different LCA parameters for the two most relevant sections of the olive oil production: a) the cultivation and harvesting phase and b) the extraction of 1 litre of oil from olives and its bottling into 1 litre glass bottle. Figure 2 shows the comparative relation between the impacts of the two sections for each LCA parameter.

As it possible to see from Table 3, the olive oil production has no impact on ODP, which is affected by the concentration of chlorinated and brominated compounds, which are not contemplated in any phases of the process.

On the contrary, Acidification is deeply influenced by the olive oil production activity, causing 2.84 kg SO2 equivalent. The higher contribution comes from the “production and bottling” phase (Figure 2). It is due to the amount of stainless steel and copper used for the realization of the different machines for the oil extraction. These materials, in particular copper used for the electric lines, require a considerable use of acids (e.g., nitric acid) during its processing phase and explosives during its extraction phase [24,25]. The nitrogen-based products, used for the copper extraction and transformation, cause also a significant contribution to Eutrophication category, which evaluates the accumulation of nutrients (e.g., ammonia, nitrates, nitrogen oxides) in the environment. The total emission for Eutrophication are almost 0.08 kg of PO43- equivalent, with are due for almost the 65% (Figure 2) to the cultivation and harvesting phase, affected by the use of fertilizer and insecticides. Nitrogen fertilizers, cause high levels eutrophication in freshwater bodies such as lakes, ponds and rivers. In addiction the olive oil production activity requires the operation of transport of olives to mills where oil is extracted and the transportation sustainability of organic cultivation is strongly related to the transportation of organic fertilizers (manure, Table 1) to the field and to their mechanical spreading and application. Also, the fossil fuel requirements for the mechanical agitation of the soil (i.e. tractor ploughing, harrowing and hoeing) play an important role to the increase of Eutrophication parameters. It is important to note that fertilizer give a significant contribution also to Acidification parameter: they create a difference of pH in soil and water bodies and interferes with availability of nutrient and other pollutants (heavy metals) for plants and aquatic organisms [20].

Photochemical oxidation parameter is mainly affected by the cultivation phase. In fact, it measures the accumulation of nitrogen oxides which is due, as previously reported, to the use of fertilizers and insecticides. In addition the practice to spread on the soil both OP and OMWW, rich in organic and nitrogen content (Table 2), further cause Photochemical Oxidation increase.

GER which quantifies the energy demand required for the production of 1 liter of olive oil is almost 3 MJ equivalent. Almost the 90% (Figure 2) is linked to the phase of the oil extraction and bottling. In the evaluation of GER, in fact, it is necessary to take into account not only of the electric energy demand for the running of the machines used for the olive oil extraction (Table 3) but also for the energy used for the extraction of the raw materials (copper, minerals) and for the realization of these machines. The energy amount (0.4 MJ equivalent, Table 3) related to the cultivation phase is mainly due to the electricity used for the irrigation and for the production of fertilizers and insecticides [26].

Lastly, the emissions of 2.5 kg CO2 equivalent (GWP) for the production of 1 litre of olive oil are almost equally divided between the cultivation phase and the production and bottling ones, (Figure 2). GWP is due to the emissions deriving from operation of the machineries for the oil extraction and to the air emissions of gasoline and diesel vehicles used for the transportation of the olives to the mill-centres and for the transportation of fertilizer and insecticides. It is important to underline that in this GWP estimation the emissions by the degradation of organic wastes (OP and OMWW) released on the soil is not included. This evaluation has been conducted in the following chapter.

Table 2: Relevant physichal-chemical characteristics of OP and OMWW

	OP	**OMWW**
Density (kg/m3)	960.70 ± 39.65	934.96 ± 7.14
pH	5.12 ± 0.08	4.89 ± 0.04
TS content (% *w/w*)	32.16 ± 2.06	0.91 ± 0.03
VS content (% *w/w*)	30.21 ± 2.02	0.08 ± 0.11
TAN (g/L)	0.13 ± 0.07	0.01 ± 0.00
TN (g/L)	1.78 ± 0.53	0.27 ± 0.02
TP (g/L)	0.62 ± 0.11	0.11 ± 0.01
Polyphenols concentration (mg gallic acid /L)	24.78 ± 2.38	254.45 ± 12.38

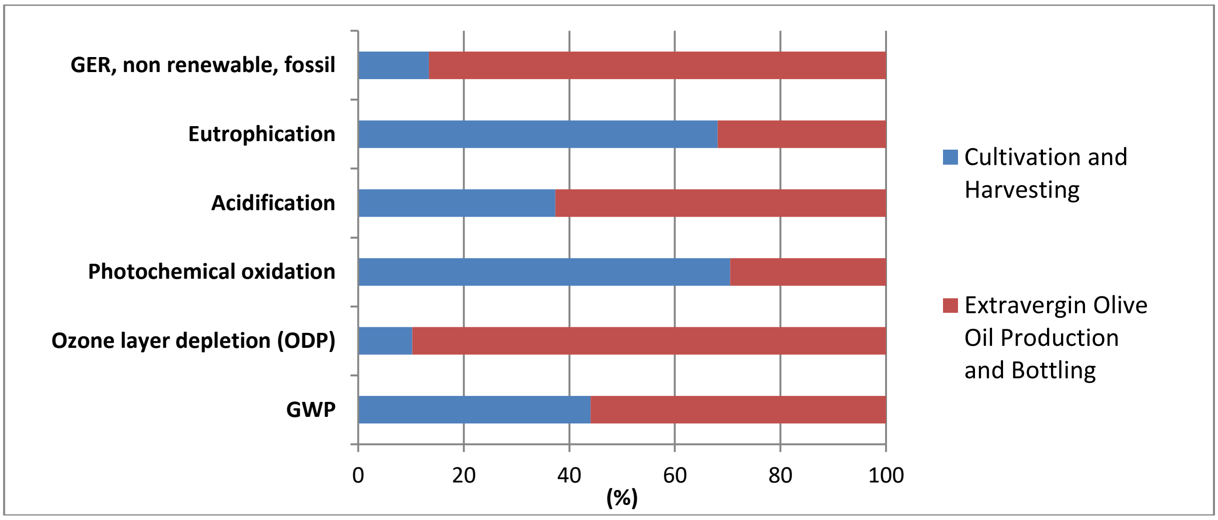

Figure 2: Relevance of each LCA parameter in the comparison between the two investigated phases of olive oil production

Table 3: Impacts evaluation for each of the selected LCA categories in the two main sections of olive oil production

Impact category	Unit	Cultivation and Harvesting	Extravergin Olive Oil Production and Bottling
GWP	kg $CO_{2\ eq}$	1.1	1.4
Ozone layer depletion (ODP)	kg CFC-11 $_{eq}$	0.00000064	0.0000056
Photochemical oxidation	kg $C_2H_{4\ eq}$	0.286	0.12
Acidification	kg $SO_{2\ eq}$	1.06	1.78
Eutrophication	kg $PO_4{}^{3-}{}_{eq}$	0.0514	0.0241
GER, non-renewable fossil	MJ $_{eq}$	0.4	2.585

3.2 Results of the waste scenarios: releasing on soil vs. Anaerobic Digestion

Table 4 shows the difference in the impacts of the two different wastes scenarios in terms of LCA parameters. It is evident the environmental advantages in the adoption of Anaerobic Digestion technology in all the considered LCA parameters. In fact, the high organic load of OP and OMWW, composed mainly by polyphenols as well as short and long –chain fatty acids, represents a serious risks of ground and surface water pollution [27]. The releasing on soil of the olive oil production wastes causes negative impact mainly in the acidification parameter: the low pH of OP and OMWW (Table 2) due to humic and fulvic acids for a total amount of 15% w/wof the dry OP and OMWW [27] cause the alteration of the pH of the ground, altering the equilibrium of the microorganisms typically present in the soil. With the AD, the acidification impact shows a sensitive reduction varying from 3.21 to 0.83 g of SO2 equivalent (Table 4). A considerable reduction is also recorded for the Eutrophication parameter, which decrease from 0.72 g of PO43- in the case of releasing the wastes on soil to 0.14 g of PO43- when they are treated by Anaerobic Digestion. OP and OMWW contain high concentration of nitrogen and phosphorous compounds, 1.78 g/L and 0.65 g/L, respectively (Table 2). In addition, some micro-nutrients, such as magnesium and potassium, are present too. They are responsible of an uncontrolled proliferation of the herbs which in many cases leads the farmers to an augmentation of the use of herbicides [28]. The best improvements is detected by GWP parameters. The release on the soil of the wastes followed by their aerobic degradation lead to the emission of about 75 g of equivalent carbon dioxide. Anaerobic digestion leads to the formation of a gaseous mixture composed, as assumed as hypothesis, by 70% v/v by methane and 30% v/v of carbon dioxide. Although methane has characterized by GWP 25 times greater than carbon dioxide, it is used for the production of electricity and consequentially does not represent an emission on the atmosphere. Table 4 shows as the CO_2 amount arising from Anaerobic Digestion is only 7.7 g. The production of electricity as obtained from the methane produced by the digestion of the wastes generated by the production of 1 L of extra virgin olive oil, causes the emission of 0.4 g CO2 equivalent. The main part of equivalent CO_2 emission (101.5 g), is produced by the aerobic degradation of the digestate from AD that is released on the soil, although it involves a lower content of organic matter as a consequence of the AD process. The use of AD allows the saving of about 200 g CO_2 equivalent emissions to the atmosphere. Taking into account the annual total mass of the olive oil wastes, as reported in the introduction chapter [7], it results as the recourse to AD allows to avoid the emissions of more than 450 t CO_2 equivalent every year. It is important to underline that the digestate can be still used for the production of fertilizer: in this way it will be possible to further reduce the GPW impact derived from olive oil production wastes.

Table 4: Comparison of the impacts produced by the two different management and disposal scenarios

		Waste Disposal on soil	Anaerobic Digestion
g CO2 from aerobic process		303,03	101,5
g CO2 from AD			7,67
g CO2 from electricity production			0,4
GWP	g $CO_{2\ eq}$	303,03	109.57
Ozone layer depletion (ODP)	g CFC-11 $_{eq}$	neglectable	neglectable
Photochemical oxidation	g $C_2H_{4\ eq}$	0,19	0,02
Acidification	g $SO_{2\ eq}$	3,21	0,83
Eutrophication	g $PO_4{}^{3-}{}_{eq}$	0,72	0,14

4. Conclusions

Extra virgin olive oil is one of the most appreciated sauce all over the world. Its production is concentrated in the Mediterranean area and in particular in Spain and Italy, where it represents a profitable activity for the national economies. The common practice to release the wastes derived from olive oil production, the OP and OMWW, represent an environmental problem which causes the alteration of the chemical properties of the soil and the contamination of the eventual aquifers. A LCA has been conducted in order to determine the impact of the production of 1 L of extra virgin olive oil. It emerged that the production of steel and copper used for the construction of machinery for the oil extraction from drupes, and the production and the use of herbicides and fertilizers, lead to a great impact on Acidification, Eutrophication and photochemical oxidation. GWP and GER have been calculated as well indicating more than 2.5 kg of CO2 equivalent and 3.0 MJ equivalent, respectively. In addition, the traditional scenario of releasing OP and OMWW on soil has been compared with an alternative scenario utilizing the anaerobic digestion process of these wastes. This last option permits considerable environmental benefits in all the considered LCA parameters, permitting, in particular, to save 450 t CO2 equivalent every year just in the case only the olive oil wastes generated in Italy would be treated by Anaerobic Digestion.

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