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Global Warming Potential Analysis of Olive Pomace Processing

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The olive pomace is a by-product of olive oil production, obtained after milling operations. The milling process can be done by traditional pressing operations, or through centrifugation (that occurred in two or three phases). Depending on the used process and on the number of phases, the olive pomace has a different moisture content and requires different amounts of energy to be dried. On completion of this stage, the residual oil (up to 4 % by weight) is extracted through a mixture of steam and hexane. The drying and the extraction phase are both obtained using hot air and superheated steam produced in a boiler, which uses exhausted pomace (oil-free pomace) at the end of the process.
The aim of this study was the analysis of the CO_2 emissions and the evaluation of the Global Warming Potential (GWP) related to the production of 1 kg of pomace oil (widely used by food industry) and 1 kg of exhausted pomace (used as biofuel). The analysis was performed considering the industrial stages (gate-to-gate approach), varying the type of olive pomace, which depends on the specific milling process. Process data were collected from the chosen industrial site and the life cycle inventory was performed in according to the reference standard ISO 14040-14044.

1. Introduction and bibliographical analysis

LCA studies are generally performed considering the company as a “black box”. Nevertheless, in some cases, some papers are performed as gate-to-gate studies (De Marco et al., 2016a), specifically analysing the individual steps of the process, in order to determine both the areas of inefficiency (Iannone et al., 2016) and the possible improvements (De Marco et al., 2015a). These kind of studies allow the analysis of the emissions considering a wider range of operating parameters (De Marco and Iannone, 2017) and allowing the generalization of the process, obtaining results not specific of a single production (Sanjuán et al., 2014). Moreover, varying the characteristics of the incoming raw materials, it is possible to combine the phases related to the product life cycle (Iannone et al., 2014) and obtain the results for a wider range of applications (De Marco et al., 2015b). LCA was applied to different categories, such as pharmaceutical products (De Marco et al., 2017), semi-finished food products (De Marco et al., 2016b), food products (Roy et al., 2009), and energy (González-García et al., 2014).
In 2015, the worldwide production of olive oil amounted to 2'785'000 tons; i.e., 9% lower than production in the previous year. In particular, the Italian production has settled about 298,000 tons, down 38% (confirming Italy as the second largest producer after Spain). On the average, for each ton of olive oil produced, 2.33 tons of virgin pomace are obtained (Intini et al., 2014). Therefore, the recovery and the reuse of the virgin pomace is a very important aspect to be investigated in terms of emissions, in order to understand the impact of the entire olive oil production chain.
Figure 1 shows the main stages of the industrial processing of olives. The olive products obtained from the process of milling are: olive oil (15-20%), olive pomace (35-45%) and vegetable water (30-50%). The virgin pomace is the pulp resulting from the pressing of olives and is composed of “nocciolino” chopped, pulp residues and residue olive oil.

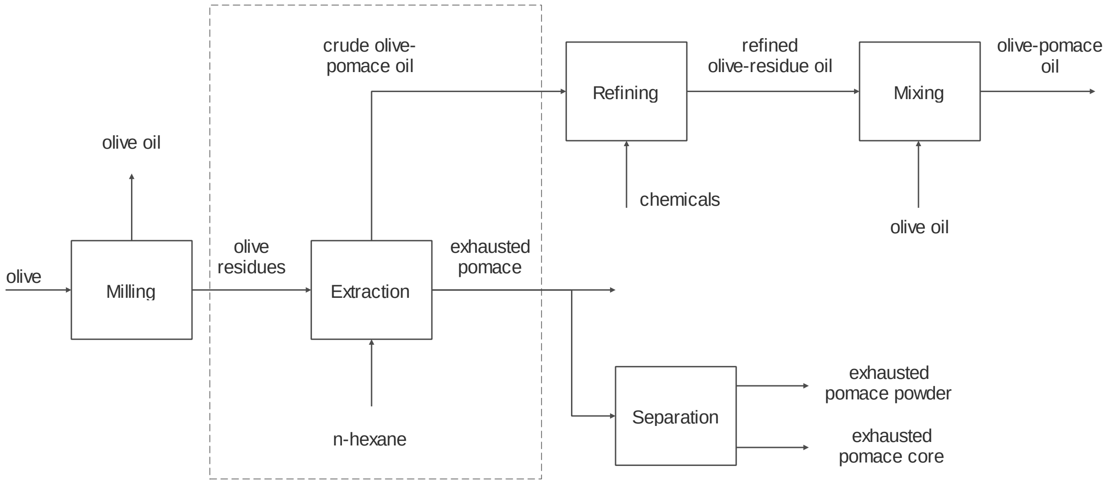

Figure 1: Production chain of olives.

In order to recover the latter fraction of residual oil, which varies between 3% (humid pomace, coming from centrifugal mills) and 6% (virgin olive pomace oil, coming from traditional pressing methods), this product is subjected to a further process, which starts from the virgin pomace or humid pomace, obtaining crude olive-pomace oil and exhausted pomace.

The crude olive-pomace oil is used both to achieve oleins for pharmaceutical and cosmetics' industries and for food usage, although it is not immediately directed to food consumption. Indeed, in the state in which it is produced, it is not edible. In order to be edible, it requires an additional chemical refining and mixing with virgin olive oil. In addition, some studies have been conducted for the use of crude pomace oil as biodiesel (Lama-Muñoz et al., 2014) or lubricant (Dodos and Zannikos, 2011).

The de-oiled pomace (or exhausted pomace) is an excellent granular material for the combustion. It is composed mainly of hazels 45-60 % and still contains 10-15 % of moisture and 0.5-1 % of residual oil. Its lower calorific value is about 16 MJ/kg. It can be used both as bio-fuel and, after further separation, as de-oiled hazen (pellets) (Christoforou and Paris, 2016).

2. Process description

The virgin pomace, at the entrance of the plant, contains a high percentage of humidity and, therefore, it is dried in drum dryers powered by grid burners, using de-oiled residues as fuel. The drying time varies depending on the air temperature and the contained moisture percentage (Göğüş and Maskan, 2006; Meziane, 2011). At the end of the drying phase, the pomace is sent to the extractors, where the dried pomace is processed with hexane. The hexane dissolves the oil and separates it from the other constituents. The mixture of oil and hexane goes to distillation, where the hexane is evaporated and the crude oil is sent to the storage silos. Extraction and distillation operations use steam generated by a boiler. The boiler is also powered by the exhausted pomace. The virgin, dried and exhausted pomaces are moved through wheeled loaders. The crude olive-pomace oil is transferred directly into silo-vehicles that transport it to the refining plants.

3. Methodology

The purpose of this study is to evaluate the environmental impacts of the production of crude olive-pomace oil and exhausted pomace from olive residues on a global scale varying the moisture contents. In Figure 1, the scheme of olive oil production and by-products treatments (industrial stages) is reported.

The definition of the functional unit (FU) is based on the mass of the product under analysis, and it is a reference to which all the inputs and outputs have to be related. The functional unit of this study was defined as 1 kg of crude olive-pomace oil and 1 kg of exhausted pomace. The boundaries of the system include the industrial phases of drying, extraction and distillation as reported in Figure 2.

The data related to the study were obtained from a real system. With these data, it was possible to realize a numerical simulator, which gave us the input and the output data related to the process, varying olive residues' humidity percentage. The comparative study was conducted with the same amount of olive residues in input (95'000 tons). The consumption of electricity was negligible compared to other forms of used energy.

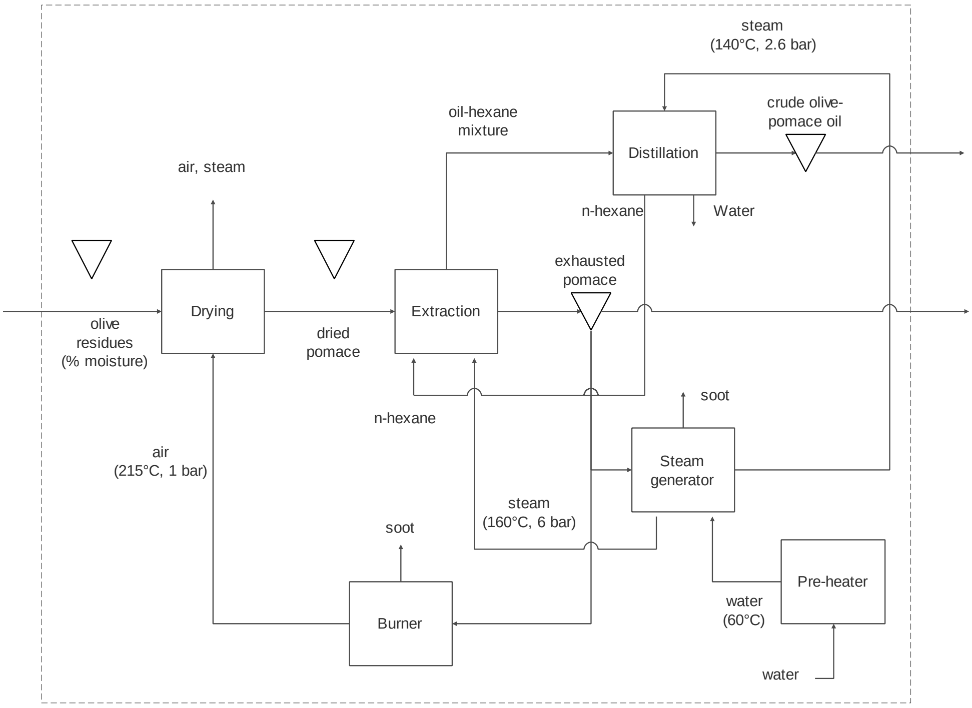

Figure 2: Scheme of the olive residues process.

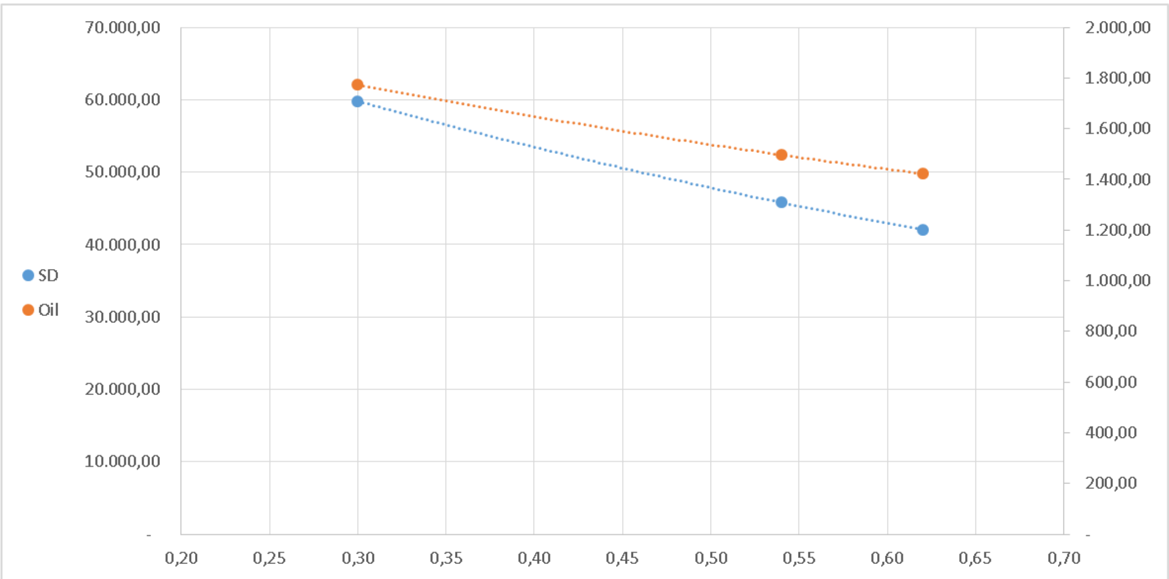

Figure 3: Total production of crude olive-pomace oil and exhausted pomace from 95'000 tons of olive residues with 0.3, 0.54 and 0.62 moisture.

Figure 3 shows that increasing the moisture, the exhausted pomace quantity significantly decreases (-30%), because an exhausted pomace growing amount is used for the drying process; consequently, also the amount of crude product residue oil decreases (-20%). In addition, the emissions due to drying processes increase, but those relating to the phase of extraction and distillation decrease, because of the lower amount of the dried pomace that has to be processed.

4. Results and analysis

The aim of this study is the interpretation of the data collected through the LCI phase and the evaluation and comparison of the impacts related to crude olive-pomace oil and exhausted pomace. The results were interpreted utilizing the advantages of the use of both midpoint and damage categories, according to IMPACT 2002+ life cycle impact assessment methodology. All types of life cycle inventory results via 15 midpoint categories can be linked to four damage categories: human health, ecosystem quality, climate change and resources. In particular, the human health is affected by carcinogens (C), non-carcinogens (NC), respiratory inorganics (RI), ionizing radiations (IR), ozone layer depletion (OLD) and respiratory organics (RO); ecosystem quality is affected by aquatic ecotoxicity (AET), terrestrial ecotoxicity (TET), terrestrial acidification/nitrification (TAN), land occupation (LO), aquatic acidification (AA) and aquatic eutrophication (AE); climate change is quantified using the global warming potential (GWP); resources are affected by non-renewable energy consumption (NRE) and mineral extraction (ME).

Table 1 shows the emissions related to the production of 1 kg of exhausted pomace and 1 kg of raw olive-pomace oil, varying moisture percentage of olive residues. In terms of the GWP value, the emission changed from 3.96 E-01 kgCO_2eq for a traditional production process up to 6.99E-01 kgCO_2eq for a 2 phases centrifugal process.

Table 1: IMPACT 2002+ midpoint results for 1 kg exhausted pomace and 1 kg pomace oil production.

Midpoint category	Unit	Moisture content		
		0.3	0.54	0.62
Carcinogens	kg C_2H_3Cl eq	1.91E-05	2.28E-05	2.42E-05
Non-carcinogens	kg C_2H_3Cl eq	2.03E-05	2.41E-05	2.55E-05
Respiratory inorganics	kg PM2.5 eq	2.87E-05	4.40E-05	4.96E-05
Ionizing radiation	Bq C-14 eq	6.03E-02	7.19E-02	7.63E-02
Ozone layer depletion	kg CFC-11 eq	1.60E-09	1.91E-09	2.02E-09
Respiratory organics	kg C_2H_4 eq	1.72E-04	1.90E-04	1.96E-04
Aquatic ecotoxicity	kg TEG water	2.93E-01	3.49E-01	3.70E-01
Terrestrial ecotoxicity	kg TEG soil	6.46E-02	7.71E-02	8.18E-02
Terrestrial acid/nutri	kg SO_2 eq	3.79E-04	5.77E-04	6.50E-04
Land occupation	m^2 org.arable	1.39E-05	1.65E-05	1.76E-05
Aquatic acidification	kg SO_2 eq	3.57E-04	5.51E-04	6.23E-04
Aquatic eutrophication	kg PO_4 P-lim	6.43E-07	7.67E-07	8.14E-07
Global warming	kg CO_2 eq	3.96E-01	6.15E-01	6.99E-01
Non-renewable energy	MJ primary	1.33E-01	1.59E-01	1.69E-01
Mineral extraction	MJ surplus	2.53E-05	3.02E-05	3.21E-05

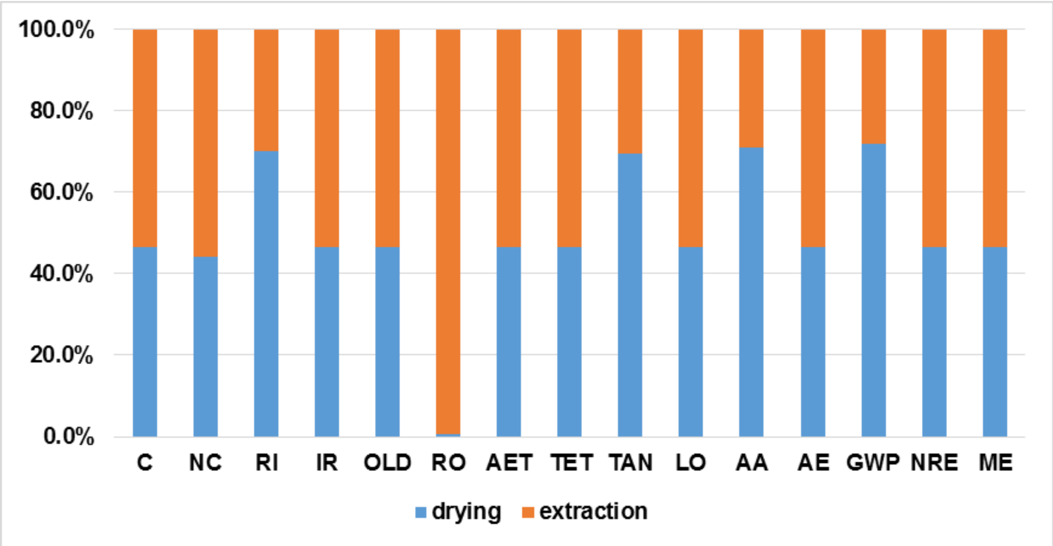

Figure 4: Contribute of drying step and extraction step on IMPACT 2002+ midpoint results for 1 kg exhausted pomace and 1 kg pomace oil production.

Figure 4, however, shows the analysis of the midpoint IMPACT 2002+ categories by comparing the drying phase and the extraction phase emissions. Obviously, the moisture growth has more effect on the drying phase due to higher processing times.

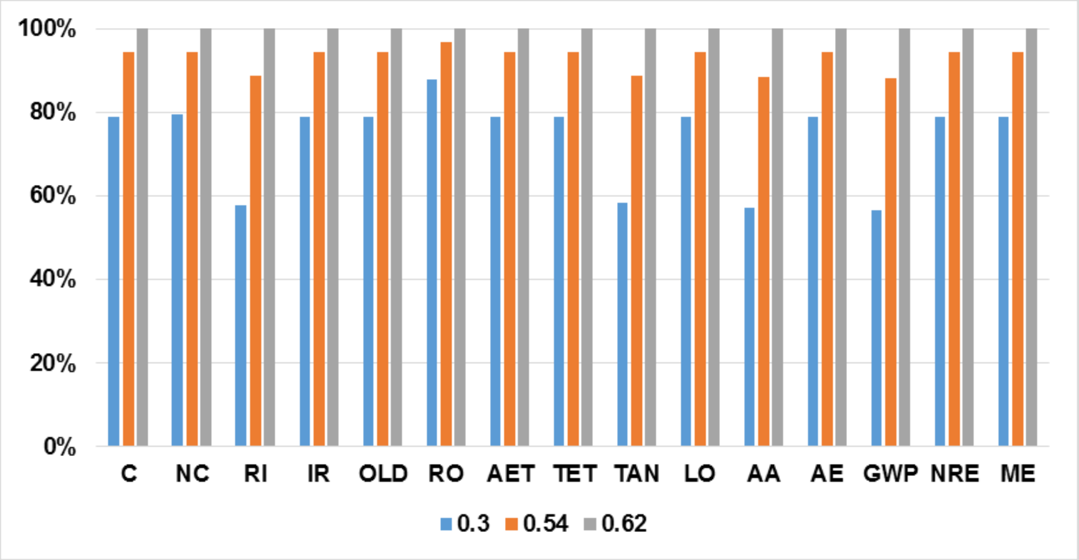

Figure 5: Effect of moisture on IMPACT 2002+ midpoint results for 1 kg exhausted pomace and 1 kg pomace oil production.

Indeed, Figure 5 confirms this effect showing the increase in emissions at different moistures. In particular, categories RI, TAN, AA and GWP are the most affected by this variation. In particular, the GWP is the most affected category. Analysing the emissions at different virgin pomace moisture content, in terms of endpoint categories (Figure 6), it is possible to observe that the climate change is the most affected category.

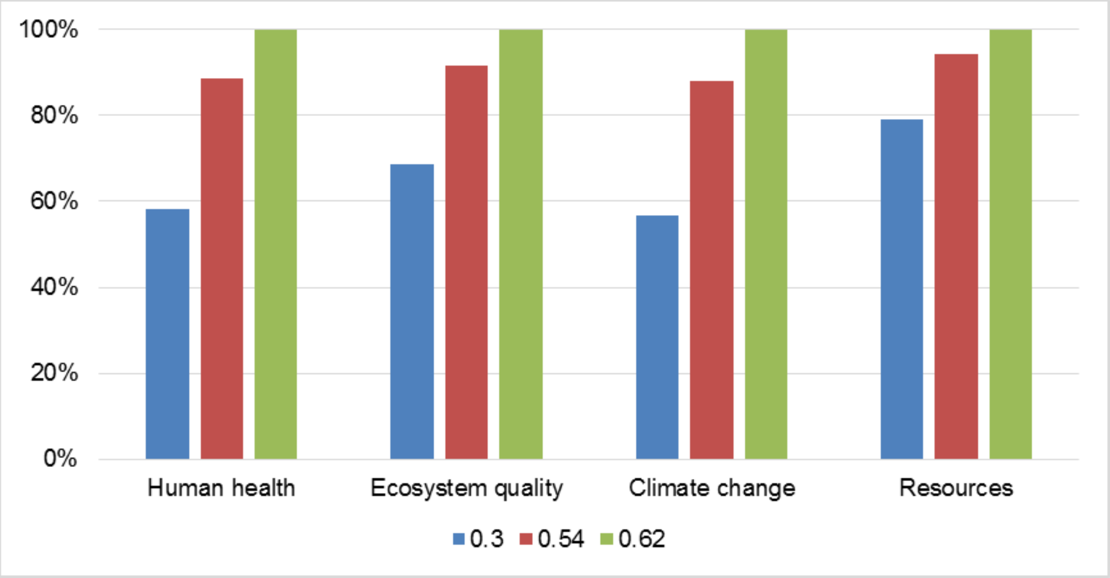

Figure 6: Effect of moisture on IMPACT 2002+ endpoint results for 1 kg exhausted pomace and 1 kg pomace oil production.

5. Conclusions

This work developed a numerical model for the analysis of emissions for the production of crude olive-pomace oil and exhausted pomace, varying the moisture of the virgin pomace in input. The study is designed as a step

for a complete analysis of the life cycle of the olive oil production. It provides information on emissions changing the humidity of the raw material, in order to allow the determination of emissions for the main oil extraction processes typology (traditional pressing, centrifugal two-phase or two and half phases).
From the analysis of the results, it is evident that the increase of the input moisture level generated an increasing of the emissions on all the midpoints category. The midpoint category most affected by moisture variation is GWP, whereas the endpoint category most affected is the climate change.

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