ATTI

XIII Convegno della Rete Italiana LCA
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Il Life Cycle Thinking a supporto delle strategie di mitigazione e adattamento ai cambiamenti climatici

Università degli Studi Roma Tre,
Dipartimento di Economia Aziendale
13-14 giugno 2019

A cura di Gabriella Arcese, Maurizio Cellura,
Sara Cortesi, Laura Cutaia, Maria Claudia Lucchetti,
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ROMA TRE UNIVERSITÀ DEGLI STUDI Dipartimento di Economia Aziendale

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Indice

Sustainable recovery of phenolic compounds from olive mill wastewater: an LCA evaluation

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Abstract

The disposal of olive mill wastewater is one of the main environmental problems of olive oil production. The interest in the recovery of olive mill wastewater has increased in recent years, as their purification from potentially harmful molecules, such as phenolic compounds. The aim of this work was to study the sustainable recoveries of phenolic compounds from olive mill wastewater, through an integrated Life Cycle Assessment and Eco-Care Matrix evaluation. The assessment was carried out on two recoveries: the first one is a chemical approach with the use of gold nanoparticles while the second one is a biological approach by using the laccase enzyme. From the combined analysis, results that the chemical methodology appears more sustainable than the biological one in the economic, human health and environmental areas.

1. **Introduction**

The worldwide olive oil production is around 3 million of tons/yr. The main producer is Spain, followed by Italy, Greece and Tunisia. In 2017/2018 the Italian production was particularly important, especially in the Southern regions. In Puglia 2 million tons (+ 98%) have been exceeded. Also, in Sicily, Calabria e Abruzzo has returned to precedent levels. In Central Italy, especially in Tuscany and Umbria the trees growth has been particularly limited because the summer drought affected all the phases vegetative. In Lazio (+ 68%) and Marche (+ 239%), on the other hand, production volumes were abundant (ISMEA, 2018). High quality productions, or protected geographical indication, require the use of a specific variety of olives and "traditional" production techniques. The first step is the olive harvest, preferably handmade and at the right ripening stage. After that, a single machine provides to washing and defoliation. Olives are then sent to the grinding step where a millstone works the drupes for 30-40 minutes. In this step is reached the right milling level, larger droplets of oil with the typical oil flavour. The following extraction step involves the use of hydraulic presses. This technique allows to maintain a low temperature. The products of this step are olive pomace (40%) and oily must (60%). Oily must is centrifuged, allowing the separation of the oil from Olive Mill Wastewater (OMWW). By using this technology system, the OMWW achieved the 42% (w/w) of the initial amount of olives used in the oil production process (Chiacchierini et al., 2007; Chiacchierini et al., 2004). The OMWW includes high nutrient content (e.g. nitrogen, phosphorus, potassium, and magnesium) and no evidence of heavy metal concentration. In the Mediterranean area, the disposal of OMWW is one of the main environmental problems of olive oil production. The interest in the recovery of OMWW has increased in recent years; examples include the production of biofuel from the OMWW, as well as the purification of the OMWW from potentially harmful molecules. Among all the substances present in olive mill wastewater there are Phenolic Compounds in high concentrations, in the range between 5 and 25 g/L (McNamara et al., 2008). The extraction of polyphenols from the OMWW is a great way to recover the PC and re-use them for different applications. The recovery on these compounds is very interesting because of their excellent characteristics, which make them usable in different sectors: cosmetic, food and pharmaceutical.

The aim of this work was to study the sustainable recoveries of phenolic compounds from olive mill wastewater, through an integrated Life Cycle Assessment (LCA) and Eco-Care Matrix evaluation.

The assessment was carried out on two recoveries: the first one is a chemical approach with the use of gold nanoparticles while the second one is a biological approach by using the laccase enzyme.

LCA is a procedure for evaluating the environmental effects/impacts of each stage of a product or a service over the entire productive cycle (from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling). The mechanism purposes to improve recycling process and integrate the phases in the life cycle of a product, from production and consumption to waste management and secondary raw materials market, such as plastics, food waste, critical raw materials, construction and demolition, biomass and bio-based products. LCA is based on the analysis and determination of quantitative variables associated with products, systems and services processed by mathematical equations, composed by data that describe the life cycle. This methodology permits to quantify the energy and materials used (input) and the output and waste released in the environment, in order to evaluate tangible opportunities to reduce the environmental negative impacts (Johnson et al., 2013). The study through the LCA method, allows to compare the production of goods by analysing the amount of first raw materials requests or the amount of CO_2 emissions (Hertwich, 2005). Currently, requests from market have changed, consumers no longer ask for products or services, but also evaluate the environmental impacts. One of the areas in which this greater sensitivity to environmental impacts is most emphasized is in the food sector, where the waste produced are closely related to the growing food demand in perspective of world population increase (Notarnicola et al., 2017).

2. **Methodologies of Sustainability Evaluation**

In this paper the sustainability of the proposed methods, to recovery phenolic compounds from OMWW, was assessed through an integrated evaluation of the Life Cycle Assessment and the Eco-Care Matrix tools.

2.1. **Life Cycle Assessment**

The LCA methodology consists of three stages: Goal and Scope definition, Life Cycle Inventory, Life Cycle Impact Assessment. Moreover, an extra-stage was usually added the Life Cycle Costing (Rapa et al., 2019; Vinci et al., 2019). In detail below:

- Goal and Scope definition: It's the first phase, necessary to clearly defining the goal and scope of the research. This stage also includes the selection of a functional unit, the intended application and audience.

- Life Cycle Inventory (LCI): the second stage of the LCA, regarding the collection of data and information, analysis and validation of data, by defining and studying the exact amount of input and output derived from the system studied. The results are based on the historical records obtained from the experiments object of this research study.

- Life Cycle Impact Assessment (LCIA): In this phase, the environmental effects are quantified as consequences of physical interaction between the production system studied and the environment. The impact categories have been chosen in accordance with the characterization model implemented in the software. In this study “Simapro 8.5” was used for the calculation of specified environmental indexes, by mathematical processing of data describing the life cycle. LCIA provides the information to interpret the environmental significance of the methods comparison.

● <u>Life Cycle Costing (LCC):</u> is an extra-LCA evaluation method that determines the overall cost of products and services, considering its entire life cycle (International Standard Organization, 2006). The analysis permits to determine the cost drivers and understand the potential cost savings that can be applied in a system thanks to innovations of materials, processes or products, especially if different alternatives are compared and the cost-effective option can be derived. In the LCC definition methodology, the overall cost is considered with the aim of assisting the decision makers in the choices regarding modification of some variables in the Life Cycle of specific products or services, for determining the most cost-efficiency and competitive solutions for the production process.

2.2. **Eco-Care Matrix**

The Eco-Care-Matrix (ECM) is a tool that is applied in Portfolio Management Process (PMP) to support product portfolio decisions, as well as in research & development process (R&D) to help with product design selection (Huppes, Ishikawa, 2007). Only in recent years the ECM has been applied in the environmental portfolio for product life cycle management, in order to graphically visualize the eco-efficiency of models in a system of x and y axis, where are represented the economic benefits and the environmental benefits respectively. In fact, the matrix is composed by variables derived from LCC and LCA calculations; in this model, the zero point is represented by the traditional system using traditional technology, while the innovative system is located in the matrix according to the environmental benefits in terms of output reduction and economics benefit for consumers in terms of health performances. If the point falls in the positive-positive quadrant, the system is sustainable while in other quadrants the system is not sustainable. The application of ECM (Figure 1) is useful for understanding the convenience of products and services development that contribute in a reduction of environmental and economic costs. Furthermore, the application as well as the interpretation of the results is consistent only if the definitions of limits, data sources and assumption is the same used for the LCC and the LCIA study.

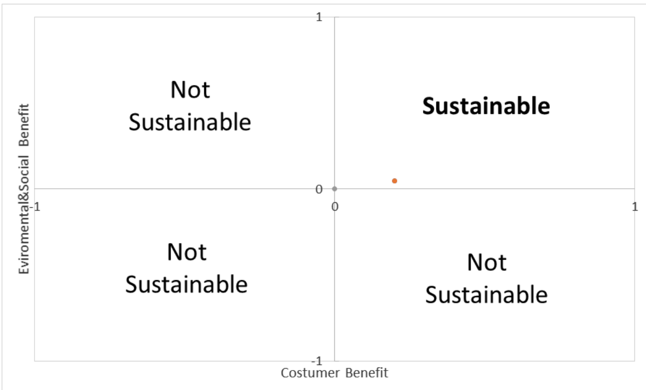

Figure 1: Eco-Care Matrix

3. **Sustainability Evaluation**

In this paper the sustainably of recovery approaches of phenolic compounds from OMWW was evaluated. The study was carried out on two recovery approaches, the first one is a chemical approach (Ciano et al., 2018) with the use of gold nanoparticles while the second one is a biological approach by using the laccase enzyme (Dias et al.,2004; Justino et al., 2010). In the first step of the evaluation an LCA was carried out. Furthermore, the Eco-Care Matrix, an innovative application of LCA result, was applied (Vinci et al., 2019).

3.1. **LCA**

Goal and Scope definition: for the evaluation of the two recovery approaches an aliquot of 10 mL of OMWW was considered as functional unity. The aim of this assessment is to highlight the most sustainable methodology to recovery phenolic compounds from OMWW.

Life Cycle Inventory: the inventory of the nanoparticles and laccase-based recovery was reported in Table 1.

Life Cycle Impact Assessment (LCIA): starting from the data collected in the inventory phase the impact assessment was carried out by using the ReCiPe 2016 method of the Simapro 8.5 software. Several impact categories have been evaluated for the two recoveries; these categories are divided for the effect on human health (express in DALY), environment (express in species/year) and economic resources (express in USD). The categories chosen were reported in Table 2, such as the impact assessment results and the percentage differences of the two recoveries.

Table 1: Life Cycle Inventory

	Nanoparticles	**Laccase**
Materials	12 mg of NPs	15 mg of laccase
Energy	0.001 kWh	13.944 kWh
Instrumentation	Spinner	Spinner, Heated bath
Time	2 h	170 h
Costs	9.8 €	12.8 €

*Table 2: Life Cycle Impact Assessment (*not significant differences)*

Impact Categories	Unity	Nanoparticles	Laccase	Delta
Global warming, Human health	DALY	9,52E-07	8,68E-05	1,10
Stratospheric ozone depletion	DALY	2,59E-10	1,94E-09	13,31
Ionizing radiation	DALY	1,51E-10	5,36E-09	2,83
Ozone formation, Human health	DALY	7,30E-10	1,88E-10	25,77
Fine particulate matter formation	DALY	1,59E-07	2,50E-06	6,34
Human carcinogenic toxicity*	DALY	2,11E-05	4,65E-08	0,22
Human non-carcinogenic toxicity*	DALY	1,16E-03	1,20E-06	0,10
Water consumption, Human health*	DALY	7,65E-09	8,39E-05	0,01
Global warming, Terrestrial ecosystems	sp/yr	1,90E-09	1,74E-07	1,10
Global warming, Freshwater ecosystems	sp/yr	5,19E-14	4,74E-12	1,10
Ozone formation, Terrestrial ecosystems	sp/yr	1,05E-10	4,30E-11	40,88
Terrestrial acidification	sp/yr	1,32E-10	2,70E-09	4,90
Freshwater eutrophication*	sp/yr	1,69E-09	2,40E-13	0,01
Marine eutrophication	sp/yr	6,43E-14	2,00E-14	31,15
Terrestrial ecotoxicity	sp/yr	6,50E-12	1,20E-11	54,08
Freshwater ecotoxicity*	sp/yr	3,18E-10	3,32E-13	0,10
Marine ecotoxicity*	sp/yr	6,32E-07	5,62E-10	0,09
Land use	sp/yr	1,01E-10	3,99E-11	39,48
Water consumption, Terrestrial ecosystem*	sp/yr	4,65E-11	5,10E-07	0,01
Water consumption, Aquatic ecosystems*	sp/yr	2,08E-15	2,28E-11	0,01
Mineral resource scarcity	USD	4,82E-03	4,47E-04	9,26
Fossil resource scarcity	USD	6,91E-03	6,49E-01	1,06

The different impacts of the methodologies can be summarised for the three impact areas: human health, ecosystem and resources. Based on these results, shown in Figure 2, is possible to point out that the two methodologies explored had different impact in the three sectors. Therefore, it is not possible to identify the most sustainable recovery methodology by this way.

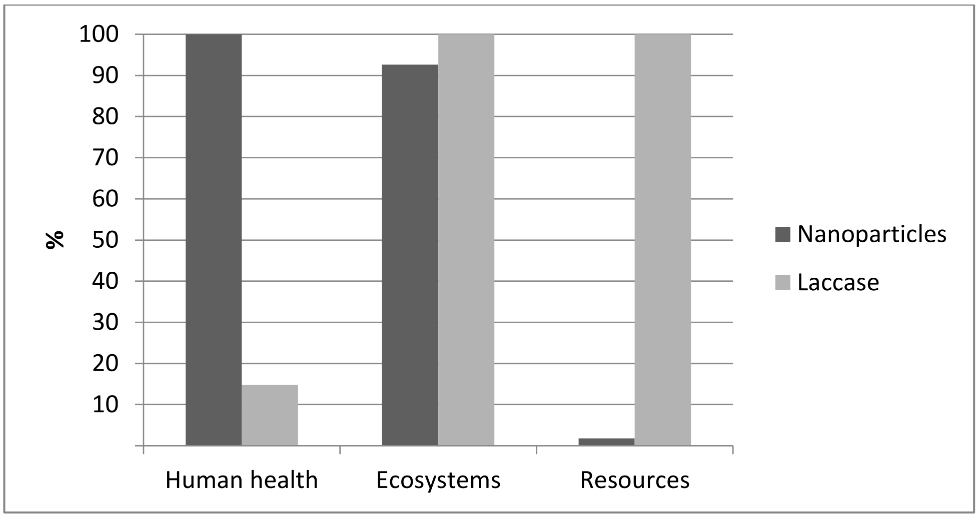

Figure 2: LCIA results in the three impact areas

Life Cycle Costing: the costing evaluation was also carried out. The cost of OMWW disposal, nanoparticles-based phenolic compounds removal and Laccase-based one were analysed. As reported in Table 3, the disposal is the cheaper solution but the most impacting one. Chemical and biological treatments require high economic resources but led to a minor impact to remove phenolic compounds from OMWW. The material costs are referred to Merck KGaA website, the energy from Italian energy market (F0 = 0,06243 €/kWh) and staff to the average hourly pay of an Italian university collaboration fellowship (9.45 €/h)

Table 3: Costs comparison: disposal, chemical and biological treatments

Cost (€)	Disposal	Nanoparticles	Laccase
Material	2.52	9.79	1.19
Energy	0.00	0.01	0.86
Staff	0.00	18.00	280.00
Total	2.52	27.8	282.05

3.2. Eco-Care Matrix

The Eco-Care Matrix tool was herein applied to the all LCA results. At first, the impact categories with no significant differences (Tab. 2) have been excluded from the calculation. Therefore, the impact calculated for the environmental and human health areas have been summed up and mediated. At the end, the two recovery methodologies have been compared in the ECM (Figure 3). From LCA results the Laccase recovery appears less sustainable than the nanoparticles one, so this recovery was chosen as central point.

The nanoparticles recovery point falls in the positive-positive quadrant, consequentially this recovery can be considered more sustainable of the Laccase one.

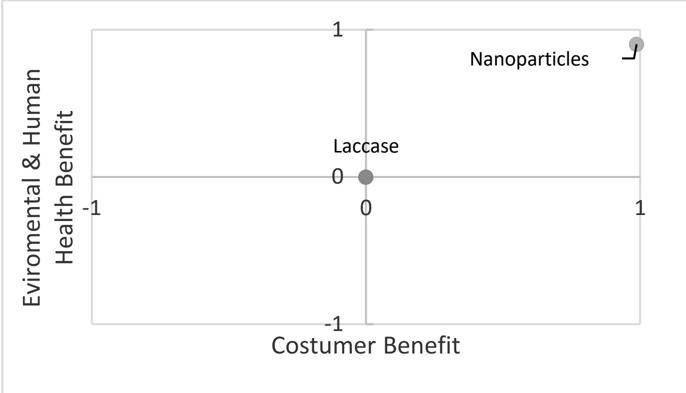

Figure 3: ECM of Nanoparticles and Laccase recovery comparison

4. **Conclusions**

The disposal of OMWW is one of the main environmental problems of olive oil production. The interest in the recovery of OMWW has increased in recent years, as the purification of the OMWW from potentially harmful molecules. The recovery of phenolic compounds, present in high concentrations in OMWW, is very interesting because of their excellent characteristics, which make them usable in different sectors: cosmetic, food and pharmaceutical. This paper studied the sustainability of the phenolic compounds recovery from olive mill wastewater, through an integrated Life Cycle Assessment (LCA) and Eco-Care Matrix (ECM) evaluation. The evaluation was carried out on two recovery approaches, the use of gold nanoparticles (chemical approach) and the use of the laccase enzyme (biological approach). From the combined analysis of LCA and EMC results that the usual disposal is the cheaper way but the most impacting. Moreover, the nanoparticles methodology appears more sustainable than the laccase one in the economic, human health and environmental areas.

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