Short Note

Innovative technologies in EVO oil extraction: an economic and environmental impact analysis

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For Italian agro-food enterprises and especially in Extra Virgin Olive Oil (EVOO) industrial process, structural investments or marginal enhancement of current plant performances could represent an important opportunity to increase the value-added of products linked, for example, to improvement of organoleptic parameters and potential reduction of environmental loads. This paper analyses the economic and environmental impacts in EVOO extraction and its effects on oil yield and quality. The technological innovation under study provides for the use of extraction plant with low oxidative impact, heating of paste before malaxation and a special decanter that avoids the final vertical centrifugation. A control scenario, with a conventional plant was considered in order to make a comparison analysis. A joint use of Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) was implemented respectively for economic and environmental analyses, by using a common methodological framework. A sensitivity analysis was carried out to identify the uncertain factors that may significantly affect the LCA and LCC results. The results demonstrated that innovative olive mill plant implies the higher quality of EVO oil obtained, although the major extraction yield was linked to conventional plant. As the economic and environmental results were strictly dependent on the production yield, the greatest extraction cost and the lower profitability, as well as the highest environmental impacts were achieved with the innovative extraction system.

Keywords: EVO oil extraction process, technological innovation, oil quality, life cycle costing, life cycle assessment.

Abbreviations and glossary: *EVOO* (Extra virgin olive oil). *LCC* (Life cycle costing). *LCA* (Life cycle assessment). *CONV* (Conventional). *INN* (Innovative). *Y* (Extraction yield). *FU* (Functional unit). *ILCD* (International reference life cycle data system). *DAC* (Discounted annual cost). *NPV* (Net present value). EC_{50} (Efficient concentration). *eq* (Equivalents). CO_2 (Carbon dioxide). *CFC* (Chlorofluorocarbon). *CTUh* (Comparative toxic unit for human). *PM 2.5* (Particulate matters 2.5 equivalents). *NMVOC* (Non-methane volatile organic compound). *molc* (Moles of charge). *CTUe* (Comparative toxic unit for ecosystems). *CC* (Climate change). *OD* (Ozone depletion). *HT noc* (Human toxicity, non-cancer effects). *HT C* (Human toxicity, cancer effects). *PM* (Particulate matter). *POF* (Photochemical ozone formation). *AC* (Acidification). *TE* (Terrestrial eutrophication). *FE* (Freshwater eutrophication). *ME* (Marine eutrophication). *FT* (Freshwater ecotoxicity). *WD* (Water resource depletion). *MFDR* (Mineral, fossil & ren resource depletion).

1. INTRODUCTION

The significant role of olive oil in Mediterranean basin is now widely acknowledged, as well as the socio-economic importance that olive farms and oil mills have for issues of public concern: maintenance of traditions, the environmental protection, the sustenance of local economy, also and especially, through improving the competitiveness of agro-food firms [1]. In this sense, the identification of effective business strategies is essential for the long-term success of companies of quality food products, like Extra Virgin Olive Oil (EVOO). Indeed, the evolutionary dynamics of current market and of consumers' preferences should be considered always as the key elements to take the managerial choices to guiding production processes. In this way, technological innovations could represent the right pathway towards quali-quantitative improvements of productivity [2, 3] linked to greater financial incomes but also, where possible, to compliance with societal claims. According to [4], the advancement of the olive oil sector is necessarily related to the millers' ability to adjust their skills to the product and process innovations, and to adopt it within their entrepreneurial context.

In the last decades, for EVO oil extraction process many innovative technologies have been developed [5, 6, 7, 8, 9] and, among others, the malaxation phase [3, 10, 11, 12] has been enhanced in order to achieve significant results in terms of improvement of oil quality. The chance for oil producers to competing on the current market is related to understanding of the key elements that influence the feasibility and potentiality of innovations. To the light of these reflections, the main objective of this paper is to verify, by means of the application of life-cycle methodologies (Life Cycle Assessment and Life Cycle Costing), the implications linked to the introduction of an innovative system with low oxidative impact for EVOO extraction. In particular, an innovative olive oil mill plant located in Sardinia (Italy), in comparison with a conventional plant, was studied in order to analyse both the effects on oil yield and quality and its implications in revenues and environmental terms.

2. MATERIALS AND METHODS

2.1 SAMPLING AND EVOO EXTRACTION SYSTEM DESCRIPTION

The trials were performed by using 600 kg of homogeneous olive fruits (*Olea europaea* L., cv. Bosana), mechanically harvested in November 2017 and divided into two batches of 300 kg of olives. A conventional continuous Pieralisi MAIP Spa plant (CONV) with a theoretical work capability of 2500 kg h^{-1}, located in Alghero (Sardinia-Italy), has been used to mill the first batch of olives. This plant was composed of hummer/blade crusher working at 2800 rpm with a theoretical work capability of 3000 kg h^{-1} followed by a malaxer machine with a work capability of 4000 kg h^{-1}. The paste obtained was malaxed for 20 minutes at 25°C and sent with a flow rate of 1800 kg h^{-1} to a two-phase horizontal decanter with a work capability of 2000 kg h^{-1} and a liquid/liquid vertical centrifuge with a work capability of 1500/1800 kg h^{-1}. The second batch was milled in an innovative Mori Tem plant (INN), located in Oliena (Sardinia-Italy). In this plant, the olives were sent to a blade crusher working at low oxygen pressure with a theoretical work capability of 2000 kg h^{-1}. Successively, the paste was conditioned at 25°C in a tubular heat exchanger with a work capability of 1000 kg h^{-1} and sent to a malaxer machine with a work capability of 400 kg h^{-1}, where it was malaxed for 20 minutes at 25°C under reduced ambient pressure (0.2 atm). The paste enters the vacuum malaxator through the bottom side and is malaxed by a vertical rotor fitted with blades. The malaxed paste was then centrifuged, without water addition, with an innovative two-phase centrifugation system with a work capability of 1000 kg h^{-1} followed by purification with cellulose filters in a filter press unit with a work capability of 600 kg h^{-1}, thus avoiding the use of vertical centrifuge. The extraction yield (Y) was the percentage ratio between the amount of oil obtained and that of olives milled. The oils obtained were bottled in 250 mL dark glass bottles and stored in the dark in a chamber at 20°C. Bottled samples were analysed within one week.

2.2 ECONOMIC AND ENVIRONMENTAL ANALYSIS

As a first step in the analysis, legal quality indices, chlorophylls, polyphenols, and tocopherols of oils obtained were detected and quantified by the widespread and consolidated experimental procedures of scientific literature [5, 13, 14, 15, 16, 17].

Successively, an environmental and economic analysis of the two olive oil extraction systems, i.e., INN and CONV mill plants, was carried out following LCA and LCC methodologies. In particular, LCA allows assessing the environmental burdens all along the life cycle of a product/process, from raw material extraction to production, use, and disposal, by identifying energy and materials usage, to suggest strategies for improvements of production processes. LCC method, through a punctual assessment of initial, operating and, end-of-life costs of the entire life cycle of a product/process, can be useful to identify more effective budget allocations, as well as better business performances.

According to the framework suggested by ISO 14040:2006 [18] and 14044:2006 [19], in this paper, LCA was performed considering the following methodological phases: Goal and Scope definition; Life Cycle Inventory; Life Cycle Impact Assessment (LCIA) and Interpretation. At the same time, LCC analysis, aimed to compute the real money flows (costs and revenues) of each unit process, was accomplished in line with the approaches of Ciroth et al. [20] and Moreau and Weidema [21].

Two mandatory elements in life cycle analyses are the so-called Functional Unit (FU), and the system boundary. The former is the measurement unit to which all

inputs and outputs data of production process are related; the latter defines the unit processes to be included in the production system under consideration. In this paper, for both LCA and LCC computation, one litre (1 L) of EVO oil was selected as FU and, a "gate to gate of olive oil mill plant" was chosen as system boundary, considering only the olive oil extraction and by excluding the olive production, the olive oil bottling and packaging, the distribution to the consumers, and the end-use.
All the unit processes linked to the olive oil extraction are illustrated In Figure 1.

variable and fixed costs. The firsts comprised the input costs for olive oil extraction (for example, electricity consumption by machinery), human labour cost and interests on advanced capital, while the seconds accounted for depreciation, insurance, and maintenance for machinery and land investments, land rent, interests on capital goods, taxes and administration overheads [24].
The total revenues were determined by multiplying the olive oil yield for its selling price, which was assumed equal to 5.40 € L^{-1} for both scenarios. A discount rate of 2% per year was assumed to discount

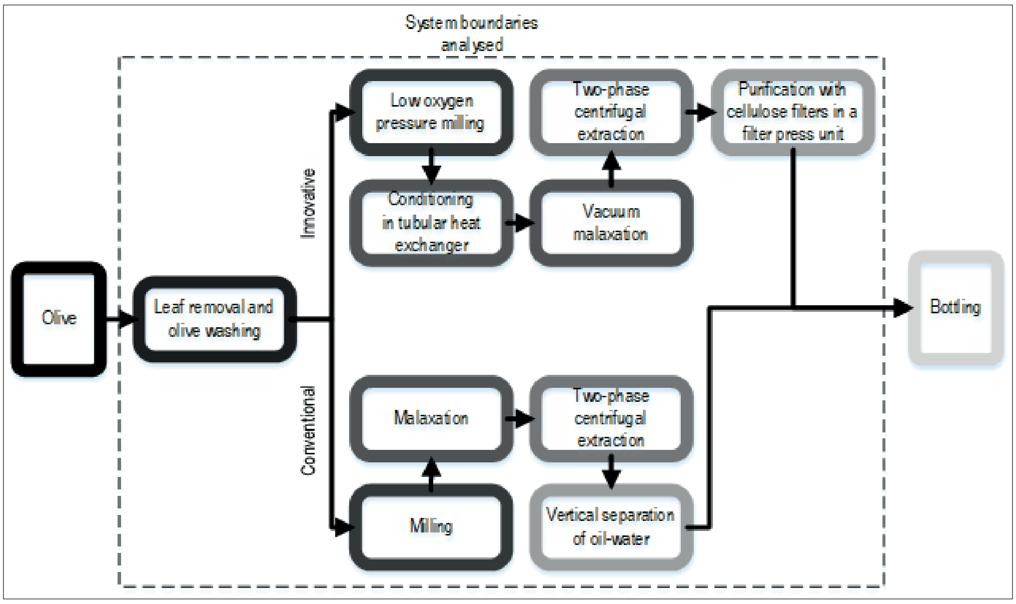


Figure 1 - System boundaries for the two EVO oil extraction technologies under study.

The inventory analysis was based on primary data collected from two mill plants located in Sardinia (i.e., electricity, water, electricity for heat consumption, olive oil yield and waste and co-product production) and from the secondary data acquired from Ecoinvent 3.4 and Agri-footprint 4.0 databases electricity and heat production, water source and waste treatment). Input and output were allocated considering the economic value of EVOO and co-products (pomace) [22]. Then the collected data were processed through Simapro 8.5 software by using the ILCD 2011 midpoint method. A sensitivity analysis was also accomplished varying oil yield to investigate the effects on eco-profile of the new mill plant.
From an economic point of view, the costs related to the extraction plant investment (start-up costs), operating costs of the extraction phase, and disposal costs (end of life costs) of the two scenarios were estimated, considering a useful life of 20 years. According to [23], all costs were estimated by multiplying the measured quantities of the collected inputs by its unit prices. Here, operating costs were split in

all costs and revenues, thus obtaining the cash flows for the overall life cycle. To explore the economic convenience to the realisation of the olive oil production investments under study, two specific indicators were evaluated, i.e., Discounted Annual Cost (DAC) and Net Present Value (NPV). The DAC indicator was calculated according to the method proposed by [25], which divide the total life cycle costs by the time horizon of 20 years. This indicator was used to estimate the monetary resource absorption per unit of time. The NPV calculation was made by summing the discounted future cash flows incurred during the whole life cycle [26].

3. RESULTS AND DISCUSSIONS

The results on Y and quality parameters linked to the two extraction technologies are depicted in Table I. When INN plant was used the higher quality of EVO oil obtained was reached, although the major extraction yield was obtained by CONV technology. The INN

Table I - Extraction yield and quality parameters of the extra-virgin olive oils analysed

Technology	Yield	Free acidity (% oleic acid)	Peroxide value (meq O^2 kg^{-1} oil)	Chlorophills (mg pheophytin a kg^{-1} oil)	Total polyphenols (mg gallic acid kg^{-1} oil)	Total tocopherols (mg α-tocopherol kg^{-1} oil)	Antioxidant activity (EC_{50} mg g^{-1})
Conventional	20.2a*	0.17a	12.2a	26.8b	412.9b	307.3b	39.19a
Innovative	17.3b	0.17a	6.9b	30.3a	487.3a	390.9a	30.23b

*Data followed by different letters for each column are significantly different by Tukey's Test at P≤0.01.

samples showed a meaningfully lower peroxide value than the CONV samples, due to the lower oxidative stress exerted by this technology, as well as a significantly increase of chlorophylls, total polyphenols, and tocopherols content. This latter result determined a significant improvement of the antioxidant activity of INN oils than CONV ones.

From an environmental point of view, a worsening trend for all the categories considered emerges, on average equal to 5% (Fig. 2). In particular for the innovative scenario the following impact values were recorded: 94.62 g of CO_2 eq; 7.13 μg of CFC-11 eq; 6.93E-09 of CTUh; 2.22E-09 of CTUh; 31.00 mg of PM2.5 eq; 215.00 mg of NMVOC eq; 4.52E-04 molc H+ eq; 7.39E-04 molc N eq; 17.00 mg of P eq; 89.00 mg of N eq; 0.20 CTUe; 94.88 g of C deficit; 0.450 L of water eq; 167.58 μg of Sb eq. These results are mainly caused by the reduction of extraction yield in the innovative plant. A sensitive analysis was performed by varying the yield for better or worse of 3% demonstrating that this is the factor that most influences the eco-profile of the oil. In fact, an increasing of 3 % of extraction yield would allow an improvement in impacts compared to conventional technology of about 10%.

Carrying out a contribution analysis it emerges that the main responsible parties of olive oil extraction impacts are milling and centrifugal extraction operation, due to the high energy demand (Fig. 3). The malaxing is the third impacting operation and play a relevant role in the innovative plant, due to the increase in energy demand caused by the pre-conditioning in the heat exchanger.

LCC results, in terms of FU, are presented in Table II. It is important to recognize that these results are directly related to the extraction yield, which was lesser in the INN plant than the CONV one. Therefore, this difference affected both the life cycle costs and profitability of the two scenarios. As can be seen, INN mill had the highest LCC with 11.17 € L^{-1} compared to the CONV one (9.77 € L^{-1}). The main cost hotspots were the start-up investment and the end of life costs. The former contributed on average 74% to the total LCC and the latter 15%. In the olive oil extraction phase, operating costs were estimated at 0.95 € L^{-1} which represents 10% of the total life cycle cost. This is on average 8% higher than the CONV scenario. The greatest contributors to the overall operating cost in both scenarios were the fixed costs, which accounts for 83% to the total. However, in the INN

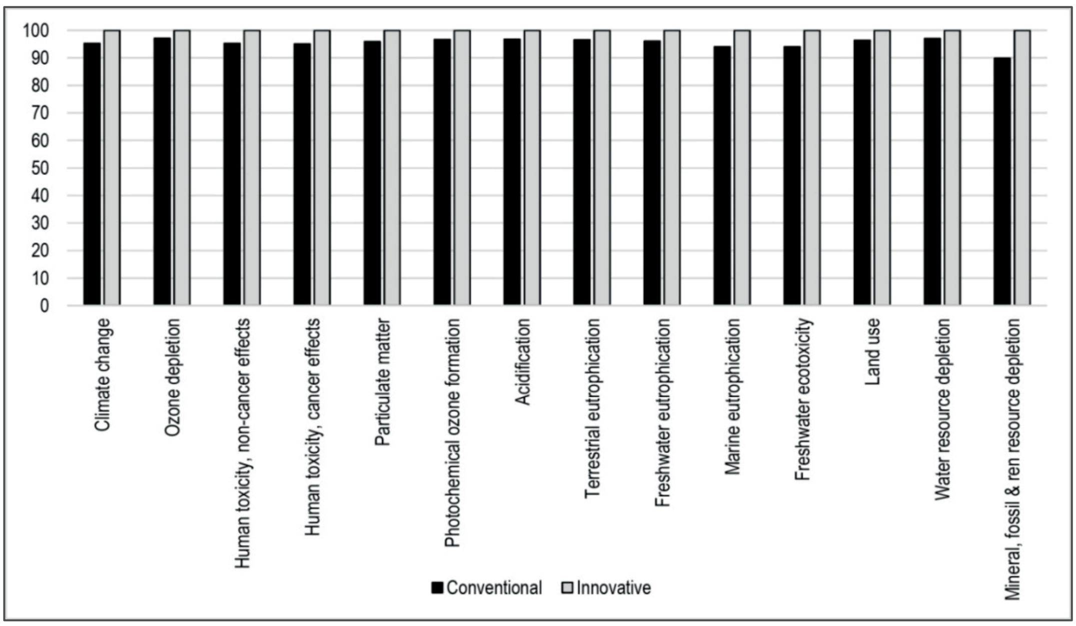
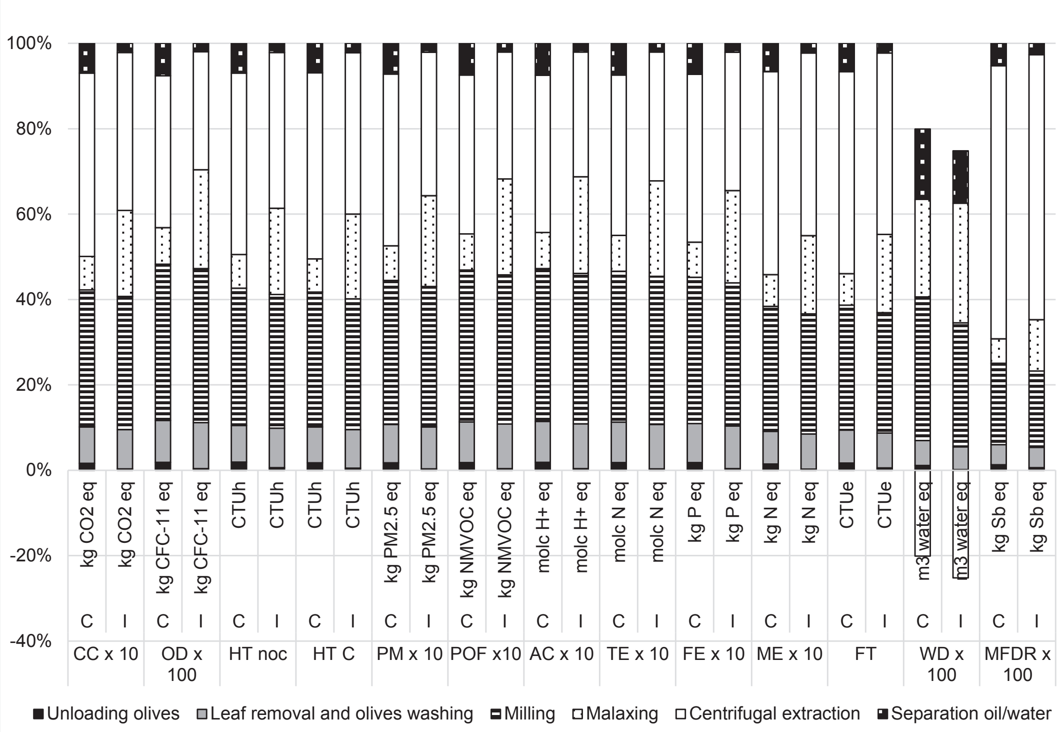


Figure 2 - Impact characterization results for 1 L of EVO oil from the two different technologies studied.



C *- Conventional;* ***I*** *- Innovative;*
CC *- Climate change;* ***OD*** *- Ozone depletion;* ***HT noc*** *- Human toxicity, non-cancer effects;* ***HT C*** *- Human toxicity, cancer effects;* ***PM*** *- Particulate matter;* ***POF*** *- Photochemical ozone formation;* ***AC*** *- Acidification;* ***TE*** *- Terrestrial eutrophication;* ***FE*** *- Freshwater eutrophication;* ***ME*** *- Marine eutrophication;* ***FT*** *- Freshwater ecotoxicity;* ***WD*** *- Water resource depletion;* ***MFDR*** *- Mineral, fossil & ren resource depletion.*

Figure 3 - Contribution analysis.

Table II - Life cycle costs of the conventional and innovative plants under study

Cost Item		**Conventional Technology**	**Innovative Technology**
		(€ L^{-1})	**(€ L^{-1})**
Start-up investment costs	Building component	2.24	2.56
	Plant component	4.98	5.76
Operating costs	Extraction Fixed Costs	0.88	0.95
	-Machinery and land investments ownership costs	*0.40*	*0.45*
	-Land rent	*0.28*	*0.28*
	-Interests on capital goods	*0.05*	*0.06*
	-Taxes	*0.02*	*0.02*
	-Administration overheads	*0.14*	*0.14*
	Extraction Variable Costs	0.18	0.19
	-Input costs for olive oil extraction	*0.065*	*0.068*
	-Human labour cost	*0.10*	*0.12*
	-Interests on advance capital	*0.006*	*0.007*
End of life costs	Plant Disposal	1.49	1.71
Total Life Cycle Cost (LCC)		9.77	11.17

plant these were 7.8% higher than the CONV one. This is mostly caused by the larger costs related to machinery and land investment (i.e. depreciation, insurance, and maintenance costs). Within the variable costs, the main contributor were the inputs employed in the extraction phase, mostly represented by the

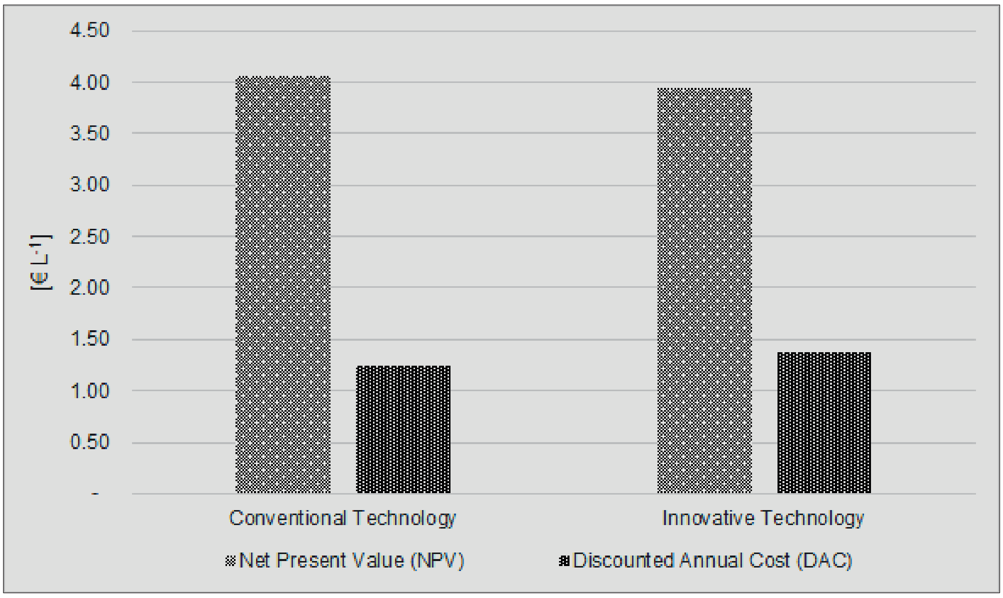


Figure 4 - Economic indicator results

electricity cost ranging from 38% for the INN plant to 37% for the CONV one.

The results of the investment analysis are reported in Figure 4. Due to the major costs and the smaller extraction yield obtained, a lower profitability was found for the INN plant than CONV one. In this regard, results showed a lower NPV value (3.94 € L^{-1} vs 4.06 € L^{-1}) and a larger DAC value (1.37 € L^{-1} vs 1.24 € L^{-1}), although these are slight differences.

Sensitivity analysis using various levels of EVO oil selling prices was carried out to identify changes in the economic performance of the innovative mill than conventional one. When the price was increased of 0.02 € L^{-1} a raising NPV by 0.50 p.p. was reached. The break-even price is attained at 5.50 € L^{-1}. These results demonstrate that a higher price certainly affect the feasibility of the innovative investment.

4. CONCLUSIONS

The economic and environmental performance of an innovative olive mill plant in South Italy were assessed by means of LCC and LCA methodologies and compared to a conventional system. The experimental trial results highlighted a meaningful improvement of EVOO quality when innovative mill was used, although the lowest oil yield was reached. Therefore, in terms of 1 L of EVO oil, larger costs and environmental loads were reached with the new extraction system. The most impacting cost items were fixed costs linked to ownership machinery and land investments and electricity cost, which entailed the highest LCC and the lowest profitability compared to conventional scenario. Due to the higher energy consumption, the malaxing process was the main responsible of the increasing environmental loads. However, the economic and environmental profile of the innovative mill could be improved if an increase in the olive oil selling price and oil yields is reached respectively, as demonstrated by the sensitivity analysis. The achieved results should lead to significant technological advances in EVOO production. However, further research must be conducted to explore new alternative extraction technologies capable to reduce total costs and environmental impacts along their overall life cycle.

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