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Research article

Olive growing in the Sorrento Peninsula: Operative, economic, and environmental evaluation trough LCA of mechanical harvesting

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ABSTRACT

Optimizing high-productivity farming techniques trough mechanization and lower workforce input in terraced olive groves is helpful to preserve local olive oil production, reducing costs and preserving ecosystem functionality. However, efficient work organisation should be provided. Moreover, mechanization can affect environmental sustainability. In this paper operative, economic and environmental performances of four olive harvesting techniques are reported; experimentations were performed in an olive grove in the Sorrento Peninsula (NA) during 2022–2023 productive seasons. Mechanized techniques (Harvesting technique 1 and Harvesting technique 4) performed highest working capacities (159.01 kg h^{-1} and 200.51 kg h^{-1}) and the lowest unitary costs (630.00 € ha^{-1} for Harvesting technique 2 and 840.00 € ha^{-1} for harvesting technique 4), whereas environmental performances were the worst (266.30 kg CO_2 eq and 252.59 kg CO_2 eq) due to diesel intakes. Thus, their applications are helpful, but morphological or agronomic boundaries may affect their effectiveness in other areas. Among aided methods, Harvesting technique 1 overcame Harvesting technique 3 in any aspect (91.01 kg h^{-1} vs 76.13 kg h^{-1}: 1822.09 € ha^{-1} vs 2793.80 € ha^{-1}; 33.01 kg CO_2 eq vs 127.21 kg CO_2 eq); the absence of diesel inputs in harvesting technique 1 and its superior work capacity explain the environmental impact differences. Thus, the former may be adopted in farms where slope and irregular shape hinder mechanized harvest. Life Cycle Assessment dataset may be helpful to perform similar analysis in other Italian olive oil supply chains.

1. Introduction

Olive (*olea europaea*) is the most widespread crop in the Mediterranean countries (Algeria, France, Greece, Italy, Morocco, Portugal, Spain, Tunisia, Turkey) [1,2]. In 2022 global olive cultivated area was 1.09 Mha, 9.8 % in Italy, while Italian olive oil production accounted for 338,631 t in 2021, 14.2 % of the total of European Union (EU) [3]. Olive oil is one of the pillars in the Mediterranean diet [4], and the increasing consciousness regarding its documented benefits to human health [5–7] will probably lead to a rise of world consumption in the next years [8]. Southern-Italy regions accounted for most of the Italian olive oil production, and, among them, Campania Region provided for 11519 t in 2022, 4.8 % of national production [9].

Italian olive oil quality is certified trough 42 Protected Designation of Origin (PDOs), [10]. These labels are widely adopted in Mediterranean olive oil supply chains due to positive effect in promoting the product in the markets [11]. In Campania Region one of the certifications refers to the oil produced in the Sorrento Peninsula, and the PDO was formalized in 1997 [12]. Likewise other agricultural contexts [13], olive growing in this area is split between hobbyist farmers oriented to traditional practices such pruning

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based on long cutting turns or manual harvesting, and innovation-oriented farms [14] who adopted organic management, training systems with yearly pruning turn and mechanized or semi-mechanized harvesting techniques.

According to local cartography provided by Ref. [15], olive groves occupy a wide portion of the Sorrento Peninsula territory. They shape the landscape with traditional terraces usually held by limestone dry walls, placed on hilly slopes, and the variety Olea europaea L. cv. *Minucciola* is the most widespread in the area. Despite the absence of genetic characterization, it has been recognized as a local ecotype of the variety Olea europaea L. cv. '*Ogliarola*', largely spread in Southern Italy [12]. Terraced olive groves, when regularly cultivated, are essential to maintain fundamental ecosystem functionality and to safeguard soil from erosion [16]. This aspect is crucial because the municipalities of Sorrento Peninsula belong to the highest tier regarding landslides risk according to the reports provided by the Italian Institute for Environmental.

Protection and Research [17]. Therefore, it is essential to introduce techniques aimed at improving farm productivity and contracting production costs to preserve local olive production. Such improvements are limited by harvest and pruning operations [18], mainly because of their high labour input. Mechanization is one of the feasible solutions in contexts where morphology allows it, but its adoption must rely on efficient work organisation [19]. However, Italian olive farms average size, equal of 1.6 ha [20] limits the adoption of machinery-based techniques in combination with farmers reluctance to new investments.

Mechanization of crop operations is a useful strategy to improve labour productivity and reduce costs. While the adoption of handheld tools reduces costs by 45 % compared to manual harvest, trunk shaker with ground nets allows for higher reductions (−70 %) and trunk shakers equipped with collecting umbrellas shows even lower costs (80 %) [21]. At the same time, mechanized harvest can also counter-effect the environmental sustainability [22]. In the olive oil supply chain, the most impactful stage is the agricultural phase [23]. Under this perspective, the most relevant operations are fertilization, pest-management and irrigation [24]. Despite this, the contribution of harvesting operation may be sensitive, especially due to water consumption and greenhouse gas emissions [25], and it can be amplified in case of the wrong management if the field operations. Under this perspective "Life Cycle Assessment", or LCA [26,27], has been applied with increasing frequency in research. LCA determines the amounts of inputs such as energy or water needed for a process and also evaluates any environmental impact emitted by outputs [28]. Its importance has been growing so far to become a fundamental tool to support sustainability policies in the European Union and beyond [29].

The aim of this studio has been to evaluate the economic and environmental performance of four olive harvesting technique, characterized by different mechanization levels and labour use input. They were tested in an olive grove in the Sorrento Peninsula during 2022 and 2023 productive season. Due to the very particular orography of the area and the consequent difficulties in carrying out agronomic management, this research fills a significant knowledge gap by examining an extreme. This case study represents a novelty in the sector, and the results offer valuable insights. The evaluation was performed considering three different aspects: i) work capacity; ii) economic convenience based on unitary harvesting costs comparison; iii) an environmental impact assessment by the LCA. The paper is organized as follows. The second paragraph is devoted to materials and methods while in the third one we present the results and discuss their implications with the help of a comparison with the available literature. At the end of the same an overall assessment including all analytical aspects of the study is provided.

2. Materials and methods

2.1. Grove and harvesting techniques description

Field trials were performed in an olive grove in Massa Lubrense Municipality, NA (40°37′04.4″N 14°20′38.6″E). It belongs to a farm managed under the limited liability company system (Società a Responsabilità limitata – SRL). Olive is the main crop cultivated, followed by vineyard, apple trees and seasonal vegetables. All crops are managed under Certified Organic regime. Total Agricultural Surface (SAT) owned by the farm is 7.74 ha, while Utilized Agricultural Surface (SAU) is 6.68 ha, whose 4.21 ha occupied by olive groves. Moreover, agrituristic business is performed in the farm, allowing to sell its own olive oil to the guests. Regarding the experimental olive grove, it extends on 1.68 ha inside a wider rented estate 7 km far from the farm centre. It is North-West-oriented and is placed on a cliff at 45 m a.m.s.l. next to the coast. The soil is loose (62 % sand, 17 % silt, 21 % clay), and its management is based on regular organic fertilizations with cattle manure and olive pruning biomass incorporation. Because of the slopes, terraces and embankments were set in previous years to facilitate the cultivation of the aforementioned territory. Plants belong to variety Olea europaea L. cv. *Minucciola* and tree density is 281 trees ha^{-1}.

The training system for the trees is the polyconic vase, adopted in 2020 trough annual reform prunings with manual equipment such telescopic saws. In polyconic vase system canopy consists of 3–5 primary branches ending with a medium-vigorous shoot on the apex, while the lower section contains secondary branches where most of the yield is concentrated [30]. This solution aims at reducing the intensity of alternate bearing [31] thanks to optimization of light interception and in respect of main physiological mechanisms of

Table 1
Equipment, level of mechanization and number of workers employed in the different harvesting techniques.

Harvesting technique	Equipment	Mechanization level	Year	Permanent workers (n)	Seasonal workers (n)
HT_1	Electric combs + nets	Aided	2022	2	2
HT_2	Trunk shaker + nets	Mechanized	2022	0	5
HT_3	Pneumatic combs + nets	Aided	2023	1	4
HT_4	Trunk shaker + umbrella	Mechanized	2023	0	3

plants (nutrient transport, bud differentiation, etc.). Plant height was measuerd on a cluster of 30 plants in 2023, resulting in an average value of 5.30 ± 0.20 m. Harvesting period occurred in the first decade of October in 2022 and in the last decade of September in 2023, when experiment trials were performed. Average olive production recorded in the period 2020–2023 was 2556 ± 1531 kg ha^{-1}, with an average oil yield of 611 ± 273 L ha^{-1} (average olive/oil is yield = 16 %). Harvesting techniques are described in Table 1. Harvesting technique 1 (HT_1_Fig. 1a), performed in 2022, involved the use of electric combs (Pellenc Olivion models 'P230' and 'T220', Siena, Italy) and nets layered on the ground surface for olive interception. Regarding the use of labour, two fixed and two seasonal workers are employed. With the latter expression we refer to a worker employed within the farm with a contract with a working period between 100 and 180 working days, according to local labour agreement [32]. Further details are provided in chapter 2.3. Before the harvest, two workers spread the nets and sewed them with manual tools. Still performed in 2022, Harvesting technique 2 (HT_2, Fig. 1b) is based on a trunk shaker, model 'Mistral D16 Impact' - D'Amico Officine, Puglia, Italy -, powered by 2WD tractor (model 'Goldoni Star 90', Modena, Italy) with an engine of 60 kW and nets for olive interception. 5 seasonal workers were employed in this case. In 2023, trials were conducted using Harvesting technique 3 (HT_3, Fig. 1c), which consisted of pneumatic combs engineered with a gasoline-propelled air compressor and nets for olive interception. The equipment was constructed by 'Campagnola' company (Bologna, Italy). In this case, 1 permanent worker and 4 seasonal workers were needed for the execution of field operations. Harvesting technique 4 (HT_4, Fig. 1d) was also performed in 2023. The same trunk shaker utilized in HT_2 was employed in conjunction with an independent self-propelled umbrella for olive interception (model 'Olivspeed 4x4 J' – Bosco Costruzione Macchine Agricole, Pavia, Italy). HT_4 needed 3 seasonal workers to machine movement. Before tree shaking, the reversed umbrella was placed under the canopy to intercept olives. Subsequently, when the reservoir was filled, the umbrella was moved next to a truck to unload olives in a greater reservoir at the board of the field. In order to work without pauses, 2 reversed umbrellas were used in sequence.

2.2. Harvesting performance

Work capacity was detected by adopting the guidelines of the *Commission Internationale de l'Organisation Scientifique du Travail en Agriculture* (CIOSTA), widely applied in other studies regarding agriculture operations [33–36]. Thus, on-field measures regarded time for olive detachment with combs as well as movement of the workers from one plant to another in aided harvesting techniques (HT_1 and HT_3). At the same time, in HT_2, the time for shaking the trees, the ripening of the olives from the nets to the bins and the subsequent opening of the nets under the canopies were recorded; similarly, in HT_4, the time required for tree shaking, movement of the umbrella and the trunk shaker, and unloading of olives from the umbrella reservoir to the truck was recorded. These measures were executed with a professional chronometer ('RSpro', RS Italia, Italy). All measures were performed on a cluster of 30 plants. Then,

Fig. 1. a) HT_1 (2022), based on electric combs; b) HT_2 HT_2 (2022) based on trunk shaker + nets; c) HT_3 HT_3 (2023) based on pneumatic combs + nets; d) HT_4 (2023), based on truck shaker + umbrella.

recorded times were summed to identify work capacity, in terms of olive mass harvested in 1 h (CA1, Kg h^{-1}); number of plants harvested in 1 h (CA2, plants h^{-1}); productivity of labour unit (CA3, Kg h^{-1} $worker^{-1}$); total surface in the unit of time (CA4, ha h^{-1}). Such parameters, whose acronyms were attributed according to American Society of Agricultural Standards (ASAE) EP496.2 standards [37], are frequently utilized in diverse studies pertaining to analogous research fields [19,38,39].

Further determination was made regarding the mass of leaves falling from the canopy during the operations and collected with the olives. For each plant leaves were separated by drupes and then weighted on a digital scale with a precision of 0.001g ('ALC-107 T535 PK130R', Winchester, VA, USA) to determine the mass percentage of leaves over the olive + leaves gross weight. This measure is useful to detect the most harmful technique, capable of reducing photosynthetic processes during the following productive season due to defoliation [30]. It also allows to determine which technique resulted in greatest rise of transportation costs to the oil mill, since such costs were calculated based on the gross weight. However, no measurements for harvesting efficiency could be provided.

2.3. *Economic cost analysis*

In adopting new agricultural technologies, one of the most important aspects to consider is the economic profitability. Once the technical feasibility of a change in a production process is established, a cost benefits analysis becomes essential in its effective adoption. In this research a method consolidated in the literature and reported by many several textbooks was adopted [40–42]. According to this approach, before the economic analysis, it is necessary to collect data about structural and entrepreneurial characteristics of the farm for which we are assuming to make changes in production technologies. Such issues are mentioned in literature as strategies for business planning and, depending on whether they involve changes in the total organization of the farm or only in some sectors, they can be addressed with the so-called total or partial budget analysis. While total or complete farm budgets are more concerned with the profitability of the total farm, partial budgets are used to adjust production methods, test new techniques or change input levels that do not appreciably affect other parts of the total farm plan. In either case, unit budgets are a useful tool to use. The unit budget specifies the quantity and price amounts in relationship to 1 ha of crop or one head of livestock, or another meaningful unit. The steps of drawing up a balance sheet are as follows:

1. definition of the change to be analysed.
2. assessment of the likely consequences of the change on the use of resources (level of use of farm and external factors and quantity of products that are produced).
3. verification of technical compatibility of the change with the quantity and quality of available resources.
4. estimates of the cost of materials to be bought and products to be sold.
5. assessment of the economic consequences, based on the information gathered in the previous steps.

The final stage is attained by distinguishing between changes in costs and revenues that increase income and those that decrease it. If we indicate the first with Increasing Variations (V_I) and the second with Diminutive Variations (V_D), the profitability judgment consists in comparing them, that is (1):

$$V_{I} \gtrless V_{D} \tag{1}$$

If V_I is higher than V_D, the new method should be adopted. Conversely, if V_I is lower than V_D, it is convenient to keep the previous situation. If V_I is equal to V_D, the alternatives are indifferent to each other. In our case, since the changes in harvesting techniques do not affect other sectors of the farm, partial budget analysis were used and calculated unit costs that is costs per hectare (AC). Firstly, we

Table 2
Economic costs determination and calculation criteria.

Cost voice	Unit	Symbol	Source
Purchase value	€	V_i	Purchase price, farm accountancy
Salvage value	€	V_f	$V_f = V_i$ x 0.1 (as mentioned in Ref. [39])
Useful Life	Years	N	[38]
Depreciation	€	Qd	$(V_i - V_f)/N$
Maintenance	€	Qm	V_i x 0.02
Interest	€	I	$(V_i + V_f)/2$ x i
Daily work wage	€ day^{-1}	A	CCNL
Total work days	Days	B	Farm accountancy
Number of employers	Units	C	Farm accountancy
Salaries	€	Sa	Sa = a x b x c
Total fixed costs	€ ha^{-1}	AFC	Sa + (Qd + I + Qm)/2.4
Other Costs	€ ha^{-1}	SV	Farm accountancy
Hirted workers wage	€ ha^{-1}	SAA	Farm accountancy
Total variable costs	€ ha^{-1}	AVC	AVC = SV + SAA
Total costs	€ ha^{-1}	AC	AFC + AVC
Olive Yield	kg ha^{-1}	Q	Average yield 2022–2023
Cost per mass unit of olives	€ kg^{-1}	ACQ_1	AC/Q
Oil yields	L ha^{-1}	O	Average yield 2022–2023
Cost per litre of olive oil	€ L^{-1}	ACQ_2	AC/O

divided costs in two categories: fixed costs (depreciation, maintenance, insurance, salaries for permanent workers, taxes) and variable costs (machinery rental fees and wages for seasonal workers). Obviously, cost framework varies depending on the harvesting technique considered. With HT_1, workers were regularly employed on the farm, with wages determined in accordance with the National Collective Labour Agreement [32]. Hourly wage is €12.90, resulting in a daily gross salary of € 103.20 for an 8-h workday. As the farm entrepreneur bought electric combs, batteries and other equipment, the depreciation quote for electric combs has been calculated trough an 8-year lifespan and a 5 % interest rate, according to overall inflation trends in 2022–2023.

For HT_2 and HT_4, the entrepreneurs used outsourced machinery services, thus such costs are based on rental fees. In HT_3, workers were both farm employees and rented ones, while pneumatic combs and air compressor were only rented. The cost analysis was determined through the application of the criteria outlined in Table 2.

These costs are expressed in terms of unit of harvested area (AC), unit of harvested olives (ACQ_1) and for 1 L of olive oil (ACQ_2). To account for the discrepancies in yield between the productive seasons, it is necessary to remove the associated uncertainties. Therefore, the average yield of harvested olives (Q, equal to 1505.0 kg ha^{-1}) and olive oil produced (242.5 L ha^{-1}) In 2022–2023 were selected as the parameters to be used. Such an operation is justified by the low differences between the production values observed in the two seasons (1392.0 kg ha^{-1} in 2022 and 1617.0 kg ha^{-1} in 2023). The cost per kg of olives ($ACQ_{1)}$ was calculated by dividing the cost per unit of harvested area (AC) by the yield of the grove unit of area (Q). Finally, the cost per hectare (ACQ_2) is calculated by dividing the cost per unit of harvested area with the oil production of 1 ha of harvested olives (O), assuming an average oil yield of 16 %.

2.4. Life Cycle Assessment analysis

LCA methodology was performed in accordance with the ISO 14040 and ISO 14044 guidelines [26,27]. Therefore, methodology is divided into four distinct phases. In the initial step, the scope of the study is defined. The objective is to quantify the pollutant emissions of different harvesting techniques applied in a specific productive context and to highlight the differences between them. Such differences are expected to be relevant due to variations in machineries and fuel inputs between the harvesting techniques. As stated by

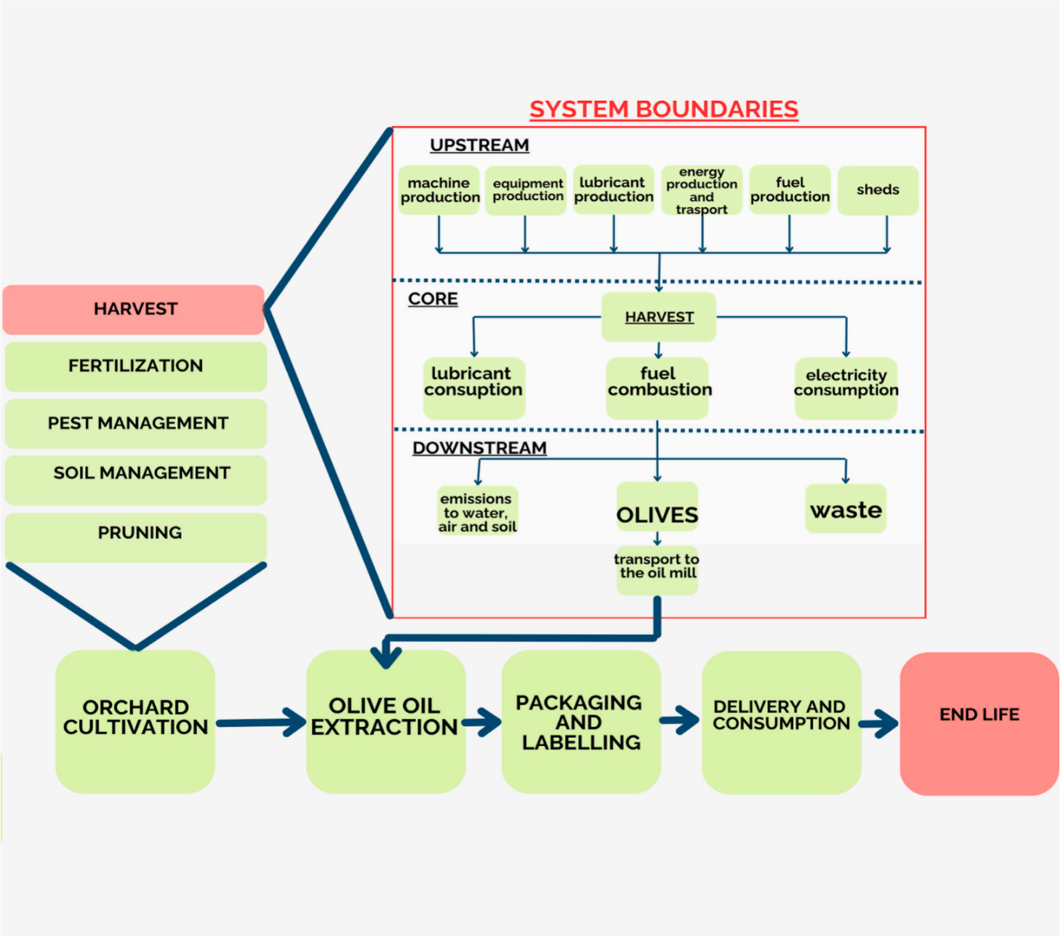

Fig. 2. System Boundaries framework of the LCA analysis. The red box delineates the upstream section, which encompasses the inputs, the core section, which pertains to the emission processes, and the downstream section, which represents the emissions and wastes produced.

Ref. [19], performing an LCA analysis on such a specific aspect of the cultivation phase is useful for building regionalized datasets to address data scarcity and highlight the influence of site-specific elements on environmental impacts. The system boundaries include the sequence of field harvesting operations and subsequent transport of olives from the grove to the oil mill, as described in Fig. 2. Therefore, a “gate to gate” approach has been adopted. It is possible to isolate the harvesting operation from other agricultural practices because this phase does not affect the execution of other field operations. The only significant difference lies in the variations of the amount of labour required for the pruning phase to adjust the architecture of the trees. However, in the LCA analysis, emissions directly resulting from human respiration are neglected and not considered in this study. Transport has also been included in the system boundaries, and the distance between the oil mill and the grove is 5 km.

The primary functional unit (FU) to express the results is "1 ha of harvested area." This allows for the clear association of environmental impacts of harvesting techniques with variations in work capacity, with the latter being considered within the context of overall economic results. The "1 kg of harvested olives" FU is also selected, and results are obtained by dividing the emission results expressed with the FU “1 ha harvested area” with the yield of the harvesting site. The second step is the construction of the life cycle inventory (LCI), as reported in Table 3 processing and analysis of the LCI data was executed with the software Open LCA version 2.0.2 (Greendelta, Germany) [43]. This software was chosen because it is an open access and provided with all essential features to perform the analysis. The LCI was constructed using the Agrybalise database, version 3.1 [44,45] which provides detailed and up-to-date inventory data.

For each harvesting scenario, LCI included agricultural machine and equipment manufacturing and use, shed building, fuel and lubricant production and consumption and electricity consumption. One potential source of uncertainty in this process is the allocation of inputs [46]. For agricultural machinery and equipment, their productivity is allocated over different years. A proper approach for allocation is to divide the mass of any input by the number of years it will be used in the specific operation. Consequently, direct primary data on the mass of the machine (or equipment) in question was collected and subsequently processed using the method (2) reported by Ref. [47]:

$$\text{Mw} = [\text{Weight (kg)} * \text{operation time (h)} / \text{lifetime (h)}] \tag{2}$$

Where MW represents the mass allocated for any machine or equipment considered. The raw data regarding the mass has been collected from the technical handbooks of the machines, while the total lifetime considered is 10,000 h for the machines and 2000 h for the combs and the air compressor. Agribalyse does not provide specific values for aided tools, therefore we have chosen to separate them from their raw materials. Additional references were collected from manufacturing companies, as suggested by Fernández-Lobato et al. (2022). In particular:

- electric combs mass is made of 90 % steel/10 % carbon fibre (not available in the Agribalyse database, thus was neglicted);
- for batteries, the proportion is 80 %/20 % polyvinyl chloride (PVC);
- for pneumatic combs, 90 % of the mass consists of aluminium (industrial extrusion process);
- bins have been replaced 100 % with PVC produced through injection moulding using PVC granules.;
- nets are completely made of high-density polyethylene (HDPE) produced with extrusion process.

The fuel and lubricant consumption per harvested area per single harvesting technique were determined according to formulas (2) and (3), using the information reported in the technical handbooks of the equipment.

$$L_x = \text{Hcl} * \text{Lo}_x * \rho \text{l} \tag{3}$$

Where:
Lx = lubricant consumption for the xth harvesting technique (kg ha^{-1}).
Hcl = lubricant hourly consumption (L h^{-1}).

Table 3
Life Cycle Inventory (LCI) of the harvesting techniques.

Input	Unit	HT_1	HT_2	HT_3	HT_4
Trunk Shaker	kg ha^{-1}	0.00	1.40	0.00	1.29
Umbrella	kg ha^{-1}	0.00	0.00	0.00	0.20
Electric combs (steel)	kg ha^{-1}	0.04	0.00	0.00	0.00
Electric combs (pvc)	kg ha^{-1}	0.01	0.00	0.00	0.00
Electric combs (lithium battery)	kg ha^{-1}	0.02	0.00	0.00	0.00
Pneumatic combs (alluminium)	kg ha^{-1}	0.00	0.00	0.06	0.00
Nets (HDPE)	kg ha^{-1}	1.10	0.63	1.53	0.00
Air compressor	kg ha^{-1}	0.00	0.00	0.81	0.00
Electricity	kWh ha^{-1}	1.20	0.00	0.00	0.00
Polyurethane tubes	kg ha^{-1}	0.00	0.00	0.17	0.00
Diesel	kg ha^{-1}	0.00	58.99	26.55	61.11
Lubricants	kg ha^{-1}	0.00	0.39	0.19	0.44
Bins	kg ha^{-1}	0.38	0.22	0.53	0.00
Sheds	m^2 ha^{-1}	0.02	0.01	0.03	0.01

Lo_x = working capacity of the xth harvesting technique ($h\ ha^{-1}$).
ρl = lubricant density ($kg\ L^{-1}$).

$$C_x = \mathrm{Hcf}^{*}\mathrm{Lo}_x{}^{*}\rho c \tag{4}$$

Where:
Cx = fuel consumption for the xth harvesting technique ($kg\ ha^{-1}$).
Hcf = fuel hourly consumption ($L\ h^{-1}$).
Lo_x = working capacity of the xth harvesting technique ($h\ ha^{-1}$).
ρc = fuel density ($kg\ L^{-1}$).

The third phase of the process is the Life Cycle Impact Assessment (LCIA), which was conducted using the ReCiPe 2016 method (H), implemented at midpoint and endpoint level. This method allows for the evaluation of environmental impacts associated with various inventory flows through intermediate impact categories. We considered 17 out of 18 impact categories available: agricultural land occupation, global warming potential, fossil depletion, freshwater ecotoxicity, freshwater eutrophication, human toxicity, ionizing radiation, marine ecotoxicity, marine eutrophication, metal depletion, natural land transformation, ozone depletion, particulate matter formation, photochemical oxidant formation, terrestrial acidification, terrestrial ecotoxicity, urban land occupation and water depletion. Marine eutrophication was not included in the results as the impact observed for all the harvesting systems was negligible, effectively registering as zero. The endpoint results were utilized to obtain the single score parameter, and this was utilized to build the final assessment of the study. To the same scope the CA1 results and the unitary costs of 1 h of harvesting operation were considered to evaluate the three harvesting methods within an overall framework.

3. Results and discussions

3.1. Olive harvesting techniques performance

Results of the work capacity obtained after processing the work time measurements are reported in Table 4. Both aided harvesting techniques (HT_1 and HT_3) obtained lower working capacities than the mechanized methods based on the trunk shaker (HT_2 and HT_4). In 2022, HT_2 registered a rise of the number of olives harvested in the unit of time compared to HT_1 (CA1, 159.1 kg h^{-1} vs 91.0 kg h^{-1}, +75 %); the same trend is confirmed comparing the labour productivity (CA3, 31.8 kg h^{-1} $worker^{-1}$ vs 22.8 kg h^{-1} $worker^{-1}$, +39 %). Tests performed during the following season show similar results: HT_4 registered higher working capacity than HT_3in terms of productivity per unit of time (200.5 kg h^{-1} vs 76.1 kg h^{-1} + 263 %) and of labour productivity (66.8 kg h^{-1} worker $^{-1}$ vs 15.2 kg h^{-1} $worker^{-1}$, +438 %).

Higher results of HT_4 compared to HT_2 is be justified considering the ease of handling given by the umbrella and the additional advantage represented by the lower number of workers employed for the harvesting operations. It is important to note that similar yields between 2022 and 2023 allow to ignore the influence of such factor over the results. However, higher yields would alter the scenario increasing the difference between aided methods and mechanized systems.

Additional evidence emerge after the confrontation with work capacities results available in similar research, summarized in Table 5 with further information (varieties, planting density etc.).

In the case of aided methods [38] reports higher values for CA1 and CA3, respectively 140.0 kg h^{-1} (+35 %) and 35.0 kg h^{-1} (+35 %), with similar planting densities. According to the same author, mechanized techniques registered higher reductions. In fact, reported work capacities are higher than both HT_2 (+64 % for CA1, +64 % for CA3) and HT_4 (+55 % for CA1, +71 % for CA3). However, such differences are associated to higher yields, but other influencing factors such as different harvesting site organisation and different number of employed workers should be considered. Regular grove morphologies and high yield would also explain major work capacities reported in other publications (e.g. 2516.0 kg h^{-1} and 1175.0 kg h^{-1} reported by Refs. [19,39] for a working scenario similar to HT_2); despite the absence of high slopes, machines movement was affected by irregular distances between trees and the absence of sufficient space at the edges of the field. Additional disadvantages consist in the higher detachment forces required for small olives [30] such as the ones obtained by *Minucciola* variety (<1.5 g $fruit^{-1}$) and the precocious maturation recorded in 2022 and 2023 due to high temperatures in summer [52].

Another aspect regards canopy defoliation. HT_2 showed the higher ratio between the gross weight of the harvested mass and the leaves weight (16 %), followed by HT_3 (13 %), HT_4 (12 %) and technique I (8 %) [30]. reports values of 5 % for aided methods. Finally, it must be noted that during 2022 harvest, plants trunks were damaged by the claw of the shaker, causing the breaking of the cortex.

Table 4
Yield, number of workers, work capacities.

Harvesting Technique	Yield (kg ha^{-1})	Workers	CA1 (kg h^{-1})	CA2 (plants h^{-1})	CA3 (kg h^{-1} $worker^{-1}$)	CA4 (ha h^{-1})
HT_1	1392	4	91.01	8.94	22.75	0.07
HT_2	1392	5	159.13	10.91	31.83	0.11
HT_3	1617	5	76.13	7.50	15.23	0.05
HT_4	1617	3	200.51	15.00	66.84	0.12

Table 5

Work capacity per unit of time (CA1) results available in similar publications.

Authors	Varieties	Planting density (trees ha-1)	CA1 (kg h^{-1})				CA3 (kg h^{-1} worker^{-1})			
			I (aided)	II (mechanized)	III (aided)	IV (mechanized)	I (aided)	II (mechanized)	III (aided)	IV (mechanized)
[38]	–	277	140	450	140	460	35	90	35	230
[39]	*Carolea*	417	–	2516	–	–	–	503	–	–
[19]	*Grossa Cerase; Ottobratica*	204; 417[a]	–	1175	83	–	–	232	27	–
[48]	*Frantoio*	333	–	–	462	–	–	92	–	–
[49]	*Cellina di Nardò; Ogliarola Salentina*	44	–	–	–	–	–	104; 85[a]	–	–
[50]	*Frantoio; Leccino*	–	–	–	–	–	40	80	65	–
[51]	*Frantoio; Leccino*	–	–	–	–	–	–	100	–	266[a]

[a] Two different oilve groves; ** different results for reported varieties.

3.2. Economic analysis results

Results of the economic analysis of the olive harvesting systems are showed in Table 6. Thus, both mechanized systems scored lower unitary costs than aided techniques. Considering the composition of the total costs (Fig. 3), the most important items in HT_3 are the rent fees for the harvesting tools and the cost for hired labour (76 % of the unitary costs).

Otherwise, In HT_1 68 % of the unitary cost is represented by wages for fixed workers and 13 % by depreciation, maintenance, and insurance. It's worth highlighting that these results differ from those obtained by other authors [38]. reports lower AC by 8 % compared to HT_1 (1669.00 € ha^{-1} vs. 1822.00 € ha^{-1}), almost by 95 % in the case of HT_3 (1669.00.

€ ha^{-1} vs. 3248.0 € ha^{-1}), by 11 % in the HT_4 (749.00 € ha^{-1} vs. 840.00 € ha^{-1}), and finally a rise of 54 % (971.00 € ha^{-1} vs 630.00 € ha^{-1}) is recorded. These comparisons are related to similar scenarios both in terms of work volume and work organization [19]. found that HT_3 registered higher AC (2793.80 € ha^{-1} vs 2134.00 € ha^{-1}, +24 %) under comparable work capacities (76.10 kg h^{-1} vs 83.20 kg h^{-1}), whereas HT_2 exhibited lower costs compared to 1 out of 4 similar scenarios (630.00 € ha^{-1} vs 803.00 € ha^{-1}, - 32 %) and higher for the latter 3 (whose unitary costs are, respectively, 289.0, 277.0 and 209.0 € ha^{-1}.

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Both the mechanized techniques (HT_2 and HT_4) were performed using the services provided by companies who subscribe contract works, then the full cost is represented by their fees and there are not specific costs for workers and machines. As shown above, it is undoubtably that production costs were affected by the low work capacity found in HT_3, as shown previously. Moreover, both HT_1 and HT_3 cases demonstrate that the fixed voice costs were increased in direct proportion to the length of operations. This was due to the inclusion of the working days for the grass mowing, the disposal of nets (before the harvest) and their rearrangement (after the harvest) in the balance sheet. However, given that low trees productivity reduced the farm income, the differences in economic performances can be accurately interpreted considering the productive yields. In fact, the low productivity of the trees reduced the farm income. As shown in Fig. 4, this evidence emerges from a comparison with the results obtained by Ref. [38]. Compared to results of the present studio, the author report that the harvesting cost per litre of olive oil are 68 % lower in the case of HT_1, as well as 46 % lower for HT_2, 79 % lower for HT_3, and finally 71 % lower for HT_4.

Under these conditions, the harvesting techniques would have performed different cost changes: HT_1 would have recorded a rise from 1822.0 € ha^{-1} to 3338.2 € ha^{-1}, HT_2 a from 630.0 € ha^{-1} to 2520.0 € ha^{-1}, HT_3 from 2793.8 € ha^{-1} to 6973.5 € ha^{-1}) and, finally, HT_4 from 840.0 € ha^{-1} to 2520.0 € ha^{-1}. Similarly, costs per litre of oil for would change significantly: in HT_1 there would be a decrease of 38 % (from 4.5 € L^{-1} to 7.5 € L^{-1}), whereas for HT_2 a rise of 34 % (from 2.6 € L^{-1} to 3.5 € L^{-1}); HT_3, even keeping the highest value among the tested techniques, would have experienced a reduction of 16 % (from 9.7 € L^{-1} to 11.5 € L^{-1}). In the end, in the case of HT_4, there would have been an increase of 1 % (from 3.46 € L^{-1} to 3.50 € L^{-1}). These results suggest that HT_1 would achieve a work capacity capable of significantly reducing unit costs as yield increased. HT_3 and HT_4 would have recorded minimal contractions; however, for the latter, the impact of low work productivity is evident, making this scenario unsustainable even with an ordinary olive grove yield. For HT_2, the unitary cost per 1L of olive oil would have been slightly higher compared to the findings provided by Ref. [38] recording the minimum difference among unit costs (see Table 7).

3.3. Environmental sustainability of olive harvesting systems

The LCA results of the olive harvesting methods show that HT_2 generates higher impact per hectare, followed by HT_4 (Table 8), HT_3 and HT_1. The comparative analysis of the environmental impacts associated with four olive harvesting techniques reveals significant differences across various impact categories. Mechanized methods (HT_2 and HT_4) consistently exhibit higher environmental impacts, particularly in categories such as fossil resource scarcity (89.30 and 86.95 kg oil eq, respectively), global warming potential (266.30 and 262.59 kg CO2 eq), and ozone formation affecting human health (2.76 and 2.82 kg NOx eq). In contrast, aided methods (HT_1 and HT_3) generally show lower impacts in these categories, though HT_3 notably presents a high value in non-carcinogenic toxicity (169.82 kg 1.4-DCB). Stratospheric ozone depletion is a unique case where HT_3 displays a significantly

Table 6
Results of the economic analysis of the olive harvesting systems.

Voice[a]	HT_1 (aided)	HT_2 (mechanized)	HT_3 (aided)	HT_4 (mechanized)
AFC (€ ha^{-1})	1476.80	0.00	670.80	0.00
AVC (€ ha^{-1})	345.28	0.00	2123.00	0.00
AC (€ ha^{-1})	1822.09	630.00	2793.80	840.00
Q (kg ha^{-1})	1505.00	1505.00	1505.00	1505.00
ACQ$_1$ (€ kg^{-1})	1.21	0.42	1.86	0.56
Oil yield (L ha^{-1})	242.50	242.50	242.50	242.50
(ACQ$_2$, € L^{-1})	7.51	2.59	11.52	3.46

[a] AFC = total fixed costs; AVC = total variable costs; AC = total unitary costs per unit of harvested area; Q = average olive yield (2022–2023); ACQ$_1$ = unitary costs per kg of harvested olives; ACQ$_2$ = unitary costs per litre of oil.

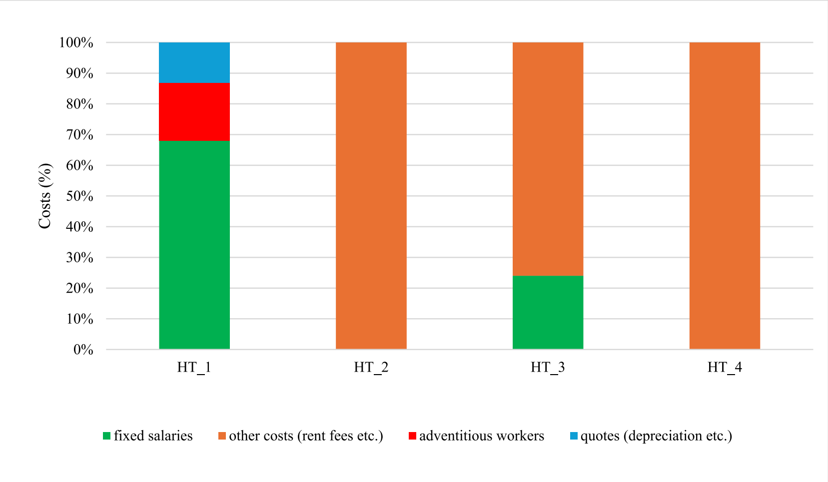

Fig. 3. Percentage distribution of costs per hectare by harvesting technique.

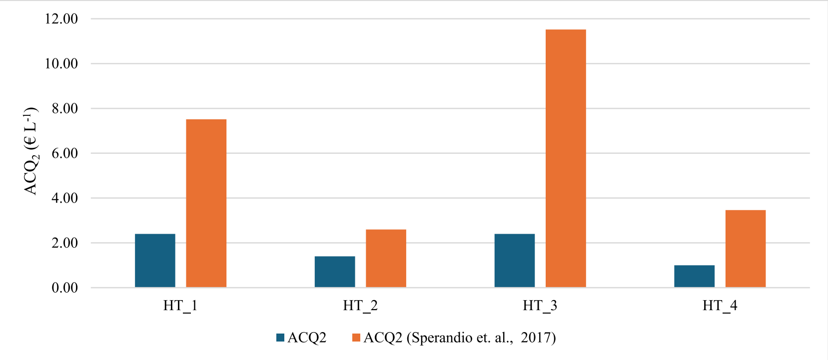

Fig. 4. *Comparison of costs* per *litre of olive oil by harvesting technique.* (ACQ$_2$ = Unitary cost per 1 L of olive oil). In order to separate the effect produced by the work capacity and the grove yield, a sensitivity analysis is performed by applying the same yield of [38] to our scenario (equal to 4500.0 kg ha^{-1} of olives and 720 L ha^{-1} (16 % yield of olive oil) and by recalculating operating costs under the same work productivity observed. The results are shown in Tab 7.

Table 7
results of sensitivity analysis.

Voice[a]	HT_1 (aided)	HT_2 (mechanized)	HT_3 (aided)	HT_4 (mechanized)
AC (€ ha^{1})	3338.24	2520.00	6973.45	2520.00
AC (€ ha^{-1} [38],	1669.00	971.00	1669.00	749.00
Oil yield (L ha^{1})	720.00	720.00	720.00	720.00
ACQ$_2$ (€ L^{-1})	4.64	3.50	9.69	3.50
ACQ$_2$ (€ L^{-1} [38],	2.40	1.40	2.40	1.00

[a] AC = unitary costs per 1 ha of harvested area; ACQ$_2$ = unitary costs per 1 L of olive oil.

higher impact (6.66 kg CFC11 eq) compared to the negligible values observed in mechanized methods. While aided methods demonstrate advantages in several impact categories, they are not without challenges; for instance, HT_1 and HT_3 show considerable impacts in terrestrial ecotoxicity (147.70 1.4-DCB and 474.14 kg 1.4-DCB, respectively). Land use impact is highest for HT_3 (11.10 m2a crop eq), indicating a potential trade-off between mechanized efficiency and land resource consumption. Global warming, also known as climate change, is arguably the most critical environmental impact of our time. This is primarily due to its widespread and far-reaching effects on ecosystems, weather patterns, sea levels and human health.

Global warming potential (GWP), usually measured in kg CO$_2$ equivalents, is a critical indicator in environmental impact assessments because it includes the cumulative effect of different greenhouse gases on climate. A more detailed examination of the results pertaining to this environmental impact reveals that the highest emissions might be attributed primarily to fuel consumption (Fig. 5). HT_3 has a lower result than the mechanized techniques (123.3 kg CO$_2$ eq), but it is higher compared to the aided HT_1 (33.0 kg CO$_2$

Table 8
LCA analysis results with 1 ha as FU.

Impact categories	Unit	HT_1 (aided)	HT_2 (mechanized)	HT_3 (aided)	HT_4 (mechanized)
Fine particulate matter formation	kg PM2.5 eq	0.05	0.72	0.22	0.73
Fossil resource scarcity	kg oil eq	13.22	89.30	43.74	86.95
Freshwater ecotoxicity	kg 1.4-DCB	1.41	2.82	1.80	2.88
Freshwater eutrophication	kg P eq	0.01	0.02	0.01	0.02
Global warming	kg CO_2 eq	33.01	266.30	123.27	262.59
Human carcinogenic toxicity	kg 1.4-DCB	1.75	5.35	3.09	4.03
Human non-carcinogenic toxicity	kg 1.4-DCB	56.49	113.34	169.82	113.24
Ionizing radiation	kBq Co-60 eq	1.68	7.11	3.42	5.35
Land use	m2a crop eq	8.00	5.72	11.10	4.76
Marine ecotoxicity	kg 1.4-DCB	2.01	4.19	2.69	4.25
Mineral resource scarcity	kg Cu eq	0.13	0.89	0.29	0.62
Ozone formation, Human health	kg NOx eq	0.11	2.76	0.67	2.82
Ozone formation, Terrestrial ecosystems	kg NO_x eq	0.11	2.80	0.71	2.86
Stratospheric ozone depletion	kg CFC_{11} eq	1.26	0.00	6.66	0.00
Terrestrial acidification	kg SO_2 eq	0.11	1.40	0.41	1.41
Terrestrial ecotoxicity	kg 1.4-DCB	147.70	541.24	474.14	526.51
Water consumption	m^3	0.25	0.74	0.47	0.61

eq), because of gasoline combustion in the air by the compressor engine. In HT_1, 42 % of the total emissions are caused by the transportation of the olives to the oil mill, followed by the polyethylene raw material for the construction of the equipment (21 %) and the construction of the sheds for the harvesting tools (15 %). In the HT_2 scenario, both diesel fuel combustion (70 %) and its production (12 %) were the main contributors, while 6 % was related to the production of trunk shakers (6 %). However, in HT_3, gasoline combustion was the main source of emissions (56 %), while transportation and gasoline production contributed for 11 % and 10 %, respectively. Finally, in HT_4, the main emission factors were diesel combustion (74 %), diesel production (12 %) and transport to the oil mill (6 %).

The differing results in emissions might be attributed to the combination of fuel consumption and work capacity. In the HT_2 scenario, 1 h of harvesting consumed 9.92 L h^{-1} of diesel, whereas in the HT_3, the lowest work capacity offset the lower consumption (1.25 L h^{-1}). Moreover, in the HT_4 scenario, the operations exhibited the highest hourly fuel consumption (12.37 L h^{-1}), which was a result of both the tractor and the intercepting umbrellas activity. However, HT_1 exhibited the lowest values among the alternatives in all the impact categories considered in the study.

Subsequently, the LCA results should be analysed through a direct comparison with available literature (Table 9). However, this comparison was possible only for HT_2 and HT_3. In order to convert the emissions from the FU "1 h of harvesting time" to "1 ha of area," it is necessary to consider the work capacities and yield data reported by the author. However, it is important to recognize that these data may be subject to uncertainty, as the author utilized a different version of the Recipe LCIA method.

Mechanized harvesting HT_2 registered slightly higher CO_2 emissions (+8 %) compared to the literature reference. On the other hand, HT_3 demonstrated an increase of 57 % for the same impact category than [19]. The author reported hourly diesel consumption

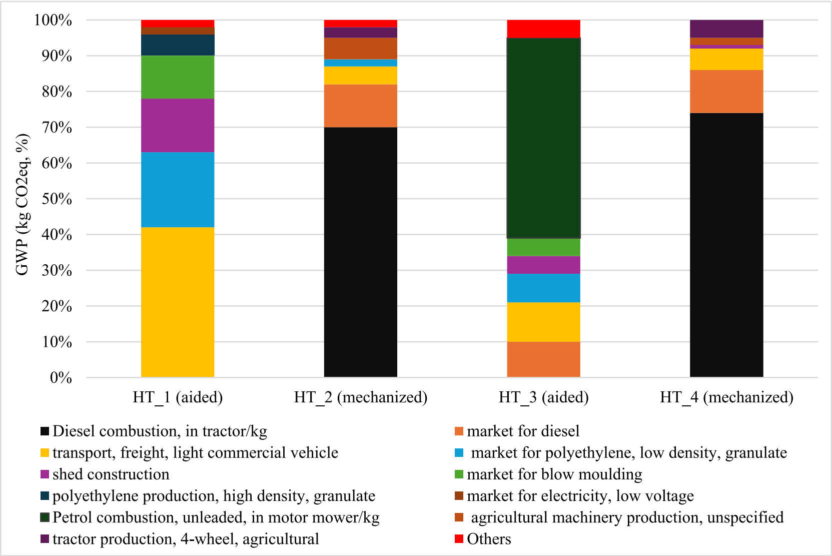

Fig. 5. Percentage of GWP ($kgCO_2eq.$) missions associated with each of the four olive harvesting techniques, categorized by emission source.

Table 9
LCIA results comparisons between experimental trials and available literature.

Impact Category	Unit	HT_2 [19]	HT_2 (mechanized)	HT_3 [19]	HT_3 (aided)
Global Warming	kg CO_2 eq	245.70	266.30	290.88	123.47
Terrestrial acidification	kg SO_2 eq	1.71	1.40	1.86	0.41
Freshwater eutrophication	kg P eq	0.04	0.02	0.07	0.01
Marine Eutrophication	kg N eq	0.09	0.00	0.10	0.00
Human toxicity	kg 1.4-DCB	54.86	113.34	121.48	169.82
Terrestrial toxicity	kg 1.4-DCB	0.01	541.24	0.02	474.14
Freshwater ecotoxicity	kg 1.4-DCB	0.01	2.82	2.93	1.80
Marine ecotoxicity	kg 1.4-DCB	0.01	4.19	2.93	2.69

of 8.15 L h^{-1} in HT_2 and 0.72 L h^{-1} in HT_3. In the former harvesting time per unit of area were like our scenario, as the higher yield (8000.0 kg ha^{-1} vs 1392.0 kg ha^{-1}) was compensated with a superior work capacity. In the latter situation it is still likely to attribute the emissions differences to the different grove yields (5615.00 kg ha^{-1} vs 1617.00 kg ha^{-1}), but the gap between the hourly diesel consumption and the different technological features of the equipment could play a crucial role in justifying those differences. Therefore, emissions values were converted to the FU "1 Kg of olives" (Table 10). Results highlight that the HT_2 (trunk shaker + nets) reached a considerably lower emission value per unit of harvested olives (−84 %) compared to out harvesting scenario, mainly because of the better working capacity. Nevertheless, the author reported a slightly inferior value for the pneumatic combs + nets harvesting scenario in comparison to the HT_3. In this case, the work capacities are comparable, thus necessitating the consideration of other factors to justify the observed differences in emissions.

The final overall assessment (Fig. 6) offers an overview of the three aspects of the study based on 1 h of working operation. Hourly costs (HAC) were obtained by dividing the unitary costs per 1 ha of olive grove (CA) the number of hours needed to harvest 1 ha of surface. The latter is obtained by dividing the olive grove yield (Q) with the CA1 data of any technique, resulting in 15 h ha^{-1} for HT_1, 9 h ha^{-1} for HT_2, 21 h ha^{-1} for HT_3 and 8 h ha^{-1} for HT_4. Moreover, we calculated the single score for the LCA impacts considering the endpoint approach, to gather all the aspects regarding the sustainability issue in a single reference, despite the increasing uncertainty in the result. It is possible to assume that higher work capacities found in HT_4 and HT_2 were compensated by higher environmental impacts and lower costs, while aided techniques were characterized by higher hourly costs and lower work capacities as well as better environmental impacts. However, HT_1 seems more suitable than HT_3 because its environmental sustainability is accompanied by better working capacities than HT_3. Indeed, HT_3 can be addressed as the most inappropriate technique among those analysed.

4. Conclusions

This study aimed at evaluating the most feasible harvesting technique, outlining how the examined aspects (work capacity, economic and environmental sustainability) would differ and how they were reciprocally linked. Mechanized techniques (HT_1 and HT_4) performed the highest working capacities (159.01 kg h^{-1} for HT_2 and 200.51 kg h^{-1} for HT_4), whereas environmental performances were the worst due to diesel intakes (266.30 kg CO_2 eq for HT_2 and 252.59 kg CO_2 eq for HT_4). Regarding the economic assessment, lower total unitary costs registered for these alternatives (630.00 € ha^{-1} for HT_2 and 840.00 € ha^{-1} for HT_4) were partially influenced by higher work capacities and mostly by cheap hourly rental rates. Thus, advantages linked to their applications is demonstrated, but their effective application in other groves of the area is strongly affected by morphological or agronomic aspects. Regarding aided methods, HT_1 performed better results for all the evaluated aspects than HT_3 (91.01 kg h^{-1} vs 76.13 kg h^{-1}: 1822.09 € ha^{-1} vs 2793.80 € ha^{-1}; 33.01 kg CO_2 eq vs 127.21 kg CO_2 eq). In particular, the environmental differences are attributed to the absence of diesel inputs in HT_1. The nature of the costs for the aided techniques consisted of fixed and variable items for HT_1 and of rental rates and fixed items for HT_3. Therefore, both those differences and the work capacities results affected the economic outcomes. This evidence would suggest implementing the former alternative in farms where factors such slope and irregular shape of the olive groves allow not to use mechanized techniques. However, the low yield of the experimental grove is so influential to these results that the adaptation of the abovementioned techniques in other groves might lead to different outcomes. In addition, olive oil revenues for the local farms are boosted by customers esteem for traditional local products, allowing farmers to choose farming techniques not only according to economic aspects. Finally, other factors such as the labour availability should be considered. The mechanized alternatives, in combination with the development of subcontracting companies, may offer solutions to enhance competitiveness in the olive oil sector and mitigate bottlenecks in the agricultural phase.

Analysis on the harvesting efficiency (regarding possible loss of production during the execution of operations as well as possible olives not left unripen on the plants) should be considered to evaluate operative aspects in the most comprehensive manner. However, our methodology represents a novel in this research field as it evaluates the performances of electric combs which were not previously considered despite their widespread utilization in Italian farms. Finally, datasets obtained in the LCA analysis may be helpful for further studies regarding the harvesting operation. As a matter of fact, LCAs analysis in agriculture increase their accuracy when practitioners rely on a wider range of case studies, as they may find the one closely representative of their context. In addition, extending the environmental evaluation to the entire sector in the area would benefit all the actors if those analysis are applied to labelling certifications for the environmental impact.

This study aimed at evaluating the most feasible harvesting technique in an olive grove, outlining how the examined aspects (work

Table 10
Greenhouse gas emissions values of experimental trials and similar harvesting scenarios, referred to “1 kg of olives” FU.

Parameter	Unit	HT_2 [19]	HT_2 (mechanized)	HT_3 [19]	HT_3 (aided)
GWP*	kg CO2 eq	0.03	0.19	0.05	0.08
CA1**	kg h^{-1}	1175.32	159.13	83.21	76.15
Yield	kg ha^{-1}	7999.00	1392.00	5615.00	1617.00

**CA1: work capacity per unit of time; ** Obtained by dividing the kg CO2 eq amount with the yields of the harvesting sites to state additional evidence.

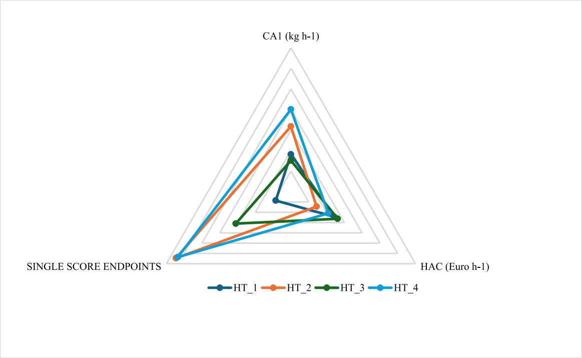

Fig. 6. Results of work capacity (CA1), hourly unitary costs (HAC) and single score. Due to scaling necessities, single score results were divided by 1x10^6.

capacity, economic and environmental sustainability) would change. Mechanized techniques (HT_1 and HT_4) performed the highest working capacities (159.01 kg h^{-1} for HT_2 and 200.51 kg h^{-1} for HT_4), whereas environmental performances were the worst due to diesel intakes (266.30 kg CO_2 eq for HT_2 and 252.59 kg CO_2 eq for HT_4). Regarding the economic assessment, lower total unitary costs registered for these alternatives (630.00 € ha^{-1} for HT_2 and 840.00 € ha^{-1} for HT_4) were partially influenced by higher work capacities and mostly by cheap hourly rental rates. Thus, advantages linked to their applications is demonstrated, but their effective application in other groves of the area is strongly affected by morphological or agronomic aspects. Regarding aided methods, HT_1 performed better results for all the evaluated aspects than HT_3 (91.01 kg h^{-1} vs 76.13 kg h^{-1}: 1822.09 € ha^{-1} vs 2793.80 € ha^{-1}; 33.01 kg CO_2 eq vs 127.21 kg CO_2 eq). In particular, the environmental differences are attributed to the absence of diesel inputs in HT_1. The nature of the costs for the aided techniques consisted of fixed and variable items for HT_1 and of rental rates and fixed items for HT_3. Therefore, both those differences and the work capacities results affected the economic outcomes. This evidence suggests implementing the former alternative for other farms where factors such slope and irregular shape of the olive groves may not allow the use of mechanized techniques. However, these statements would not be adaptable to other olives groves, as they are also strongly influenced by the low yields obtained in the experimental grove. In addition, olive oil revenues for the local farms are boosted thanks to customers esteem for traditional products from this territory, allowing farmers to choose farming techniques not only according to economic aspects. In addition, other factors such the labour availability should be considered. The mechanized alternatives, in combination with the development of subcontracting companies, may offer solutions to enhance competitiveness in the olive oil sector and eliminate bottlenecks in the agricultural phase.

The results must be evaluated considering the law yield of the olive grove, and this can be considered the main limit of our study. In addition, analysis on the harvesting efficiency should be taking in consideration to evaluate operative aspects in the most comprehensive manner. However, our methodology represents a novel in this research field as it evaluates the performances of electric combs which were not previously considered despite their widespread utilization in Italian farms. Moreover, we built up an insight about a farm placed in an area where olive oil production is advantaged by higher revenues, allowing the farmers to continue olive cultivation despite the increasing costs. Finally, datasets obtained in the LCA analysis may be helpful for further studies regarding the harvesting operation. As a matter of fact, LCAs analysis in agriculture increase their accuracy when practitioners rely on a wider range of case studies, as they may find the one closely representative of their context. In addition, extending the environmental evaluation to the entire sector in the area would benefit all the actors if those analysis are applied to labelling certifications for the environmental impact.

CRediT authorship contribution statement

Maura Sannino: Writing – review & editing, Writing – original draft, Supervision, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Salvatore Faugno:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Guglielmo Maresca:** Writing – review & editing, Writing – original draft, Visualization, Investigation, Formal analysis, Data curation. **Alessandro Suardi:** Writing – original draft, Validation, Data curation, Conceptualization. **Teresa Panico:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Fiorentino Costanza:** Writing – review & editing, Writing – original draft, Alberto assirelli, Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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