agronomy

Article

Economic and Environmental Sustainability of Olive Production: A Case Study

Giulia Maesano [1], Gaetano Chinnici [1,*], Giacomo Falcone [2], Claudio Bellia [1], Maria Raimondo [3] and Mario D'Amico [1]

[1] Department of Agriculture, Food and Environment (Di3A), University of Catania, Via Santa Sofia 98-100, 95123 Catania, Italy; gmaesano@unict.it (G.M.); c.bellia@unict.it (C.B.); mario.damico@unict.it (M.D.)
[2] Department of Agriculture, Mediterranean University of Reggio Calabria, Feo di Vito, 89122 Reggio Calabria, Italy; giacomo.falcone@unirc.it
[3] Department of Law, Economic, Management and Quantitative Methods, University of Sannio, Via Delle Puglie 82, 82100 Benevento, Italy; raimondo@unisannio.it
* Correspondence: chinnici@unict.it

Abstract: This paper aims to achieve an economic feasibility and life cycle assessment of three different olive cultivation systems in the Mediterranean area through the joint use of economic and environmental indicators, in order to identify the key elements to optimize their economic performance and a lower environmental impact. Three different management systems of olive cultivation were analysed by distinguishing Treatment 1—Fully Irrigated, Treatment 2—Partially Irrigated, and Treatment 3—Non-Irrigated, which were conducted through different levels of irrigation strategies. The three scenarios were examined using a Life Cycle Assessment methodology to assess the environmental impacts, and the impact in terms of water footprint was investigated using the Water Scarcity Index approach. The economic sustainability evaluation of olive cultivation was carried out through economic indicators, taking into account all of the cost and revenue factors of the olive cultivation in each management system. The results showed, overall, a suitable level of profitability of different scenarios, except for the Partially Irrigated treatment, as the investment costs of the irrigation system are not economically sustainable with regard to the revenue obtained. Furthermore, the findings highlighted the importance of irrigation management strategies to decrease agricultural practice costs and the negative environmental impact of olive production.

Keywords: olive; life cycle assessment (LCA); cost production; sustainability; economic; environment

check for updates

Citation: Maesano, G.; Chinnici, G.; Falcone, G.; Bellia, C.; Raimondo, M.; D'Amico, M. Economic and Environmental Sustainability of Olive Production: A Case Study. *Agronomy* **2021**, *11*, 1753. https://doi.org/10.3390/agronomy11091753

Academic Editor: David W. Archer

Received: 29 July 2021
Accepted: 28 August 2021
Published: 31 August 2021

1. Introduction

The olive tree (*Olea europaea* L.) is a species of the Oleaceae family originating from a dry-subtropical climate [1], from the Eastern Mediterranean [2]. Olive cultivation in Mediterranean areas is an important agro-industrial sector [1], and it represents a considerable economic, agricultural and ornamental concern, whilst also playing a role in the maintenance of biodiversity, showing a link with some wild crop relatives of considerable conservation value [1,3] and benefit in the economic and social dimensions in rural areas [1,4–6].

Despite the economic importance of this product in many countries, olive production is associated with several negative effects on the environment, with consequences on resource depletion, soil degradation, air emissions and waste generation [7–13]. The impacts can vary significantly due to the practices and techniques employed in olive growing and olive production [1,14].

The olive tree is very adapted to extreme environmental conditions, such as drought and high temperatures [5,15]. The Mediterranean climate is characterized by an amount of rainfall ranging from 150 to 800 mm per year, and by an uneven distribution of rains, concentrated above all in the winter and spring months [5,16]. The Mediterranean area, characterized by a climate with a limited level of rainfall, has experienced a certain increase in average temperatures and an uneven distribution of rainfall in the last decade [5,15]. These aspects result in a greater demand for the use of water for irrigation even in non-traditional times [5,17].

The olive tree can be considered one of the best bio-indicators of climate-changing in the Mediterranean Basin [18]; in fact, the great climatic variability affects the phenological aspects and the productivity of this crop, causing serious income imbalances for farmers in recent years [19].

Although the olive tree can be considered—due to its morphological and anatomical characteristics—a xerophytic species, the combination of prolonged water stress and high temperatures during the summer significantly affects the plant's response in terms of both overall growth and productivity. In areas of southern Italy, although its survival is not compromised, it is subject to high levels of water deficit, which can cause a reduction in stomatal conductance and net photosynthesis [20–22]. These reductions are a self-regulating mechanism for overcoming periods of water stress with an impact on plant production [21,23].

In Italy, the highest deficit values are recorded in the southern areas, including Sicily, Sardinia and Puglia [2,3,6]. Although it is a resistant species against drought events, it is not impossible to imagine that in the future, the cultivation in some areas may no longer be able to guarantee profitability such as to justify its maintenance in the company's production systems [24].

In light of this, the new National Olive Growing Plan, among its objectives, envisages increasing national olive production, without increasing the already strong pressure on natural resources, in particular on water [25]. This will be realised through the rationalization of the cultivation of traditional olive groves, the renewal of the plants, and the introduction of new cultivation systems capable of reconciling environmental and economic sustainability [4,26,27]. To this aim, the use of innovative methods for the assessment of sustainability can represent a powerful tool to increase the knowledge about new paradigms of agricultural production processes [28].

The sustainability of agricultural production is one of the most interesting areas of discussion in the current academic debate [29–34]. Since the 1990s, different analytical and methodological approaches have been developed to establish criteria for measuring the impact of crops on the surrounding environment. To this end, numerous researchers have identified objective standards based on the use of specific indicators, providing useful findings for the identification of specific guidelines to measure the impacts of agricultural practices on the environment both per unit of surface area and per product unit [35].

Several studies have investigated the main characteristics of sustainable entrepreneurship linked to specific agricultural sectors, such as olive oil [4,32,33,36–38], viticulture or the wine industry [39–41], and the citrus sector [34,42]. Some studies have focused on the assessment of the environmental impact of different cultivation practices [41]; other studies, on the other hand, have evaluated the economic sustainability of cultivations [43]. In this study, an environmental and economic sustainability assessment was performed.

Nevertheless, in the Mediterranean area, olive growing is affected by several critical factors related to farm management, giving rise to economically unsustainable productions [44].

The paper aims to achieve the economic feasibility and environmental sustainability of three different olive cultivation systems through the joint use of economic and environmental indicators to identify the key elements to minimize the environmental impacts in an olive-growing area and maximize economic performance.

The purpose of the paper is to analyse the economic impact of olive production in a Mediterranean region in order to support the economic company choices, as well as to evaluate the impacts related to the life cycle (Life Cycle Assessment) through a comparison of different irrigation management: Treatment FI (fully irrigated) with 100%

return of ET crop evapotranspiration, Treatment PI (partially irrigated) and Treatment NI (non-irrigated).

The Life Cycle Assessment (LCA) method allows us to investigate sustainability issues through a conceptual model, based on the deepening of all impacts that a product or a service generates during its whole life cycle, related to all sustainability components, from design to the disposal of the used product [45–47]. However, an assessment of sustainability cannot be distinct from the profitability evaluation [48], a factor that mainly affects decision-making in business activity, in the absence of specific constraints.

The economic sustainability evaluation of olive cultivation has been carried out through economic indicators. This approach has allowed us to take into account all of the costs and revenue factors of cultivation. Our findings highlighted the importance of irrigation management strategies to decrease agricultural practice costs and to increase the transformation yield of olive production.

The paper is organized as follows. The Section 2 presents a brief overview of olive surface and production figures in the Sicily region. The Section 3 describes the method and an overview of the studies in the literature. The Section 4 summarizes the main findings of our research. The Section 5 provides the concluding remarks.

2. Olive Surfaces and Production in Sicily Region

Knowledge of the productive and organizational structure of the regional olive sector represents one of the first objectives of the research as a strategic component of the profitability of the individual production units.

Regarding the olive groves in Italy, a substantial condition of stability has been observed in recent years, with a slight but not very significant growth of the Italian olive surfaces, which in 2019 reached 1,164,568 hectares [49], mainly concentrated in the regions of South Italy (Figure 1). Furthermore, for the production, the regions of South Italy are the main productive area of the country, generating an oil production equal to about 78% of the national total. More specifically, the Puglia, Calabria and Sicily regions constitute over 66.5% of the national total production [49]. The Sicily region, which represents 12.3% of the national production, today shows a decreasing trend. The average production of Sicilian oil is around 262,551 tons (the mean of 2016–2019 years) [49].

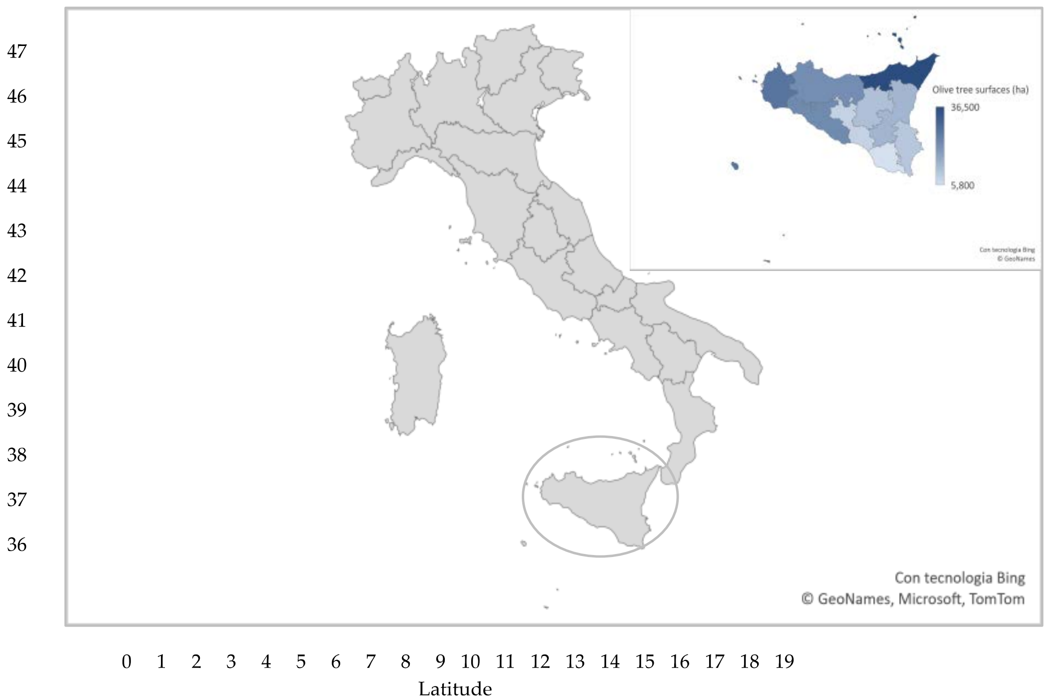

Figure 1. Olive cultivation surface in Sicily (2019).

The total area invested in olive growing in Sicily amounted to 157,891 hectares in 2019 [49]. The province of Messina is the first by surface, equal to 23.1% of the region. Similar surfaces are found in the province of Trapani, which counted 27 thousand hectares in 2019. The reasons for the increasing trend are due to the fact that producers are aiming for quality production, in particular as regards the olive oil produced in the areas where the Protected Designation of Origin (PDO) is in force.

The provinces of Agrigento (22,580 hectares), Palermo (21,880 hectares) and Enna (11,820 hectares), which represent respectively 14.3%, 13.9% and 7.5% of the island's olive-growing area, showed a slightly negative trend in recent years. The cultivated area in the province of Catania is almost constant (13.7 thousand hectares), the percentage of which with regard to the regional total represents 8.7%. The provinces of Syracuse (10 thousand hectares), Caltanissetta (8.2 thousand hectares) and Ragusa (5.8 thousand hectares) are located on less consistent levels, although in these territories there are specific conditions of excellence. In more detail, Syrac use saw its area decrease, reaching approximately 10.3 thousand hectares, equal to 6.5% of the total. Caltanissetta, which in 2019 had 8.2 thousand hectares, represented 5.2% of the regional total. The province of Ragusa recorded just over 5.8 thousand hectares in 2019, equal to 3.7% of Sicilian olive groves.

Regardless of the territories considered, there is also a double evolutionary phenomenon on the island, consisting on the one hand of the progressive spread of highly specialized olive farms (with high degrees of mechanization of their cultivation operations) and on the other of a parallel marginalization, and consequent gradual exit from the market of those companies that are scarcely competitive (high degrees of company fragmentation and pulverization) and not infrequently characterized by the high obsolescence of the plants (irregular sixths, not very productive varieties, excessive slopes and the absence of irrigation, etc.).

The general picture of olive oil production in Sicily reveals a total average production in the period of 2016–2019 of 262,551 tons, and 37,431 tons of olive oil (Figure 2). The provinces that participate to a greater extent are Palermo, Trapani, Agrigento and Catania, compared to Messina, Caltanissetta, Ragusa and Syracuse (Figure 2). The province of Palermo, confirming the high production specialization achieved in some areas, is the first for volumes of oil produced (20.3% of the regional total), with over 53 thousand tons. In second place comes Catania, with an average production of 42.8 thousand tons, preceding the province of Trapani, whose productions exceed 38.9 thousand tons. The contribution of the two provinces to regional production is, respectively, 16.3% and 14.8%.

Lower volumes are attested to by the provinces of Agrigento (30,899 tons) and Messina (22,875 tons), which respectively represent 11.8 and 8.7% of the total Sicilian production. Emblematic is the situation of Messina, which although it has a larger olive-growing area than Palermo and more than double that of Catania, records considerably lower productions, above all due to the absence of significant technical improvements in the first Sicilian olive-growing province.

The differences between the provinces are due to pedoclimatic differences, cultural techniques and the choice of the cultivar, which lead to a different unitary yield between the provinces. Furthermore, on the one hand, in marginal and mountain areas, there is a type of olive growing that adapts to extreme and marginal conditions, which has a function more linked to the maintenance of biodiversity and marginal rural areas; on the other hand, new selections and cultivars with higher yields, with greater tolerance to biotic and abiotic stress, and which are adaptable to high-density planting systems and resistant to climate change, are present in the more specialized areas.

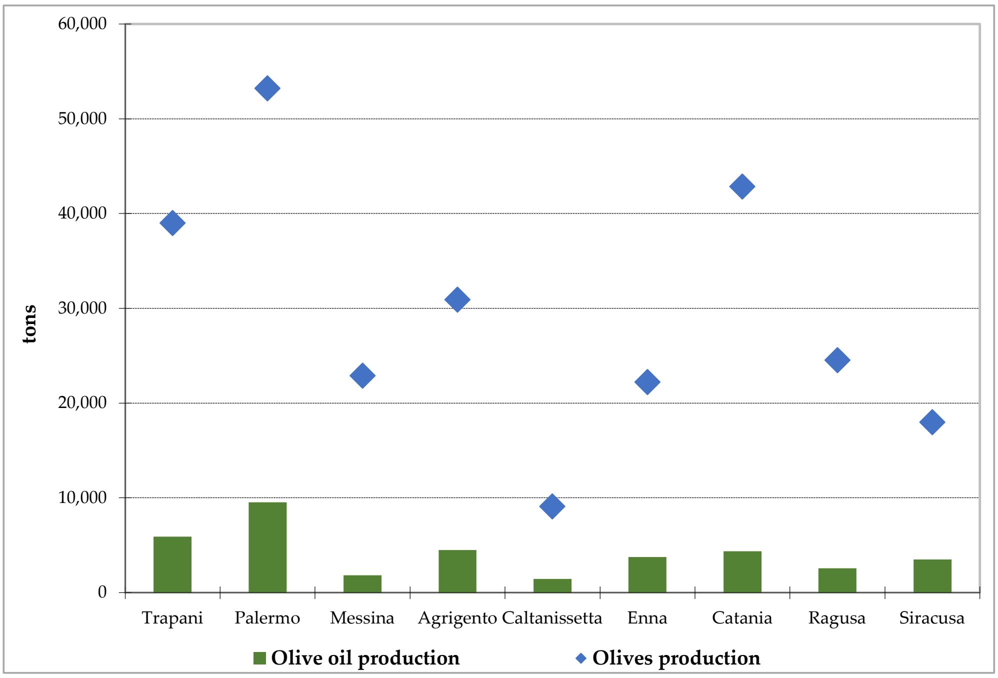

Figure 2. Olive production and olive oil production in Sicily (2019).

3. Materials and Method

3.1. Experimental Design

In this study, different olive production systems located in Southern Italy have been compared in order to assess their environmental and economic sustainability performance. The experimental design involved different management systems of olive cultivation: Treatment (1), fully irrigated (FI) cultivation by drip irrigation with a 100% return of ET crop evapotranspiration; Treatment (2) partially irrigated (PI) cultivation with partial root-zone drying—PRD (50% ET); and Treatment (3), non-irrigated (NI). There were 3 contiguous and homogeneous plots, in which the 3 different irrigation management treatments were carried out.

All of the data was collected from an interview with the olive grower, who provided data on the oil olives' production, the olive oil production and the inventory of the agronomic operations carried out, which was useful for the purpose of drawing up the inventory, as described in Section 3.3; Environmental Impact Analysis. A semi-structured questionnaire was developed to collect information relating to the cultivation operations which were useful for the analysis of environmental impacts, and the costs for the analysis of the production cost.

The data used in this research are the first results of a multidisciplinary research project of the University of Catania on the sustainable management of olive crops through deficient irrigation techniques. The experiment was carried out in the years 2019–2020. This activity was carried out in the area of the Valle dei Margi farm, located in Catania (geographic coordinates Lat. 32°15′00″ and Lon. 14°35′55″). In order to evaluate the impacts related to the life cycle of olive production in support of company choices, an analysis of environmental impacts was used through LCA and the study of economic impacts through the analysis of the corporate income of the management model object of the trial in question.

In order to assess the environmental and economic sustainability, the typologies and quantities of inputs and outputs were directly observed (as primary data) for the establishment of a single inventory, which was useful for further elaborations. The inventory data were monetized considering the current market prices in order to determine the economic results of different crop scenarios. The acquisition of the company data was functional to the identification of the technical-economic characteristics of the cultivation. Based on the information acquired, it was possible to determine the economic and environmental impact, and therefore to develop those judgments of the convenience of the sustainable production models being tested.

The first phase of the study concerned the acquisition of data and information capable of supporting the creation of a technical datasheet capable of representing the different processes affecting the life cycle of olive cultivation. In this initial phase, information was collected about the olive cultivation techniques traditionally and generally used in the reference context. This information was acquired through bibliographic research, field inspections, and interviews with olive growers. The information collected was acquired with the help of a specially prepared questionnaire form, and was then used for the development of a descriptive scheme of olive grove management techniques.

The questionnaire form allowed us to collect the following data: (a) identification—location and company contacts; (b) technical-agronomic—cultivated area, planting layout, cultivar, plant age, productivity per hectare, type of soil, slope; (c) cultivation operations—type and number of cultivation operations, irrigation, pest management and fertilization carried out during the year, the period and duration of the interventions, and the characteristics and consumption of the tools/machinery and products used; (d) the unit prices of the factors of production used (input) and of the products obtained (output). Such data and information are useful both to determine the technical components and for the quantification of the company's economic results (revenues, costs, and profits). Furthermore, the technical aspects will be fundamental for the preparation of a specific LCA analysis methodology. In order to carry out an LCA study to assess the environmental impact of olive growing in different irrigation treatments, weekly field surveys were conducted to collect the data.

3.2. Economic Data Collection and Analysis

In order to highlight the economic performance of the olive cultivation systems under study, the total production costs and revenues referring to 1 ha cultivated surface and 1 kg olive oil were evaluated as in other previous studies [43,50,51].

The survey was designed based on previous methodological approaches conducted on the profitability of small farms [40,47,52,53]. In particular, to evaluate the economic results of the agricultural activity, the cost of production and profitability were taken into account [39,54,55].

The data were collected during face-to-face interviews by administering a specific questionnaire to the olive oil producers. The questionnaire was structured into two sections:

- The first was aimed at collecting technical information on the structural and managerial characteristics of the farms (location, agricultural land, surfaces, characteristics of the crop, etc.);
- The second focused on the economic results of the sample. To this end, data relating to total crop production, sale prices, annual work units (family members, salaried workers, etc.), and total costs were calculated.

Regarding the production costs, the study was based on three main classes: "materials", "work and services" and "depreciation and other costs". Specifically, materials include the cost of all non-capital inputs used during the accounting years, such as fertilizers, pesticides, herbicides, fuel, water and other crop specifications. Labour and services include the hourly wages of workers for manual and mechanical operations during the accounting year. The total cost of labour was calculated by multiplying the number of hours worked by the hourly cost of labour. Non-agricultural services refer to ancillary costs relating to "activities carried out by external companies", which include the renting of agricultural machinery and vehicles, insurance, mediation for the sale of products, and transport. Duties included machinery, equipment, land and building depreciation costs, working and running capital, taxes and fees.

We have calculated the average net value of the farm by subtracting the total production costs from the total output value. The latter is related to yield expressed as olive oil production (kg), sales prices (€) and CAP subsidies, while total costs included "materials", "labour and services" and "depreciation and other costs" (Table 1).

Table 1. Economic indicators used.

Economic Indicators	Description	Unit	
A—Materials	Cost of all non-capital inputs.	€/ha	€/kg Olive oil
B—Labour and service	Hourly wages of workers for manual and mechanical operations.	€/ha	€/kg Olive oil
C—Depreciation and other costs	Machinery, equipment, land and building depreciation costs, intellectual work, interests, taxes and fees.	€/ha	€/kg Olive oil
D—Total cost (A + B + C)	Materials + Labour and service + Depreciation and other costs.	€/ha	€/kg Olive oil
E—Revenues	Yield expressed as olive oil production (kg), and sales prices (€).	€/ha	€/kg Olive oil
F—CAP Direct Payment	EU subsidies.	€/ha	€/kg Olive oil
G—Total Output value (E + F)	Revenues + CAP Direct Payment.	€/ha	€/kg Olive oil
H—Net Value (G − D)	Total Output value—Total cost.	€/ha	€/kg Olive oil

This analysis allowed us to investigate those activities affecting more strongly the production and profitability, in order to reduce production costs and improve profit margins, as suggested by Testa et al. [43] and Iotti and Bonazzi [56]. Specifically, regarding input costs, following Falcone et al. [47], they were calculated taking into consideration each material and energy flow input considered in the Environmental Life Cycle Inventory and pricing them according to the current market.

The analysis conducted made it possible to identify the technical and economic variables. The methodological approach was aimed at the determination of the economic results, the determination of revenues, the determination of variable costs and fixed production costs, and the analysis of the profits of the olive grove (partial budget). In line with the proposed methodology, the costs and revenues of the olive growing scenarios were quantified.

3.3. *Environmental Impact Analysis*

The olive oil industry represents a sector of considerable importance both in terms of production, and of the techniques and transformation processes carried out, as characterized by a multitude of different practices and techniques. Depending on these different procedures, olive production is associated with several adverse effects on the environment, both in the agricultural and in the olive oil production phase. Therefore, tools such as LCA are becoming increasingly important for this type of industry.

LCA has been widely applied to olive oil in the last decade in order to identify environmentally critical points and propose recommendations to limit environmental impacts [57]. Through the LCA study, the aim is to obtain an assessment and quantification of the energy and environmental loads and of the potential impacts associated with a process or product along its entire life cycle ("from cradle to grave"), including all of the phases that make up the production process.

The importance of this method is due to its innovative approach, which evaluates all phases of a process as related and dependent on each other. The quantification of the impacts reaches a very high level of detail, allowing us to obtain the information necessary to make judgments of convenience on all of the stages of the production process.

The environmental dimension of sustainability was analysed using the LCA methodology according to ISO norms [58,59], "an objective process to evaluate the environmental burdens associated to a product, a process, or an activity by identifying energy and materials usage and environmental releases, and to evaluate opportunities to achieve environmental improvements" [60]. According to ISO 14040:2006 [58], an iterative approach based on four steps is necessary to implement a rigorous LCA study. Primarily, the phase of goal and scope definition should be carried out, including a clear statement on the specification of the Functional Unit (FU)—i.e., the measurement unit to which all input and output data are related—as well as of system boundaries, data quality, limitations and procedures of allocation.

From the literature review, it emerges that the most used LCA analysis applied in the olive sector is of a comparative type. The first LCA study applied to the olive sector [61] focused, in fact, on the comparison between irrigated and dry olive growing systems. This analytical framework, combining various systems and methods in different ways, has recently been applied and replicated in other papers [14,36,37,62]. This literature review includes LCA studies that directly or indirectly refer to the broader term "olive industry", thus including applications not only to olive oil production but also to olives in general.

Despite several studies existing on the impacts of crops evaluated through LCA, the specific issue of olive cultivation management is very topical, especially in the Mediterranean context. To confirm this, by carrying out an explorative survey on the Scopus database (Table 2), it emerges that almost all of the studies refer to olive cultivation in the Mediterranean basin.

Table 2. Analysis of the literature reporting on LCA tools in the olive industry.

Authors	Title	Year	Source
Bernardi B., Falcone G., Stillitano T., Benalia S., Bacenetti J., De Luca A.I. [63]	Harvesting system sustainability in Mediterranean olive cultivation: Other principal cultivar	2021	Science of the Total Environment
Tziolas E., Bournaris T. [64]	Economic and Environmental Assessment of Agro-Energy Districts in Northern Greece: a Life Cycle Assessment Approach	2019	Bioenergy Research
Stillitano T., Falcone G., De Luca A.I., Piga A., Conte P., Strano A., Gulisano G. [65]	Innovative technologies in evo oil extraction: An economic and environmental impact analysis	2019	Rivista Italiana delle Sostanze Grasse
Espadas-Aldana G., Vialle C., Belaud J.-P., Vaca-Garcia C., Sablayrolles C. [57]	Analysis and trends for Life Cycle Assessment of olive oil production	2019	Sustainable Production and Consumption
Bernardi B., Falcone G., Stillitano T., Benalia S., Strano A., Bacenetti J., De Luca A.I. [38]	Harvesting system sustainability in Mediterranean olive cultivation	2018	Science of the Total Environment
De Luca A.I., Iofrida N., Falcone G., Stillitano T., Gulisano G. [31]	Olive growing scenarios of soil management: Integrating environmental, economic and social indicators from a life-cycle perspective	2018	Acta Horticulturae
De Luca A.I., Falcone G., Stillitano T., Iofrida N., Strano A., Gulisano G. [33]	Evaluation of sustainable innovations in olive growing systems: A Life Cycle Sustainability Assessment case study in southern Italy	2018	Journal of Cleaner Production
De Luca A.I., Stillitano T., Falcone G., Squeo G., Caponio F., Strano A., Gulisano G. [32]	Economic and environmental assessment of extra virgin olive oil processing innovations	2018	Chemical Engineering Transactions
Pattara, C., Salomone, R., & Cichelli, A. [66]	Carbon footprint of extra virgin olive oil: A comparative and driver analysis of different production processes in Centre Italy	2016	Journal of Cleaner Production

Table 2. *Cont.*

Authors	Title	Year	Source
Tsarouhas P., Achillas C., Aidonis D., Folinas D., Maslis V. [67]	Life Cycle Assessment of olive oil production in Greece	2015	Journal of Cleaner Production
De Luca A.I., Molari G., Seddaiu G., Toscano A., Bombino G., Ledda L., Milani M., Vittuari M. [68]	Multidisciplinary and innovative methodologies for sustainable management in agricultural systems	2015	Environmental Engineering and Management Journal
Mohamad R.S., Verrastro V., Cardone G., Bteich M.R., Favia M., Moretti M., Roma R. [69]	Optimization of organic and conventional olive agricultural practices from a Life Cycle Assessment and Life Cycle Costing perspectives	2014	Journal of Cleaner Production
Rajaeifar M.A., Akram A., Ghobadian B., Rafiee S., Heidari M.D. [70]	Energy-economic life cycle assessment (LCA) and greenhouse gas emissions analysis of olive oil production in Iran	2014	Energy
Pergola M., Favia M., Palese A.M., Perretti B., Xiloyannis C., Celano G. [30]	Alternative management for olive orchards grown in semi-arid environments: An energy, economic and environmental analysis	2013	Scientia Horticulturae
De Gennaro B., Notarnicola B., Roselli L., Tassielli G. [37]	Innovative olive-growing models: An environmental and economic assessment	2012	Journal of Cleaner Production
Notarnicola, B., Tassielli, G., Nicoletti, G.M., [71]	Environmental and economical analysis of the organic and conventional extra-virgin olive oil.	2004	New Medit

In this regard, given the fundamental importance of olive cultivation in the characterization of the land where it is practiced, the issue must be further explored.

The olive oil supply chain can be described as follows [72], through different stages starting from the cultivation of the olive tree to the production of products and by-products, transport and distribution, consumption and waste management. The cultivation phase includes the cultivation of olives using different treatments, such as soil management, pruning, fertilization, irrigation, pest treatment and harvesting.

The analysis of the literature on the adoption of LCA in the olive sector in previous studies has shown an unequivocal environmental hotspot, the agricultural phase, which represents the most impactful phase of the life cycle of olive oil, due to fertilization, pesticide treatment and irrigation [57].

In this research, a system boundary from the ‘cradle to gate farm’ was chosen, and all of the inputs of the olive cultivation system were considered (Figure 3). For the evaluation of the environmental impacts of irrigation management systems, both the hectare of surface area and the kg of product obtained were chosen as functional units.

From the point of view of the multifunctionality of agriculture, the purpose of choosing the hectare as a functional unit is linked to the desire to evaluate the ecosystem function of olive growing in a suitable area, and not just the purely productive function. Moreover, the kg of olive production was also used as a functional unit, in order to consider the main function of the agricultural production process.

In this study, applying the LCA methodology, the sustainability and environmental impacts of the individual production phases of the olive management models will be assessed and quantified, comparing the three different irrigation systems: Treatment 1—Fully Irrigated (FI), Treatment 2—Partially Irrigated (PI), and Treatment 3—Non-Irrigated (NI). No allocation criteria were defined: the choice of the functional units made it possible to evaluate the entire production process and therefore to analyse the impacts for all of the products generated by it, without focusing on them.

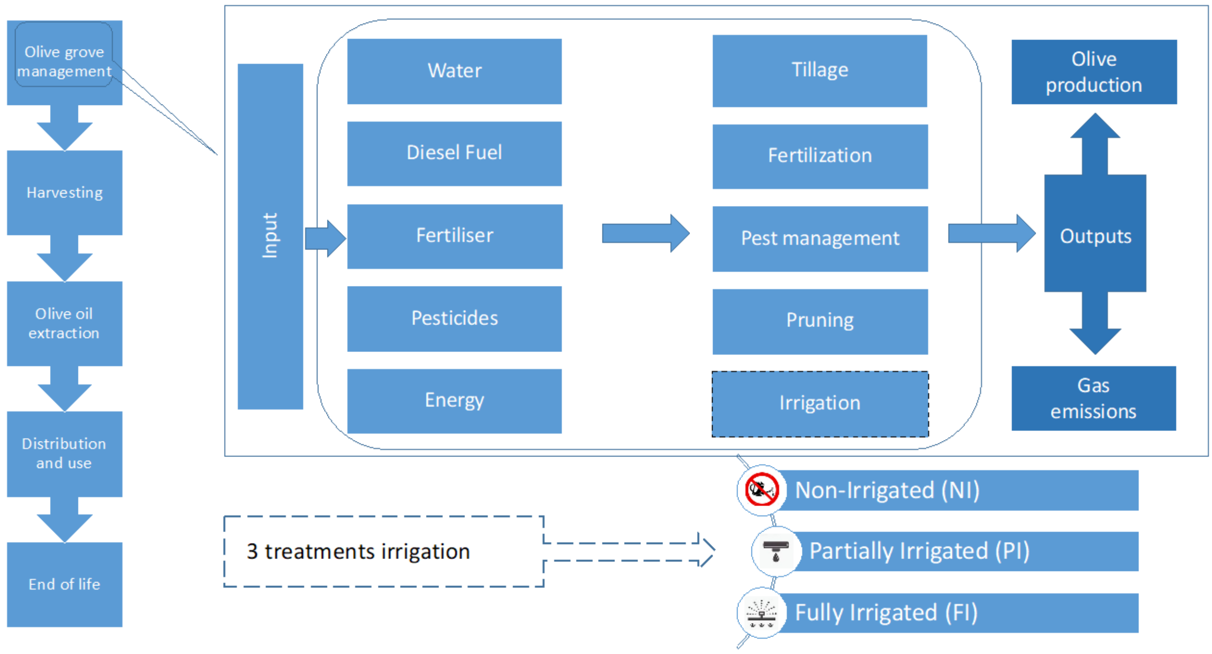

Figure 3. Production system analyses with details of the input per operation.

All of the foreground data shown in Table 3 were directly collected in the field, while the foreground data on emissions produced during cultivation operations were modelled according to Nemecek and Kägi [73]. The background process data were obtained from secondary sources and from the Ecoinvent 3.5 database. The three scenarios examined differ in their irrigation management techniques.

Table 3. Inventory of the LCA in the three treatments.

Description	Input/Output	Treatment FI	Treatment PI	Treatment NI
Tillage	- Diesel	89 L/ha	89 L/ha	89 L/ha
Fertilization	- Diesel	13 L/ha	13 L/ha	13 L/ha
	- Allegoria micro: MgO 2%; B 0.1% Fe 0.7% Mn 0.2% 0.1% 14%	1.5 kg/ha	1.5 kg/ha	1.5 kg/ha
	- Proalga Bio Organic Carbon 1.7%	2.5 kg/ha	2.5 kg/ha	2.5 kg/ha
	- Aios N30 N 30%	3.5 kg/ha	3.5 kg/ha	3.5 kg/ha
Pest management	- Diesel	13 L/ha	13 L/ha	13 L/ha
	- Fosmet spada200 17.70%	3.75 L/ha	3.75 L/ha	3.75 L/ha
Pruning	- Diesel	2 L/ha	2 L/ha	2 L/ha
Irrigation	- Power	117.7 kWh/ha	58.8 kWh/ha	-
	- Water	486 m^3/ha	243 m^3/ha	-

Source: Data collected through direct survey.

The Life Cycle Impact Assessment phase was carried out using the ReCiPe 2016 Midpoint method [74]. The supplementary assessment was carried out with the specific intention to deepen the impacts of different scenarios in terms of the water footprint. As such, the Water Stress Index method [75] was applied. The analysis was conducted using SimaPro 9 software [74].

4. Results

4.1. Economic Impact Analysis

The analysis of the data collected for the three scenarios shows the different production of olives for oil, which was 15.31 kg/plant for FI, 13.02 kg/plant for PI, and 10.72 kg/plant for NI. The three plots recorded different olive oil productions, as better specified in Table 4, with oil yields of 18.0% for FI, 18.4% for PI and 19.0% for NI.

Table 4. Production of the olives and olive oil production in the farm examined.

Indications	Production				Yield (%)
	Olives		Olive Oil		Olive Oil/Total Olives Production
	kg/ha	kg/Plant	kg/ha	kg/Plant	
NI	2977.43	10.72	565.71	2.04	19.0
PI	3615.45	13.02	668.86	2.41	18.4
FI	4253.47	15.31	765.63	2.76	18.0

Source: Data collected through direct survey. OO = Olive Oil.

The methodological approach is aimed at determining the economic results, the determination of revenues, the determination of variable costs and fixed production costs, and the analysis of the profits of the olive grove (partial budget). The results show a total production cost of 4368.39 euro/ha with a positive return of 435.36 euro/ha, and a total production cost of 3127.96 euro/ha with a positive return of 476.31 euro/ha in the treatments FI and NI, respectively. In the PI, the net value was positive at 188.95 euro/ha (Table 5). The total revenues derive from the sale of all of the olive oil production obtained for an average price of 6 euros/kg, to which must be added the CAP Direct Payment.

Table 5. Economic analysis.

Indications	Non-Irrigated (NI)		Partially Irrigated (PI)		Fully Irrigated (FI)	
	€/ha	€/kg OO	€/ha	€/kg OO	€/ha	€/kg OO
- Materials	334.91 *100.0*	0.59	374.95 *112.0*	0.56	414.99 *123.9*	0.54
- Labour and services	1909.71 *100.0*	3.68	2268.66 *118.8*	3.69	2527.05 *132.3*	3.60
- Depreciation and other costs	883.34 *100.0*	1.26	1390.60 *157.4*	1.78	1426.35 *161.5*	1.56
Total Cost	3127.96 *100.0*	5.53	4034.20 *129.0*	6.03	4368.39 *139.7*	**5.71**
- Revenues	3394.27 *100.0*	6.00	4013.15 *118.2*	6.00	4593.75 *135.3*	6.00
- CAP Direct payment	210.00 *100.0*	0.37	210.00 *100.0*	0.31	210.00 *100.0*	0.27
Total Output Value	3604.27 *100.0*	6.37	4223.15 *117.2*	6.31	4803.75 *133.3*	**6.27**
Net Value	476.31 *100.0*	0.84	188.95 *39.7*	0.28	435.36 *91.4*	**0.57**

Source: Data collected through direct survey. OO = Olive Oil.

However, the total cost does not consider economies of scale, being a pilot plant. Regarding the production of olive oil, the total cost amount was 6.03 euros/kg of oil in the PI treatment, 5.71 euros/kg of oil in the FI treatment, and 5.53 in the NI treatment.

Labour is the highest cost factor, accounting for almost 65% for both cost items (land and oil production). The charges attributable to "depreciation and other costs" represent the second class of total costs, with an average of just over 25%, while the material is the least expensive cost class, with an average of about 10% both for surfaces and the production of olive oil. The structural conditions of Italian olive growing do not allow us to easily leverage factors capable of reducing—in a short time and in a consistent manner—production costs and increasing productivity (t/ha) [4,43].

Regarding oil production, it must be remembered that this depends on various factors such as the different yields of cultivar oil and the technology of the milling systems adopted. Furthermore, the production results are strongly influenced by the average selling price of olive oil, which records large fluctuations, as well as by the volumes and times of sale and distribution channel, as previously reported in the current literature [4,30].

These aspects, just mentioned, influence company profitability, making it impossible to achieve economies of scale. These factors, together with the difficulties in concentrating supply, insufficient direct positioning on the market and constantly evolving demand, are directing olive growing towards ever less “entrepreneurial” forms, regardless of whether it is carried out as a main or complementary activity [4].

4.2. Life Cycle Assessment Analysis

The LCA methodology is an efficient method to assess the impact on the environment, used mainly in industry, but also in agriculture in recent years [31–33,68]. LCA is a collection and evaluation of the inputs, outputs and environmental impacts of a product system during its life cycle [58,59]. Table 6 shows the characterisation factors for each impact category analysed in order to facilitate their interpretation.

Table 6. Impact category units of measurement.

Measurement Units	Definition
kg CO_2 eq	kg carbon dioxide equivalent
kg CFC11 eq	kg freon-11 equivalent
kBq Co-60 eq	kBq cobalt-60 equivalent
kg NO_x eq	kg nitrogen oxide equivalent
kg PM2.5 eq	kg of particulate matter equivalent
kg SO_2 eq	kg sulfur dioxide equivalent
kg P eq	kg phosphorus equivalent
kg N eq	kg nitrogen equivalent
kg 1,4-DCB	kg 1.4-dichlorobenzene equivalent
m^2a crop eq	area time (crop) equivalent
kg Cu eq	kg copper equivalent
kg oil eq	kg oil equivalent
m^3 cubic	meters

The analysis of the results of the environmental impact assessment (Tables 7 and 8) shows that the NI scenario is less impactful in all of the impact categories considered. The contribution of irrigation to the impacts per hectare of the land area is evident when comparing the three treatments in Figure 4, where it emerges that this process, in addition to the water consumption category, represents one of the main hotspots for the categories of Global Warming, Ionizing Radiation, Freshwater Eutrophication, Marine Ecotoxicity, Human Carcinogenic Toxicity, Land Use, and Mineral and Fossil Resource Scarcity.

Table 7. Life Cycle Impact Assessment through the ReCiPe Midpoint method (per hectare).

Impact Category	Unit	NI	PI	FI
Global warming	kg CO_2 eq	2.19×10^{2}	2.9×10^{2}	3.62×10^{2}
Stratospheric ozone depletion	kg CFC11 eq	9.8×10^{-4}	1.01×10^{-3}	1.04×10^{-3}
Ionizing radiation	kBq Co-60 eq	1.93×10^{1}	2.51×10^{1}	3.09×10^{1}
Ozone formation, Human health	kg NO_x eq	5.20×10^{0}	5.39×10^{0}	5.58×10^{0}
Fine particulate matter formation	kg PM2.5 eq	1.45×10^{0}	1.57×10^{0}	1.69×10^{0}
Ozone formation, Terrestrial ecosystems	kg NO_x eq	5.28×10^{0}	5.48×10^{0}	5.68×10^{0}
Terrestrial acidification	kg SO_2 eq	3.08×10^{0}	3.36×10^{0}	3.64×10^{0}
Freshwater eutrophication	kg P eq	1.30×10^{-1}	1.55×10^{-1}	1.80×10^{-1}
Marine eutrophication	kg N eq	1.80×10^{-2}	2.00×10^{-2}	2.20×10^{-2}
Terrestrial ecotoxicity	kg 1,4-DCB	2.59×10^{4}	2.61×10^{4}	2.63×10^{4}
Freshwater ecotoxicity	kg 1,4-DCB	4.97×10^{1}	5.29×10^{1}	5.60×10^{1}
Marine ecotoxicity	kg 1,4-DCB	2.52×10^{1}	2.94×10^{1}	3.37×10^{1}
Human carcinogenic toxicity	kg 1,4-DCB	1.32×10^{1}	1.95×10^{1}	2.58×10^{1}
Human non-carcinogenic toxicity	kg 1,4-DCB	7.15×10^{2}	7.92×10^{2}	8.69×10^{2}
Land use	m^2a crop eq	1.60×10^{1}	2.26×10^{1}	2.91×10^{1}
Mineral resource scarcity	kg Cu eq	2.70×10^{0}	3.45×10^{0}	4.20×10^{0}
Fossil resource scarcity	kg oil eq	1.72×10^{2}	1.95×10^{2}	2.18×10^{2}
Water consumption	m^3	2.39×10^{0}	2.46×10^{2}	4.90×10^{2}

Table 8. Life Cycle Impact Assessment through the ReCiPe Midpoint method (per kg of olive production).

Impact Category	Unit	NI	PI	FI
Global warming	kg CO_2 eq	7.36×10^{-2}	2.33×10^{-1}	8.51×10^{-2}
Stratospheric ozone depletion	kg CFC11 eq	3.30×10^{-7}	8.11×10^{-7}	2.46×10^{-7}
Ionizing radiation	kBq Co-60 eq	6.47×10^{-3}	2.01×10^{-2}	7.27×10^{-3}
Ozone formation, Human health	kg NO_x eq	1.75×10^{-3}	4.32×10^{-3}	1.31×10^{-3}
Fine particulate matter formation	kg PM2.5 eq	4.87×10^{-4}	1.26×10^{-3}	3.97×10^{-4}
Ozone formation, Terrestrial ecosystems	kg NO_x eq	1.77×10^{-3}	4.39×10^{-3}	1.34×10^{-3}
Terrestrial acidification	kg SO_2 eq	1.03×10^{-3}	2.69×10^{-3}	8.56×10^{-4}
Freshwater eutrophication	kg P eq	4.35×10^{-5}	1.24×10^{-4}	4.24×10^{-5}
Marine eutrophication	kg N eq	6.06×10^{-6}	1.60×10^{-5}	5.16×10^{-6}
Terrestrial ecotoxicity	kg 1,4-DCB	8.70×10^{0}	2.09×10^{1}	6.19×10^{0}
Freshwater ecotoxicity	kg 1,4-DCB	1.67×10^{-2}	4.23×10^{-2}	1.32×10^{-2}
Marine ecotoxicity	kg 1,4-DCB	8.47×10^{-3}	2.36×10^{-2}	7.91×10^{-3}
Human carcinogenic toxicity	kg 1,4-DCB	4.44×10^{-3}	1.56×10^{-2}	6.06×10^{-3}
Human non-carcinogenic toxicity	kg 1,4-DCB	2.40×10^{-1}	6.34×10^{-1}	2.04×10^{-1}
Land use	m^2a crop eq	5.38×10^{-3}	1.80×10^{-2}	6.84×10^{-3}
Mineral resource scarcity	kg Cu eq	9.07×10^{-4}	2.76×10^{-3}	9.88×10^{-4}
Fossil resource scarcity	kg oil eq	5.77×10^{-2}	1.56×10^{-1}	5.12×10^{-2}
Water consumption	m^3	8.02×10^{-4}	1.97×10^{-1}	1.15×10^{-1}

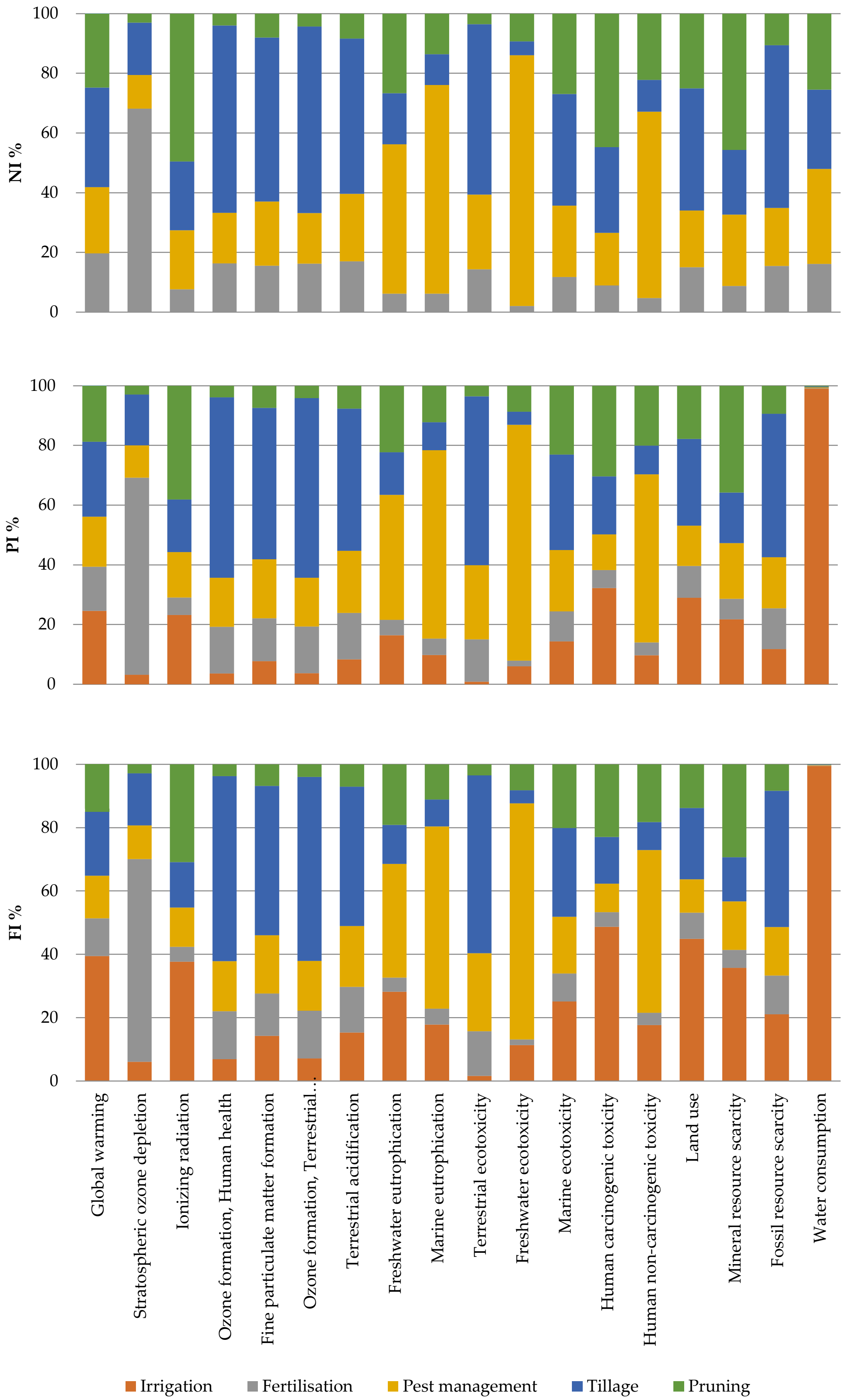

Figure 4. Environmental impacts per treatment per agronomic operation (%).

These results derive from the high energy use required for irrigation, in addition to the impact generated by the construction and use of the irrigation system. As the analysis of the economic results also shows, the olive tree is a plant that adapts well to temperate/arid climates, thus becoming a good source of agricultural income in all those areas where water is a limiting factor. In particular, the olive tree grows in the same environments as vines and citrus plants, probably representing the most appropriate option if water becomes a scarce resource, especially considering the effects of climate change.

In this regard, the impact of the three scenarios in terms of water footprint was also investigated using the Water Scarcity Index approach [75]. This approach assesses water consumption based on withdrawal to availability (WTA) [41]. Under this assessment, "Water, unspecified natural origin, IT" was used as the irrigation source, such that impacts are determined based on the specific characterization factor (Table 9).

Table 9. Water footprint measured using the water scarcity index (WSI) approach.

Impact Category	Unit	NI	PI	FI
WSI (per hectare)	m3	1.08×10^{0}	6.77×10^{1}	1.34×10^{2}
WSI (per kg)	m3	3.63×10^{-4}	5.42×10^{-2}	3.16×10^{-2}

The water footprint analysis shows a considerable impact of the practice of irrigation in the FI treatment, while the other operations are not relevant compared to the irrigation practice. In the NI treatment, on the other hand, pest management plays a more impactful role, equal to 35%, followed by fertilization with 30% of the impact, while pruning and fertilization are not relevant (Figure 5).

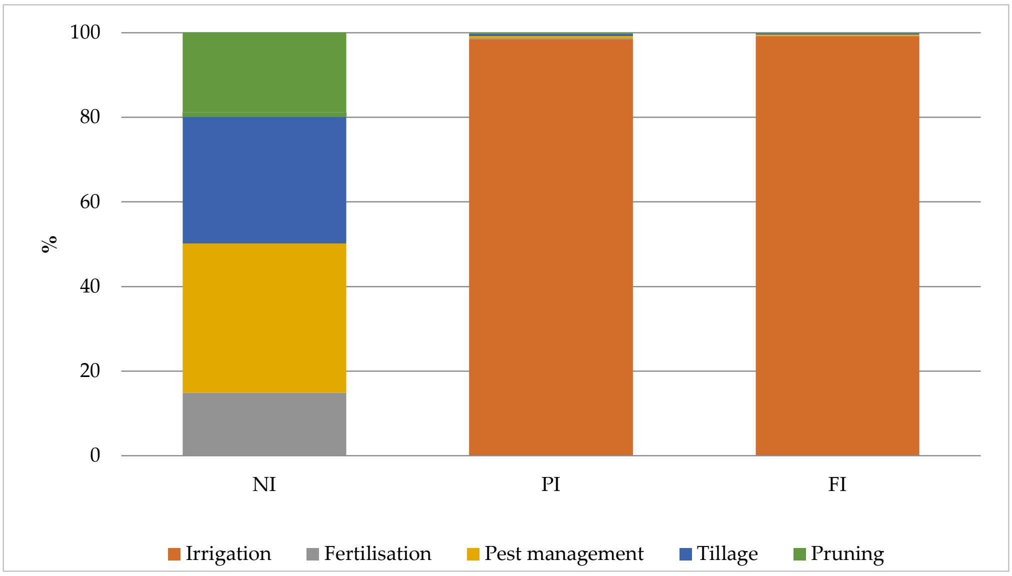

Figure 5. Water footprint per agronomic operation (%).

5. Discussion

In this study, an environmental and economic sustainability assessment was performed. The analysis of the economic and environmental sustainability carried out in this study has made it possible to carry out assessments that can suggest how the olive sector in Mediterranean regions can address important environmental and economic issues. In this study, an environmental and economic assessment of three olive systems was performed: fully irrigated (FI), partially irrigated (PI) and non-irrigated (NI).

The irrigation of the olive tree for oil production is currently a very common practice to increase production yields [76], especially in areas of the world where this crop is widespread, highly intensive, and represents the most common land utilization. However, this practice is also at odds with the origins of olive cultivation, which has historically been widespread in water-poor areas [77] due to the olive tree's extraordinary resistance to long periods of drought.

The analyses of our results showed the best performance of the NI treatment, which is considered more sustainable from an environmental and economic point of view compared to the other two irrigation treatments. In this scenario, in fact, on the one hand, there is a lower total output value compared to the other scenarios, but on the other hand, it is offset by lower initial investment costs that the company has to face. Interestingly, the net value is better for the non-irrigated treatment. The second-order scenario for sustainability is represented by the fully irrigated treatment (FI). Although the total cost is higher in the FI scenario than in the IP, the economic result is better in the FI treatment as it has a higher net value compared to the other scenario. Finally, the partially irrigated treatment (PI) has the lowest net value compared to the other scenarios. It is possible to explain this result due to the higher production cost of the irrigation system used in this scenario, which is partially exploited due to the irrigation deficit imposed on the crop, does not justify the cost of the initial investment in this scenario, and cannot therefore be considered economically sustainable.

The results obtained are in line with other studies in the literature on economic evaluation and profitability in irrigated olive cultivation, and support the recommendation of other authors who suggest the use of deficient irrigation in the olive tree [78]. When the water resource is scarce or expensive, the deficient irrigation technique improves the farmer's net income compared to full irrigation [79–82].

Some authors have suggested that a deficit irrigation strategy is the most financially profitable when both land and water are limited [83], confirming that the deficit irrigation technique represents a strategy that maximizes the value of limited water input rather than the conventional microeconomic behaviour of maximizing the return to the land [84].

The question must therefore be asked whether and how sustainable the practice of irrigating olive trees is from both an environmental and an economic point of view. Given the great relevance of this cultivation in the Mediterranean basin, it is fundamental to understand the impact that this agronomic practice has at a "spatial" level. However, a lower impact per hectare of a process does not make a product more sustainable, because agricultural productivity is strongly influenced by the cultivation technique adopted. Therefore, the determination of the environmental impacts in terms of the product obtained has proved to be a fundamental step in understanding the actual impact that irrigation can have on the product.

From the environmental point of view, the LCA carried out using the ReCiPe method allowed us to define the ecoprofile of both the different olive grove management techniques (area based FU) and the olives produced according to these management techniques (mass based FU). ReCiPe was widely used as an impact assessment method in olive production assessment [33], and is an update of the original 2008 version. As for the first version, it is present both as a midpoint and as an endpoint method. In the present study, the midpoint version of the ReCiPe method was used, which is problem-oriented and not damage-oriented, as in the case of the ReCiPe endpoint method. In this regard, the ReCiPe 2016 midpoint considers 18 impact categories that cover "Global warming", "Stratospheric ozone depletion", "Ionizing radiation", "Ozone formation, Human health", "Fine particulate matter formation", "Ozone formation, Terrestrial ecosystems", "Terrestrial acidification", "Freshwater eutrophication", "Marine eutrophication", "Terrestrial ecotoxicity", "Freshwater ecotoxicity", "Marine ecotoxicity", "Human carcinogenic toxicity" "Human non-carcinogenic toxicity", "Land use", "Mineral resource scarcity", "Fossil resource scarcity" and "Water consumption". Tillage represents the most impacting operation for "Ozone formation, Human health", "Fine particulate matter formation", "Ozone formation, Terrestrial ecosystems" and "Terrestrial acidification", and its impact is largely attributable to the combustion of diesel. In this sense, the results can be compared with

Bernardi et al. [38,63], who, analysing only the operation of mechanical harvesting, showed that in crop operations that require the use of agricultural machinery, the greatest impact is generated by the combustion of fuel.

The production of this input and the emissions resulting from its use also affect other operations such as the distribution of fertilisers and pesticides, and mechanical pruning. This is particularly evident when analysing the global warming impact category, where impacts are distributed evenly across operations. In scenarios with irrigation, this operation represents the main hotspot because of the energy consumption related to it. It should be noted that the scenarios analysed are characterised by low fertiliser and input use in general. In open-field cultivation, urea is often used as a fertiliser, and this would have an impact on the global warming category [85].

This aspect also concerns the categories "Terrestrial ecotoxicity", "Freshwater ecotoxicity", "Marine ecotoxicity", "Human carcinogenic toxicity" and "Human non-carcinogenic toxicity", which normally have fertilisation as the main hotspot, followed by plant protection treatments [86], while in the present study fertilisation plays a secondary role due to the very low quantities of fertilisers used. Plant protection treatments become the main hotspot, followed by irrigation in the scenarios where this technique is adopted. Fuel consumption also becomes the main cause of impact in resource use categories where impacts are distributed evenly across all farming operations. Obviously, irrigation accounts for almost 100% of the impacts related to water depletion in the irrigated scenarios.

Concerning the impact of irrigation in terms of water consumption, the application of the Water Scarcity Index suggests a contribution of the different crop operations, similar to what has been seen for the water depletion indicator of the ReCiPe method; however, the results are very different in quantitative terms because, as already mentioned, WSI considers water consumption based on WTA, and therefore the impact also depends on the water availability of the area where the impact occurs.

Evidently, by analysing the impacts per hectare, the NI scenario obtains the best environmental results from all points of view, followed by the PI scenario, and finally by the FI scenario, which is found to be the most impactful using both the ReCiPe method and even more so using the WSI method. The result is simple to explain and seems obvious: comparing the inventory data, the only process that differentiates the scenarios is irrigation, so the more you use this technique the higher the impact per hectare. However, this result becomes fundamentally important when combined with evaluations of impacts per unit of product. In fact, through the joint analysis of the results per unit of area and unit of product, it is possible to identify the best compromise between increased productivity, which translates into a lower impact on the product, and the impact on the territory.

The hotspot analysis is not changed substantially by changing the functional unit, because in this specific case it is simply a scaling operation, as no other products and by-products are present within the system boundaries.

From the analysis of the results per kg of product, the best solution is represented by the PI scenario, which combines good productivity with an average water consumption between the two extreme scenarios, NI and FI. We should also consider the quality of the oils obtained, as it is well established that the use of irrigation has an impact on the final quality of oils [87], but this is an issue outside the objectives of this study.

Considering that in Italy alone 164,568 hectares [49] are currently used for the cultivation of olive trees, and in the Mediterranean basin this totals over 10 million [88], the impact that the practice of irrigation has on the consumption of water resources is clear, especially if we consider that in most areas where olive trees are grown the availability of water is very low, such that the water footprint—measured as the water stress index—would have significantly higher results. This indicator measures the subtraction of water concerning the availability of water in the country where consumption occurs. Italy is a country rich in water; therefore, the impact in terms of WSI, although significant, is significantly lower than what would occur under the same conditions in other countries such as Algeria or Syria.

The technique of irrigation has already been analysed through the LCA method in some works that evaluate mainly from the point of view of the comparison the impacts of different irrigation techniques [86,89–91]. Pradeleix et al. [92] studied the issue of irrigation in arid areas such as Tunisia, while Nunez and Finkbeiner [93] developed a "regionalized" analysis model to assess the implications of salinization caused by irrigation.

To the best of our current knowledge, no study has been carried out with a focus on irrigation practice in olive cultivation, even though this crop is the most emblematic in the Mediterranean basin and irrigation represents one of the major innovations in olive cultivation, especially in combination with new intensive and super-intensive planting systems. Therefore, in our opinion, it is crucial to identify the technique that represents the ideal solution both from the production point of view and from the ecosystem point of view, especially because of the global push towards sustainable development models promoted by various international programs such as the European Green Deal [94].

6. Conclusions

The environmental and economic sustainability of agricultural production is one of the most interesting areas of discussion in the current academic debate. Olive oil production is an important agro-industrial sector in Mediterranean regions, which nowadays have to face environmental and economic issues.

In this study, we performed an environmental and economic assessment of three olive-growing systems with different irrigation management techniques. The analysis integrated LCA and economic indicators. The environmental analysis carried out through LCA showed the better performance of the non-irrigated system for all of the impact categories, due to the non-use of water resource and lower energy inputs. Furthermore, the water footprint—measured using the water scarcity index (WSI) approach—showed a lower impact in the NI treatment both per hectare and per kg of product. There were a few differences between the FI and PI treatments in terms of environmental impact. Furthermore, from an economic point of view, the NI treatment could be considered more convenient than both irrigated treatments; in fact, the lower total output value is counterbalanced by the lower initial investment costs the company has to face.

The total result is that the Net Value is better for the non-irrigated treatment, followed by the fully irrigated treatment, while the net value is very low in the partially irrigated treatment. This result is mainly driven by the higher production cost of the irrigation system, which does not justify the initial investment cost in the case of partial irrigation. Future studies could investigate the economic and environmental sustainability of olive production by accounting for precision agriculture techniques, and by considering the fertigation system.

There are some limitations that need to be addressed in future work. The major limitation of the study was the investigation of a single case study. However, this work used a double methodology, which made it more robust and innovative. This methodology can be replicated in wider areas, as well as in different agricultural sectors. To the best of our current knowledge, no literature studies have focused on the practice of irrigation in olive growing, despite irrigation being one of the major innovations in olive growing. The complexity of the phenomenon and the need to conduct further investigations provide researchers with ample scope for new research.

Author Contributions: Conceptualization, G.M., G.F. and G.C.; methodology, G.M., G.F. and G.C.; software, G.M., G.F. and G.C.; validation, M.D.; formal analysis, G.M., G.F., G.C. and C.B.; investigation, M.R. and M.D.; resources, M.D., G.C. and C.B.; data curation, G.M. and G.C.; writing—original draft preparation, G.M., G.F., G.C. and M.R.; writing—review and editing, C.B. and M.D.; visualization, G.C.; supervision, M.D.; project administration, M.D. and G.C.; funding acquisition, G.C., C.B. and M.D. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the project "Gestione sostenibile di impianti di ulivo attraverso tecniche di irrigazione deficitaria e uso di acque reflue—H_2Olivo" (Grant Number: E34I18001650001)—Project Coordinator: Prof. Salvatore Barbagallo. The granting of contributions for the implementation of research projects in the field of olive oil—oil sector, D.M. n. 30311 of 31 October 2018 of the Department of European and International Policies and Rural Development; and by the project MODESTI, by Starting Grant "Piano di incentivi per la ricerca di Ateneo 2020/2022 (Pia.ce.ri.)", University of Catania (5A722192150); by the project PIAno di inCEntivi per la Ricerca di Ateneo (PIACERI) UNICT 2020/22 line 2, University of Catania (5A722192154).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Vossen, P. Olive oil: History, production, and characteristics of the world's classic oils. *HortScience* **2007**, *42*, 1093–1100. [CrossRef]
2. Perrino, E.V.; Calabrese, G.; Ladisa, G.; Viti, R.; Mimiola, G. First data of vascular flora and floristic biodiversity on secular olive groves in Apulia (Primi dati sulla biodiversità della flora vascolare di oliveti secolari in Puglia). *Inf. Bot. Ital.* **2011**, *43*, 39–64.
3. Perrino, E.V.; Wagensommer, R.P.; Medagli, P. The genus Aegilops (Poaceae) in Italy: Taxonomy, geographical distribution, ecology, vulnerability and conservation. *Syst. Biodivers.* **2014**, *12*, 331–349. [CrossRef]
4. Di Vita, G.; Chinnici, G.; D'Amico, M. Sustainability of olive oil production in sicilian marginal agricultural areas. *Qual.-Access Success* **2015**, *16*, 118–125.
5. Fraga, H.; Moriondo, M.; Leolini, L.; Santos, J.A. Mediterranean Olive Orchards under Climate Change: A Review of Future Impacts and Adaptation Strategies. *Agronomy* **2021**, *11*, 56.
6. Palese, A.M.; Pergola, M.; Favia, M.; Xiloyannis, C.; Celan, G. A sustainable model for the management of olive orchards located in semi-arid marginal areas: Some remarks and indications for policy makers. *Environ. Sci. Policy* **2013**, *27*, 81–90. [CrossRef]
7. Solomou, A.D.; Sfougaris, A. Contribution of Agro-Environmental Factors to Yield and Plant Diversity of Olive Grove Ecosystems (*Olea europaea* L.) in the Mediterranean Landscape. *Agronomy* **2021**, *11*, 161. [CrossRef]
8. Berbel, J.; Posadillo, A. Review and analysis of alternatives for the valorisation of agro-industrial olive oil by-products. *Sustainability* **2018**, *10*, 237. [CrossRef]
9. Klisović, D.; Novoselić, A.; Režek Jambrak, A.; Brkić Bubola, K. The utilisation solutions of olive mill by-products in the terms of sustainable olive oil production: A review. *Int. J. Food Sci. Technol.* **2021**, 1–5. [CrossRef]
10. Raimondo, M.; Caracciolo, F.; Cembalo, L.; Chinnici, G.; Pappalardo, G.; D'Amico, M. Moving towards circular bioeconomy: Managing olive cake supply chain through contracts. *Sustain. Prod. Consum.* **2021**, *28*, 180–191. [CrossRef]
11. Hamam, M.; Chinnici, G.; Di Vita, G.; Pappalardo, G.; Pecorino, B.; Maesano, G.; D'Amico, M. Circular economy models in agro-food systems: A review. *Sustainability* **2021**, *13*, 3453. [CrossRef]
12. Borrello, M.; Pascucci, S.; Cembalo, L. Three propositions to unify circular economy research: A review. *Sustainability* **2020**, *12*, 4069. [CrossRef]
13. Zarbà, C.; Chinnici, G.; La Via, G.; Bracco, S.; Pecorino, B.; D'Amico, M. Regulatory Elements on the Circular Economy: Driving into the Agri-Food System. *Sustainability* **2021**, *13*, 8350. [CrossRef]
14. Salomone, R.; Ioppolo, G. Environmental impacts of olive oil production: A Life Cycle Assessment case study in the province of Messina (Sicily). *J. Clean. Prod.* **2012**, *28*, 88–100. [CrossRef]
15. Mafrica, R.; Piscopo, A.; De Bruno, A.; Poiana, M. Effects of climate on fruit growth and development on olive oil quality in cultivar carolea. *Agriculture* **2021**, *11*, 147. [CrossRef]
16. Ponti, L.; Gutierrez, A.P.; Ruti, P.M.; Dell'Aquila, A. Fine-scale ecological and economic assessment of climate change on olive in the Mediterranean Basin reveals winners and losers. *Proc. Natl. Acad. Sci. USA* **2014**, *111*, 5598–5603. [CrossRef]
17. Brilli, L.; Lugato, E.; Moriondo, M.; Gioli, B.; Toscano, P.; Zaldei, A.; Leolini, L.; Cantini, C.; Caruso, G.; Gucci, R.; et al. Carbon sequestration capacity and productivity responses of Mediterranean olive groves under future climates and management options. *Mitig. Adapt. Strateg. Glob. Chang.* **2019**, *24*, 467–491. [CrossRef]
18. Moriondo, M.; Trombi, G.; Ferrise, R.; Brandani, G.; Dibari, C.; Ammann, C.M.; Mariotti Lippi, M.; Bindi, M. Olive trees as bio-indicators of climate evolution in the Mediterranean Basin. *Glob. Ecol. Biogeogr.* **2013**, *22*, 818–833. [CrossRef]
19. MiPAAF. *La Discussione sul Futuro Della Pac: Quadro Comunitario e Interessi Dell'italia*; Ottobre: Roma, Italy, 2010.
20. Biel, C.; de Herralde, F.; Save, R.; Evans, R.Y. Effects of CO_2 Atmospheric Fertilization on Greenhouse Production of Olive Trees (*Olea europaea* L. 'Arbequina'). *Eur. J. Hortic. Sci.* **2008**, *73*, 227–230.
21. Arampatzis, G.; Hatzigiannakis, E.; Pisinaras, V.; Kourgialas, N.; Psarras, G.; Kinigopou-lou, V.; Panagopoulos, A.; Koubouris, G. Soil water content and olive tree yield responses to soil management, irrigation, and precipitation in a hilly Mediterranean area. *J. Water Clim. Chang.* **2018**, *9*, 672–678. [CrossRef]
22. Tognetti, R.; Sebastiani, L.; Vitagliano, C.; Raschi, A.; Minnocci, A. Responses of two olive tree (*Olea europaea* L.) cultivars to elevated CO2 concentration in the field. *Photosynthetica* **2001**, *39*, 403–410. [CrossRef]

23. Lorite, I.J.; Gabaldon-Leal, C.; Ruiz-Ramos, M.; Belaj, A.; de la Rosa, R.; Leon, L.; Santos, C. Evaluation of olive response and adaptation strategies to climate change under semi-arid conditions. *Agric. Water Manag.* **2018**, *204*, 247–261. [CrossRef]
24. Moriondo, M.; Ferrise, R.; Trombi, G.; Brilli, L.; Dibari, C.; Bindi, M. Modelling olive trees and grapevines in a changing climate. *Environ. Model. Softw.* **2015**, *72*, 387–401. [CrossRef]
25. MiPAAF. Piano di Settore Olivicolo Oleario 2016. Accordo in Sede di Conferenza Stato-Regioni 24 marzo 2016, Repertorio atti 42/CSR, Ministero delle Politiche Agricole Alimentari e Forestali, Roma, Italy, 2016. Available online: https://www.politicheagricole.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/1984 (accessed on 25 March 2021).
26. Coppola, A.; Ianuario, S.; Chinnici, G.; Di Vita, G.; Pappalardo, G.; D'Amico, M. Endogenous and exogenous determinants of agricultural productivity: What is the most relevant for the competitiveness of the Italian agricultural systems? *Agris On-line Pap. Econ. Inform.* **2018**, *10*, 33–47. [CrossRef]
27. Perrino, E.V.; Ladisa, G.; Calabrese, G. Flora and plant genetic resources of ancient olive groves of Apulia (southern Italy). *Genet. Resour. Crop Evol.* **2014**, *61*, 23–53. [CrossRef]
28. Sands, G.R.; Podmore, T.H. A generalized environmental sustainability index for agricultural systems. *Agric. Ecosyst. Environ.* **2000**, *79*, 29–41. [CrossRef]
29. Pergola, M.; D'Amico, M.; Celano, G.; Palese, A.M.; Scuderi, A.; Di Vita, G.; Pappalardo, G.; Inglese, P. Sustainability evaluation of sicily's lemon and orange production: An energy, economic and environmental analysis. *J. Environ. Manag.* **2013**, *128*, 674–682. [CrossRef] [PubMed]
30. Pergola, M.; Favia, M.; Palese, A.M.; Perretti, B.; Xiloyannis, C.; Celano, G. Alternative management for olive orchards grown in semi-arid environments: An energy, economic and environmental analysis. *Sci. Hortic.* **2013**, *162*, 380–386. [CrossRef]
31. De Luca, A.I.; Iofrida, N.; Falcone, G.; Stillitano, T.; Gulisano, G. Olive growing scenarios of soil management: Integrating environmental, economic and social indicators from a life-cycle perspective. In *VIII International Olive Symposium 1199*; ISHS: Leuven, Belgium, 2016; pp. 209–214. [CrossRef]
32. De Luca, A.I.; Stillitano, T.; Falcone, G.; Squeo, G.; Caponio, F.; Strano, A.; Gulisano, G. Economic and environmental assessment of extra virgin olive oil processing innovations. *Chem. Eng. Trans.* **2018**, *67*, 133–138. [CrossRef]
33. De Luca, A.I.; Falcone, G.; Stillitano, T.; Iofrida, N.; Strano, A.; Gulisano, G. Evaluation of sustainable innovations in olive growing systems: A Life Cycle Sustainability Assessment case study in southern Italy. *J. Clean. Prod.* **2018**, *171*, 1187–1202. [CrossRef]
34. Di Vita, G.; Stillitano, T.; Falcone, G.; De Luca, A.I.; D'Amico, M.; Strano, A.; Gulisano, G. Can sustainability match quality citrus fruit growing production? An energy and economic balance of agricultural management models for 'PGI Clementine of Calabria'. *Agron. Res.* **2018**, *16*, 1986–2004.
35. Van der Werf, H.M.; Petit, J. Evaluation of the environmental impact of agriculture at the farm level: A comparison and analysis of 12 indicator-based methods. *Agric. Ecosyst. Environ.* **2002**, *93*, 131–145. [CrossRef]
36. Busset, G.; Belaud, J.P.; Clarens, F.; Espi, J.J.; Montréjaud-Vignoles, M.; Sablayrolles, C. Life Cycle Assessment of olive oil production in France. In Proceedings of the 4th International Conference on Engineering for Waste and Biomass Valorisation, Porto, Portugal, 10–13 September 2012; pp. 987–992.
37. De Gennaro, B.; Notarnicola, B.; Roselli, L.; Tassielli, G. Innovative olive-growing models: An environmental and economic assessment. *J. Clean. Prod.* **2012**, *28*, 70–80. [CrossRef]
38. Bernardi, B.; Falcone, G.; Stillitano, T.; Benalia, S.; Strano, A.; Bacenetti, J.; De Luca, A.I. Harvesting system sustainability in Mediterranean olive cultivation. *Sci. Total Environ.* **2018**, *625*, 1446–1458. [CrossRef]
39. Chinnici, G.; Pecorino, B.; Rizzo, M.; Rapisarda, P. Evaluation of the Performances of Wine Producers in Sicily. *Qual.-Access Success* **2013**, *14*, 108–113.
40. Di Vita, G.; Bellia, C.; Pappalardo, G.; D'Amico, M. The Role of Innovation and Organization in Small Size Wineries: The Case of Malvasia delle Lipari PDO Wine. *Qual.-Access Success* **2013**, *14*, 107–112.
41. Falcone, G.; Strano, A.; Stillitano, T.; De Luca, A.I.; Iofrida, N.; Gulisano, G. Integrated sustainability appraisal of wine-growing management systems through LCA and LCC methodologies. *Chem. Eng. Trans.* **2015**, *44*, 223–228. [CrossRef]
42. Falcone, G.; Stillitano, T.; De Luca, A.I.; Di Vita, G.; Iofrida, N.; Strano, A.; Gulisano, G.; Pecorino, B.; D'Amico, M. Energetic and economic analyses for agricultural management models: The Calabria PGI clementine case study. *Energies* **2020**, *13*, 1289. [CrossRef]
43. Testa, R.; Di Trapani, A.M.; Sgroi, F.; Tudisca, S. Economic analysis of process innovations in the management of olive farms. *Am. J. Appl. Sci.* **2014**, *11*, 1486–1491. [CrossRef]
44. Raimondo, M.; Caracciolo, F.; Nazzaro, C.; Marotta, G. Organic Farming Increases the Technical Efficiency of Olive Farms in Italy. *Agriculture* **2021**, *11*, 209. [CrossRef]
45. Rebitzer, G.; Ekvall, T.; Frischknecht, R.; Hunkeler, D.; Norris, G.; Rydberg, T.; Schmidt, W.-P.; Suh, S.; Weidema, B.P.; Pennington, D.W. Life cycle assessment: Part 1: Framework, goal and scope definition, inventory analysis, and applications. *Environ. Int.* **2004**, *30*, 701–720. [CrossRef]
46. Guinée, J.B.; Cucurachi, S.; Henriksson, P.J.; Heijungs, R. Digesting the alphabet soup of LCA. *Int. J. Life Cycle Assess.* **2018**, *23*, 1507–1511. [CrossRef]
47. Falcone, G.; Stillitano, T.; Montemurro, F.; De Luca, A.I.; Gulisano, G.; Strano, A. Environmental and economic assessment of sustainability in Mediterranean wheat production. *Agron. Res.* **2019**, *17*, 60–76. [CrossRef]

48. Di Vita, G.; D'Amico, M.; Bracco, S. Economic performances of smallholders PDO viticulture in eastern Sicily. *Qual.-Access Success* **2013**, *14*, 99–105.
49. ISTAT. Data Warehouse, Rome. Available online: http://dati.istat.it (accessed on 25 March 2021).
50. Pardo, G.; Aibar, J.; Cavero, J.; Zaragoza, C. Economic evaluation of cereal cropping systems under semiarid conditions: Minimum input, organic and conventional. *Sci. Agric.* **2009**, *66*, 615–621. [CrossRef]
51. Sartori, L.; Basso, B.; Bertocco, M.; Oliviero, G. Energy use and economic evaluation of a three year crop rotation for conservation and organic farming in NE Italy. *Biosyst. Eng.* **2005**, *91*, 245–256. [CrossRef]
52. Di Vita, G.; Chinnici, G.; Pappalardo, G.; D'Amico, M.; Bracco, S. Standard output versus standard gross margin, a new paradigm in the EU farm economic typology: What are the implications for wine-grape growers? *J. Wine Res.* **2014**, *25*, 229–242. [CrossRef]
53. Bellia, C.; Adernò, C.; Allegra, V. Economic Sustainability of a Niche Supply Chain: The Case of Maletto Strawberry. *Qual.-Access Success* **2015**, *16*, 47–56.
54. Chinnici, G.; Pecorino, B.; Scuderi, A. Environmental and economic performance of organic citrus growing. *Qual.-Access Success* **2013**, *14*, 106–112.
55. Chinnici, G.; Pappalardo, G.; Pecorino, B. Economic evaluation of innovative solutions for food safety in cereal sector in Sicily. *Qual.-Access Success* **2014**, *15*, 41–47.
56. Iotti, M.; Bonazzi, G. Profitability and financial sustainability analysis in Italian aquaculture firms by application of economic and financial margins. *Am. J. Agric. Biol. Sci.* **2015**, *10*, 18–34. [CrossRef]
57. Espadas-Aldana, G.; Vialle, C.; Belaud, J.P.; Vaca-Garcia, C.; Sablayrolles, C. Analysis and trends for Life Cycle Assessment of olive oil production. *Sustain. Prod. Consum.* **2019**, *19*, 216–230. [CrossRef]
58. ISO. *ISO 14040:2006 Environmental Management—Life Cycle Assessment—Principles and Framework*; International Organization for Standardization ISO: Geneva, Switzerland, 2006.
59. ISO. *ISO 14044:2006 Environmental Management—Life Cycle Assessment—Requirements and Guidelines*; International Organization for Standardization ISO: Geneva, Switzerland, 2006.
60. Society of Environmental Toxicology and Chemistry [SETAC]. *A Technical Framework for [Product] Life-Cycle Assessments*; SETAC: Smuggler's Notch, VT, USA, 1991.
61. Nicoletti, G.M.; Notarnicola, B. Life Cycle Impact Assessment: A Case Study. Life Cycle Impact Assessment: A Case Study. *J. Commod. Sci.* **1998**, *37*, 127–147.
62. Salomone, R.; Cappelletti, G.M.; Ioppolo, G.; Mistretta, M.; Nicoletti, G.; Notarnicola, B.; Olivieri, G.; Pattara, C.; Russo, C.; Scimia, E. Italian experiences in life cycle assessment of olive oil: A survey and critical review. In Proceedings of theVII International Conference on Life Cycle Assessment in the Agri-Food Sector, Bari, Italy, 22–24 September 2010; Volume 1.
63. Bernardi, B.; Falcone, G.; Stillitano, T.; Benalia, S.; Bacenetti, J.; De Luca, A.I. Harvesting system sustainability in mediterranean olive cultivation: Other principal cultivar. *Sci. Total Environ.* **2011**, *766*, 142508. [CrossRef]
64. Tziolas, E.; Bournaris, T. Economic and Environmental Assessment of Agro-Energy Districts in Northern Greece: A Life Cycle Assessment Approach. *BioEnergy Res.* **2019**, *12*, 1145–1162. [CrossRef]
65. Stillitano, T.; Falcone, G.; De Luca, A.I.; Piga, A.; Conte, P.; Strano, A.; Gulisano, G. Innovative technologies in evo oil extraction: An economic and environmental impact analysis. *Riv. Ital. Delle Sostanze Grasse* **2019**, *96*, 223–230.
66. Pattara, C.; Salomone, R.; Cichelli, A. Carbon footprint of extra virgin olive oil: A comparative and driver analysis of different production processes in Centre Italy. *J. Clean. Prod.* **2016**, *127*, 533–547. [CrossRef]
67. Tsarouhas, P.; Achillas, C.; Aidonis, D.; Folinas, D.; Maslis, V. Life Cycle Assessment of olive oil production in Greece. *J. Clean. Prod.* **2015**, *93*, 75–83. [CrossRef]
68. De Luca, A.I.; Molari, G.; Seddaiu, G.; Toscano, A.; Bombino, G.; Ledda, L.; Milani, M.; Vittuari, M. Multidisciplinary and innovative methodologies for sustainable management in agricultural systems. *Environ. Eng. Manag. J.* **2015**, *14*, 1571–1581. [CrossRef]
69. Mohamad, R.S.; Verrastro, V.; Cardone, G.; Bteich, M.R.; Favia, M.; Moretti, M.; Roma, R. Optimization of organic and conventional olive agricultural practices from a Life Cycle Assessment and Life Cycle Costing perspectives. *J. Clean. Prod.* **2014**, *70*, 78–89. [CrossRef]
70. Rajaeifar, M.A.; Akram, A.; Ghobadian, B.; Rafiee, S.; Heidari, M.D. Energy-economic life cycle assessment (LCA) and greenhouse gas emissions analysis of olive oil production in Iran. *Energy* **2014**, *66*, 139–149. [CrossRef]
71. Notarnicola, B.; Tassielli, G.; Nicoletti, G.M. Environmental and economical analysis of the organic and conventional extra-virgin olive oil. *New Medit* **2004**, *3*, 28–34.
72. Niaounakis, M.; Halvadakis, C.P. *Olive Processing Waste Management: Literature Review and Patent Survey*, 2nd ed.; Pergamon: Rijswijk, The Netherlands, 2006; Volume 5.
73. Nemecek, T.; Kägi, T.; Blaser, S. *Life Cycle Inventories of Agricultural Production Systems*; Final Report Ecoinvent v2.0; Zürich: Dübendorf, Switzerland, 2007; No 15.
74. Goedkoop, M.; Heijungs, R.; Huijbregts, M.; De Schryver, A.; Struijs, J.; Van Zelm, R. ReCiPe 2008: A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. *Search PubMed* **2009**, *1*, 1–126.
75. Pfister, S.; Koehler, A.; Hellweg, S. Assessing the Environmental Impacts of Freshwater Consumption in LCA. *Environ. Sci. Technol.* **2009**, *43*, 4098–4104. [CrossRef]

76. Romero-Trigueros, C.; Vivaldi, G.A.; Nicolás, E.N.; Paduano, A.; Salcedo, F.P.; Camposeo, S. Ripening Indices, Olive Yield and Oil Quality in Response to Irrigation With Saline Reclaimed Water and Deficit Strategies. *Front. Plant Sci.* **2019**, *10*, 1243. [CrossRef] [PubMed]
77. Langgut, D.; Cheddadi, R.; Carrión, J.S.; Cavanagh, M.; Colombaroli, D.; Eastwood, W.J.; Greenberg, R.; Litt, T.; Mercuri, A.M.; Roberts, C.N.; et al. The origin and spread of olive cultivation in the Mediterranean Basin: The fossil pollen evidence. *Holocene* **2019**, *29*, 902–922. [CrossRef]
78. Mesa-Jurado, M.A.; Berbel, J.; Orgaz Rosua, F. Estimating marginal value of water for irrigated olive grove with the production function method. *Span. J. Agric. Res.* **2010**, *8*, S197–S206. [CrossRef]
79. English, M. Deficit irrigation. I: Analytical framework. *J. Irrig. Drain. Eng.* **1990**, *116*, 399–412. [CrossRef]
80. Fereres, E.; Soriano, M.A. Deficit irrigation for reducing agricultural water use. *J. Exp. Bot.* **2007**, *58*, 147–159. [CrossRef] [PubMed]
81. Geerts, S.; Raes, D. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry are-as. *Agric. Water Manag.* **2009**, *96*, 1275–1284. [CrossRef]
82. Ruiz-Sanchez, M.C.; Domingo, R.; Castel, J.R. Deficit irrigation in fruit trees and vines in Spain. *Span. J. Agric. Res.* **2010**, *8*, S5–S20. [CrossRef]
83. Ali, M.H.; Hoque, M.R.; Hassan, A.A.; Khair, A. Effects of deficit irrigation on yield, water productivity, and economic returns of wheat. *Agric. Water Manag.* **2007**, *92*, 151–161. [CrossRef]
84. Expósito, A.; Berbel, J. Microeconomics of deficit irrigation and subjective water response function for in-tensive olive groves. *Water* **2016**, *8*, 254. [CrossRef]
85. De Klein, C.; Novoa, R.S.A.; Ogle, S.; Smith, K.A.; Rochette, P.; Wirth, T.C. N_2O Emissions from Managed Soils and CO_2 Emissions from Lime and Urea Application. Chapter 11. In *Agriculture, Forestry and Other Land Use*; Intergovernmental Panel on Climate Change (IPCC), IPCC/IGES, Eds.; IPCC: Geneva, Switzerland, 2006; Volume 4, pp. 11.1–11.54.
86. Guarino, F.; Falcone, G.; Stillitano, T.; De Luca, A.I.; Gulisano, G.; Mistretta, M.; Strano, A. Life cycle assessment of olive oil: A case study in southern Italy. *J. Environ. Manag.* **2019**, *238*, 396–407. [CrossRef]
87. Ahumada-Orellana, L.E.; Ortega-Farías, S.; Searles, P.S. Olive oil quality response to irrigation cut-off strategies in a super-high density orchard. *Agric. Water Manag.* **2018**, *202*, 81–88. [CrossRef]
88. FAOSTAT. Available online: http://www.fao.org/faostat/en/#data/QC (accessed on 25 May 2021).
89. Romeiko, X.X. A Comparative Life Cycle Assessment of Crop Systems Irrigated with the Groundwater and Reclaimed Water in Northern China. *Sustainability* **2019**, *11*, 2743. [CrossRef]
90. Eranki, P.L.; El-Shikha, D.; Hunsaker, D.J.; Bronson, K.F.; Landis, A.E. A comparative life cycle assessment of flood and drip irrigation for guayule rubber production using experimental field data. *Ind. Crop Prod.* **2017**, *99*, 97–108. [CrossRef]
91. Tanji, H.; Yoshida, K.; Soumura, H. *Issues of Life Cycle Assessment for Irrigation*; IWMI Books, Reports No H033366; International Water Management Institute: Gujarat, India, 2003; Available online: https://publications.iwmi.org/pdf/H033366.pdf (accessed on 25 May 2021).
92. Pradeleix, L.; Bouarfa, S.; Bellon-Maurel, V.; Roux, P. Assessing Environmental Impacts of Groundwater Irrigation Using the Life Cycle Assessment Method: Application to a Tunisian Arid Region. *Irrig. Drain.* **2020**, *69*, 117–125. [CrossRef]
93. Núñez, M.; Finkbeiner, M. A Regionalised Life Cycle Assessment Model to Globally Assess the Environmental Implications of Soil Salinization in Irrigated Agriculture. *Environ. Sci. Technol.* **2020**, *54*, 3082–3090. [CrossRef] [PubMed]
94. European Commission. *The European Green Deal. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions*; COM/2019/640 Final; European Union: Brussels, Belgium, 2019.