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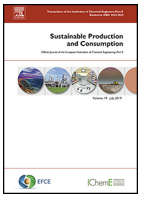

Research article

Developing a decision support tool for evaluating the environmental performance of olive production in terms of energy use and greenhouse gas emissions

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ABSTRACT

Analysis of energy consumed and greenhouse gases (GHG) emitted by farming systems is considered an important part of an environmental performance's evaluation, especially within an agroecological context. In this study, we focused on the aspects of energy use and GHG emissions of olive production, a representative Mediterranean cropping system with a global perspective. Management practices, inputs and yield were monitored in olive orchards under different management systems (organic, integrated and conventional). The aim was to support the development of a specialized software-based tool for assessing and improving the environmental performance of olive production, with regards to input management, energy use and GHG emissions. Analysis of energy use focused on farming inputs, machinery use and human labour. Both the sum energy (SE) and its non-renewable part (NRE) were considered and the SE intensity and SE and NRE efficiency were calculated. The GHG emissions were estimated in terms CO_2-equivalents, following the IPCC methodology and the emissions intensity was calculated. Main practices related to high energy inputs, were found to be the use of fossil fuels, consumed by machinery for soil management, harvesting and pruning, followed by use of synthetic fertilizers and labour. Carbon emissions presented a similar trend, with the use of synthetic fertilizers and of fossil fuels as main GHG sources. Energy use, regarding specific practices and inputs, as well as its SE intensity and efficiency and NRE efficiency, were not statistically different between management systems, except for pesticide use. Nevertheless, organic orchards presented a tendency for lower energy use. GHG emissions and emissions intensity increased significantly with management intensity, being higher under conventional management, mostly due to burning of pruning residues. Based on the above, a crop-specific Decision Support Tool (DST), named "CO_2MPUTOLIV 1.0″ was developed and validate for calculating energy use and GHG emissions in olive orchards and providing guidelines for a sustainable olive production. The software tool is freely accessible online (www.computoliv.eu), targeting stakeholders, like farmers and agronomists. It is expected to contribute to the assessment of environmental performance of olive farming and the transition towards a sustainable olive farming system.

1. Introduction

Food production, particularly as related to farm level practices, has substantial impacts on climate, biodiversity and other natural resources, such as water, soil, and atmosphere (Rockström et al., 2009; Foley et al., 2011). These impacts largely depend on the farm inputs used, both in terms of quantity and nature (Tilman et al., 2002). On the other hand, an efficient agricultural ecosystem is regarded to be self-supporting and to provide a high level of corresponding services (Power, 2010).

Improved efficiency in energy use and reduced greenhouse gas (GHG) emissions are considered fundamental to achieve agricultural sustainability (Dyer and Desjardins, 2003). However, conventional production systems are often characterized by high inputs

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of fossil fuel-derived energy, directly consumed on farm as fuel and electricity, and indirectly as the energy consumed to manufacture synthetic chemical fertilizers, plant protection products and machinery (Pimentel et al., 2005). On the other hand, the less intensive, low-input production systems, like organic farming, have been found to perform better in terms of energy use and GHG emissions, as well as for other aspects of environmental impact (Gomiero et al., 2011). Particularly, the agroecological approach in agriculture aims to holistically strengthen the sustainability and resilience of agroecosystems and food production (Altieri, 1999). This is very important for areas, like the Mediterranean, which are considered to be "environmental hotspots" in terms of impact severity, (Espadas-Aldana et al., 2019), and for the rural sector of countries like Greece (Georgopoulou et al., 2017). Consequently, the assessment of performance of a range of environmental parameters, including energy use and GHG emissions, can be of great importance for the widespread agroecological adoption and its scaling-up (Wibbelmann et al., 2013).

Different approaches have already been developed for assessing several aspects of environmental and sustainability performance in the food sector, especially at farm level, which are predominantly based on life cycle methodologies (Schader et al., 2014). Specifically, for olive oil production, at least 23 studies have quantified the environmental impacts utilising a standardised life cycle approach (Espadas-Aldana et al., 2019). Most of these studies refer to the Mediterranean area, including Greece (Georgiou et al., 2006; Chatzisymeon et al., 2013; Tsarouhas et al., 2015), while their number is still increasing (Guarino et al., 2019). On the other hand, most studies focusing on energy use and GHG emissions by tree crops (Strapatsa et al., 2006; Kavargiris et al., 2009; Litskas et al., 2011; Michos et al., 2012; M.C. 2017; 2018) and olive orchards in Greece (Kaltsas et al., 2007; Taxidis et al., 2015) and in Spain (Guzmán and Alonso, 2008; Alonso and Guzmán, 2010) used either a non-standardised life cycle based methodological scheme adapted to agriculture, or more simplified approaches, based on a life cycle perspective, that fit the purposes and limitations of the studies performed.

Moreover, the recent development of decision support tools (DST), in particular software-based ones, is expected to play a role to the quest for evidence-based decision making in agriculture to improve productivity and environmental outputs (Rose et al., 2016). Over the last few years, several public institutions or private sector initiatives have created such tools, which are also appropriate for calculating the GHG emissions of agricultural and forestry systems; examples are the "Cool farm" (Haverkort and Hillier, 2011) and EX-ACT tools (Bernoux et al., 2010), that mainly focus on arable crops in northern climates, the SMART-Farm Tool (Schader et al., 2016), built upon the international SAFA goals developed by FAO, the Carbon Navigator tool (Murphy et al., 2013) for livestock production systems, the DEXiPM tool (Angevin et al., 2017), providing multi-criteria models for crop sustainability, and the SyNE calculator (Carof and Godinot, 2018) that evaluates nitrogen efficiency aspects in farming systems.

Despite the evident advancement of studies on the environmental impact of the olive production sector, the development of a DST to provide guidance on sustainable olive farming practices and input management is lacking. Such a crop-specific tool would be an important asset for olive producers and agronomists, both in Greece and throughout the Mediterranean basin, to substantially help improve understanding of the concepts of sustainability and adaptation under conditions of natural resources depletion, and also increase the input efficiency of olive orchards. Ideally, such a tool should be simple, easy to operate, and publicly available; characteristics that have already been reported as advantageous for DSTs (EIP-AGRI, 2017).

The goal of this study was to develop a novel, software-based DST, to support olive farms assessing and improving their performance in terms of energy use and GHG emissions. Specifically, our objectives could be summarised as follows: i) to collect data and quantify the energy use and the GHG emissions of olive production over a broad spectrum of management intensity, represented by three main management systems (organic, conventional and integrated); ii) to utilise the research results to develop a specialized software DST to assess and improve input management, energy use and GHG emissions in olive production systems, accompanied by comprehensive guidelines of best management practices for sustainable olive production.

2. Materials and methods

The study was based on a simplified life cycle approach, without following the conventional life cycle assessment methodology as described by the ISO 14040/44 (ISO, 2006a, 2006b) standards. The analysis focused on the practices that represent key stages of the olive farming system, including i) soil management; ii) pest control; iii) fertilization; iv) canopy management; vi) irrigation and vi) harvesting, and the respective inputs, equipment use, human labour and output of the olive orchards, as seen in Fig. 1.

2.1. Olive orchards under study

The study was conducted in the western Messara valley (35°01′N, 24°49′E), a typical Mediterranean olive production area, in southern Crete, Greece. Twenty-four commercially managed olive orchards planted with "Koroneiki" cv, located in eight different sites, were selected. The selection was made under the criteria of covering the whole range of representative applied practices and inputs. Specifically, each study site included three neighbouring orchards: i) one complying with organic standards according to European Union (EU) legislation (European regulation EC 834/2007, EC 889/2007 and EC 271/2010); ii) a second, following an industry standard for integrated farming, according to the agri-environmental requirements of the regulation EC 2078/92 and EC 1257/99, and iii) a third complying with the EU Common Agricultural Policy (CAP) description for conventional farming. In more detail, the organic farming system was based on the standard organic production protocols used in the area the last twenty years (Kabourakis, 1999) and included soil management practices, ranging from intensive to no tillage, the use of cover crops / green manure, a standard pruning protocol for canopy management, irrigation with drip systems, organic fertilizers use and mass trapping methods for olive fly control. The integrated management applied similar, but rather more intensive, treatments regarding pruning, irrigation and soil management, though including the use of chemosynthetic herbicides and pesticides for weed management and olive fly control. Conventional orchard management resembled the integrated one, however no standard protocol was followed to applications and rates of synthetic pesticides, soil management or pruning.

In all cases, the orchards were monitored weekly for a period of two years, in order to capture the full production cycle of the olive tree, considering the biennial (alternate) bearing of the olive tree, an important pomological feature affecting its yield. More details on the applied farming practices and inputs in the olive orchards under study can be found in the Appendix (Table 4).

2.2. Quantification of inputs, energy use and emissions

The energy use and the GHG emissions under the different management systems investigated were analysed based on data collected for the following parameters: i) management practices;

Table 1
Embodied energy of olive orchard inputs and human labour.

	Unit	Embodied energy (MJ/Unit)	Source
Direct energy			
Diesel	L	35.9	IOR (2008)
Gasoline	L	32.2	IOR (2008)
Lubricant oil	L	40	IOR (2008)
		Indirect energy	
		Synthetic fertilizer	
Nitrogen (N)	kg	78.23	Gellings and Parmenter (2004)
Phosporus (P)	kg	15.8	Gellings and Parmenter (2004)
Potassium (K)	kg	9.3	Gellings and Parmenter (2004)
Urea (46–0–0)	kg	27.6	Audsley et al. (1997)
Organic fertilizers	kg	17.81	Alonso and Guzmán (2010)
PatentKali	kg	6	Mudahar and Hignett (1987a,b)
Packaged bio-fertilizer	kg	17.81	Fluck (1992)
Boron	kg	18.2	Mudahar and Hignett (1987a,b)
Cover crops / Green manure	kg	0,15	Wells (2001)
Manure	t	64.4	Pimentel (1980)
Human labour	h	2.2	Fluck (1992)

Symbols of metric units: l (liter); Kg (Kilogram); t (Ton); h (hours).

ii) equipment use; iii) inputs applied and iv) labour of each olive orchard. These data were collected using structured questionnaires, answered by the olive farmers, as well as by on-site observation on a weekly basis.

To calculate the consumed energy, we considered i) the use of agricultural machinery (tractor and attachments, pumps, chainsaw and harvesting tools), the respective operation time, and the number of machines and of labourers; ii) irrigation (electricity consumption by the municipal irrigation network or drilling machinery); iii) inputs of fertilizers, pesticides and cover crops / green manure and iv) human labour on farm.

For the embodied energy we considered both i) the direct energy consumed by fossil fuels use (diesel and gasoline), as well as lubricant oil, for operations of soil management, harvest, pruning, irrigation, application of fertilizers and transportation, and ii) the indirect energy embodied in fertilizers (synthetic and organic), pesticides and cover crops / green manure inputs (Table 1).

The human labour related energy was based on the total energy content of the food consumed by labourers (Fluck, 1992), similarly to previous studies regarding olive and other crops (Kaltsas et al., 2007; Alonso and Guzmán, 2010; Taxidis et al., 2015; M.C. Michos et al., 2017). The embodied energy of the machinery was based on the conversion factors that appear in Table 5 in the Appendix and were estimated considering the weight and lifespan of machinery used in Greece, as methodologically described in previous studies (Kaltsas et al., 2007; Alonso and Guzmán, 2010; Taxidis et al., 2015).

Energy intensity was estimated as the ratio of sum energy (SE) used (MJ ha^{-1}) to the olive fruit yield (kg). Energy efficiency was estimated as the ratio of the energy content of olive fruit yield (given to be 13.37 MJ kg^{-1}, by Alonso and Guzmán, 2010) to the energy use (MJ ha^{-1}), with regard to SE and its non-renewable sub-part (NRE), including the embodied energy of fossil fuels, synthetic fertilizers, pesticides and electricity. Energy intensity and efficiency are frequently considered as indicators in studies of energy use in olive production (Kaltsas et al., 2007; Alonso and Guzmán, 2010; Taxidis et al., 2015), while NRE efficiency is considered to have a great potential as an analysis indicator regarding the aspects of natural resources depletion and the generated environmental problems (Alonso and Guzmán, 2010).

GHG emissions due to the use of fossil fuels, synthetic and organic fertilizers considering also the denitrification process, and burning of pruning residues were estimated by using the emission factors seen in Table 2. The estimation of emissions due to the burning of pruning residues was based on the amount of fresh weight of biomass burnt and its fraction oxidized, taken as 90% (IPCC, 1996), the total dry matter of olive wood, estimated as 60% (Bouat, 1974) and its carbon content, taken as 38.8% of dry matter weight (IPCC, 1996); The carbon released is equal to the dry matter of biomass burnt multiplied by i) the fraction oxidized and ii) its carbon content.

The emissions were calculated in terms of CO_2-equivalents (CO_2-eq) following IPCC methodology (IPCC, 1996), based on the estimated global warming potential (GWP) of each greenhouse gas, expressed as the effect of one kilogram of CO_2 on global warming over a given time horizon. Non-CO_2 emissions, such as N_2O generated e.g. by the use of synthetic fertilizers or CH_4 by compost, were multiplied by the appropriate warming potential to convert to a CO_2 equivalent basis. The GWPs for N_2O and CH_4 applied were, respectively, 310 and 21, for a 100-year time horizon (IPCC, 1996).

2.3. Data analysis

A comparison between management systems was statistically performed, in order to reveal possible differences for each year of olive harvest as well as for the whole study period, taking in consideration the importance of the biennial variation of the olive tree, due to alternate bearing. Univariate analyses were carried out using SPSS 20.0® for MS Windows. Data normality was assessed by the Shapiro-Wilk test ($p<0.05$) and found to be not normally distributed, even after several transformations. Therefore, a Kruskall-Wallis test was run, with significance level at $p<0.05$, to determine whether differences occurred in i) energy use regarding SE, NRE and as related to the inputs of fossil fuels, fertilizers, pesticides and labour; ii) SE energy intensity and efficiency, and NRE efficiency; iii) GHG emissions regarding their sum and as related to fossil fuels use and pruning residues burning; iv) GHG emissions intensity.

2.4. Development of the software decision support tool

The DST development first included the formulation of a draft platform for data registration and analysis, using Microsoft Office® Excel. At a second phase, multiple well-known programming languages have been employed. Specifically, a user-friendly application interface was implemented by using Java®, a general-purpose computer programming language that is at the same time concurrent, class based, object orientated, and specifically designed to have as few implementation dependencies as possible (Gosling, 2000). The database of DST was again kept simple using Java components, in order to avoid additional software dependencies (e.g. Structured Query Language-SQL server support); thus,

Table 2
Emissions factors related to global warming potential.

	Emissions (Kg CO_2-eq)	Source
Fuel (Liters)		
Diesel (LHV)	3.10	IPCC (1996); EPA (2014)
Gasoline	2.70	IPCC (1996); EPA (2014)
Synthetic fertilizer (kg)		
Nitrogen (N)	10.80	France and Tompson (1993), Kroeze and Bogdanov (1997)
Phosphorus (P)	0.71	IPCC (1996)
Potassium (K)	0.70	Zafiriou et al. (2012)
Urea (46–0–0)	1.60	IPCC (1996); Brentrup et al. (2016)
Organic fertilizer (kg)		
Sheep and goat manure	0.06	Corinair (1996), Barker et al. (2002)
Compost / bio-fertilizer	0.05	Davis (1999)
Denitrification (per kg N)	3.70	Bouwman (1995)
Burning pruning residues (kg of FW)	0.15	IPCC (1996)

Kg: Kilogram; FW: Fresh weight

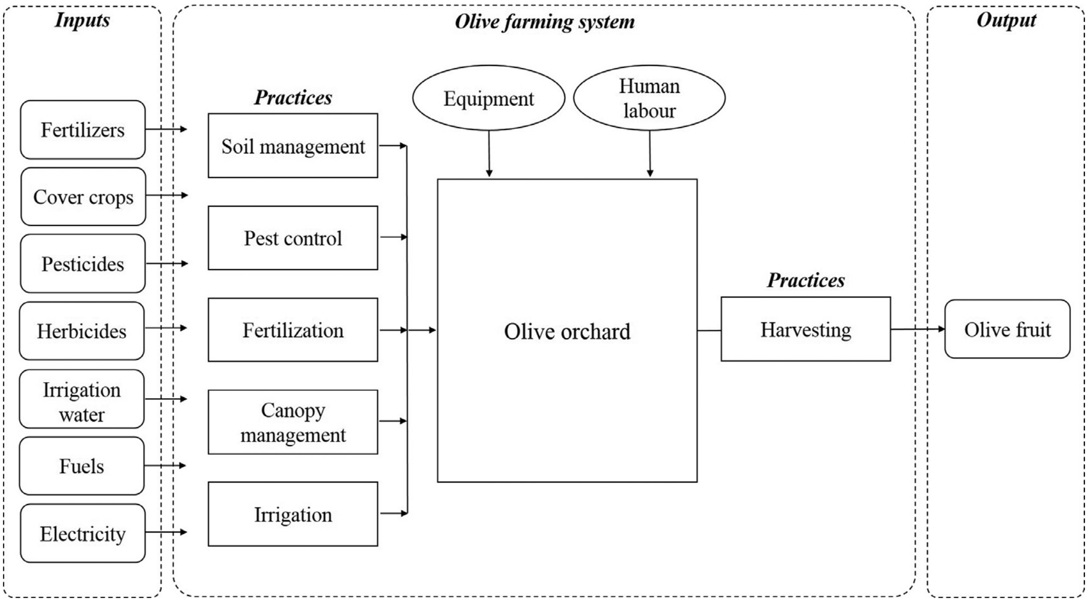


Fig. 1. Diagram of the olive farming practices, inputs and outputs considered for the study studiedFig. 1.

ensuring low installation complexity on farmer's digital equipment. The DST's output was simply constructed for providing annual reports, produced in Hypertext Markup Language (HTML) which can be viewed using any web browser. Additionally, Cascading Style Sheets (CSS) were used to enhance their readability.

3. Results and discussion

3.1. Energy use

The results on energy use regarding SE, NRE and the respective energy intensity and efficiency are presented in the Appendix (Table 6). The total use of energy over the two-year monitoring period for all orchards reached 341,172.08 MJ/ha (year 1: 187,687.20 MJ/ha; year 2: 153,484.88 MJ/ha), while NRE use accounted for 231,025.68 MJ/ha (year 1: 114,495.51 MJ/ha; year 2: 116,530.17 MJ/ha). The most important energy consuming factor (Fig. 2) was the use of fossil fuels: 195,665.64 MJ/ha (year 1: 101,944.53 MJ/ha; year 2: 93,721.12 MJ/ha), followed by the fertilizers application, both synthetic and organic: 111,539.31 MJ/ha (year 1: 67,481.26 MJ/ha; year 2: 44,058.05 MJ/ha), labour hours: 18,102.88 MJ/ha (year 1: 9135.49 MJ/ha; year 2: 8967.39 MJ/ha), and pesticides use: 4212.11 MJ/ha (year 1: 1782.73 MJ/ha; year 2: 2429.38 MJ/ha).

Breakdown of fossil fuels use (Fig. 2) showed that the sum of their consumption across all management systems was attributed mainly to soil management, harvesting and pruning, followed by pest control, cover crops / green manure, irrigation and transportation. Use of synthetic fertilizers, in conventional and integrated orchards, represented the greatest portion of the total energy consumed for fertilization purposes.

Similar studies on olive orchards in northern Greece, found that irrigation and fertilization were the practices related to higher energy inputs (Genitsariotis et al., 1996; Kaltsas et al., 2007), or fuel consumption and transportation (Taxidis et al., 2015). Also, studies on olive (Guzmán and Alonso, 2008; Hemmati et al., 2013) or other crops (Litskas et al., 2011; Mobtaker et al., 2012) reported that the major energy inputs are encountered in the use of fossil fuels, fertilization or electricity use, as well as to the soil management operations. Pesticide use only represented a minor proportion of energy use across olive orchards, as the frequency and quantities used were low, at least for the period of our study.

The mean SE intensity (± S.E.) across all orchards (Table 6 in the Appendix) was 4.19 ± 1.61 MJ kg^{-1} (year 1: 3.47 ± 0.87 MJ kg^{-1}; year 2: 7.00 ± 2.68 MJ kg^{-1}), the SE efficiency was 8.22 ± 1.14 (year 1: 8.69 ± 1.35; year 2: 10.78 ± 2.40) and NRE efficiency was 11.11 ± 1.36 (year 1: 11.01 ± 1.40; year 2: 13.70 ± 2.96). Previous studies in northern Greece and Greek islands (Kaltsas et al., 2007;

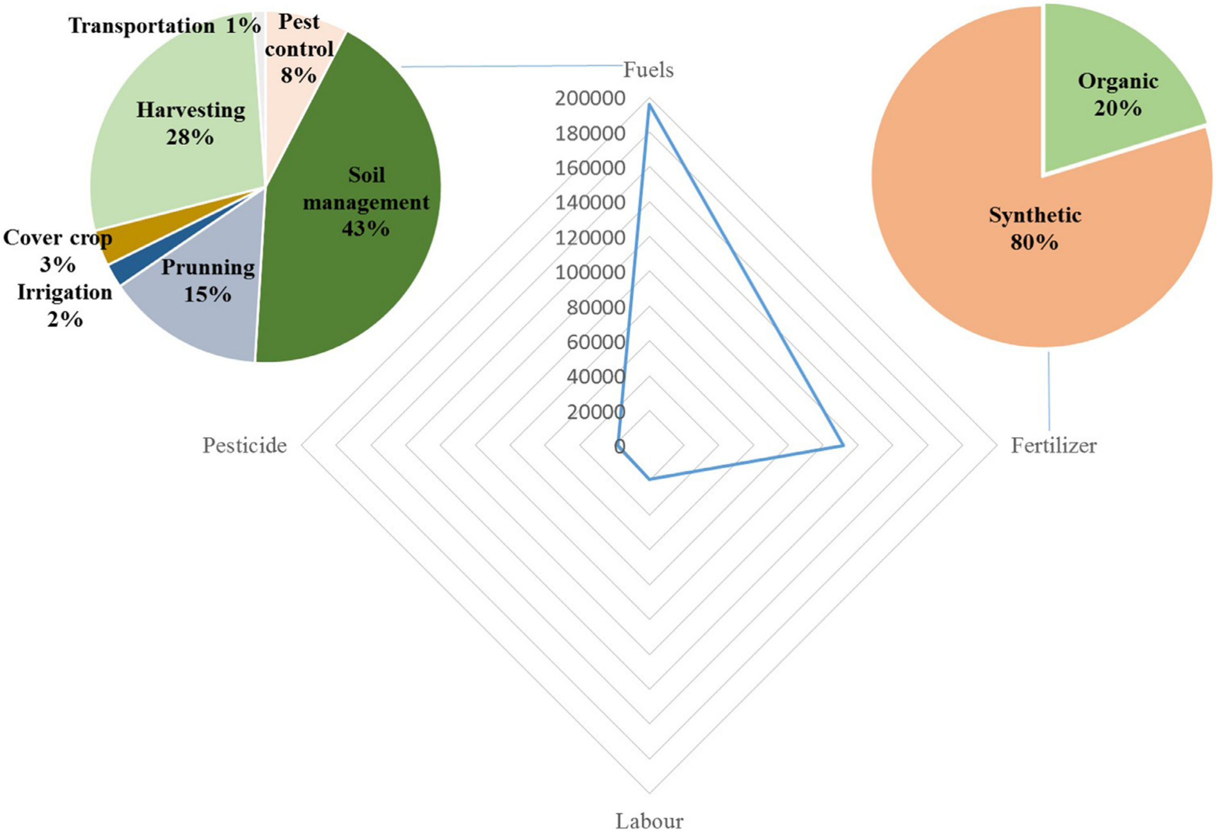


Fig. 2. Energy inputs (MJ/ha) with regard to the use of resources and the management practices in the olive orchards (two-year period).

Taxidis et al., 2015), as well as in Spain (Guzmán and Alonso, 2008) found higher values of mean SE intensity (from 20.7 to 59 MJ kg^{-1} in Greece, and 18.3 to 51.3 MJ kg^{-1} in Spain), lower mean SE efficiency (1.3 to 3.02 in Greece, and 0.7 to 3.8 in Spain), and mean NRE efficiency (2.0 to 5.2) in Spain, depending mainly on the management intensity as well as the location of the olive orchards.

Comparison between management systems delivered no statistically significant differences for the parameters compared in each harvest year and for the total study period (Table 8 in the Appendix). Pesticides were the only exception, being significantly lower in the organic orchards, as expected due to the zero pesticide use in organic management. The non-differences could be attributed to the considerably low use of synthetic fertilizers, and the use of manure instead, in the conventional and integrated orchards. Another reason would be the high variation of energy use amongst organic olive orchards, due to the different levels of mechanization and intensity of practices like the soil management applied. Similar findings are reported in other related studies in Greece (Kaltsas et al., 2007; Taxidis et al., 2015), showing energy inputs not to be affected by farming systems, although tending to be higher in conventional olive orchards, attributing it to the better adaptation of olive cultivars in local environmental conditions. Nevertheless, in this study the SE and NRE efficiency tended to be higher in less intensive management systems, like the organic one (Table 6 in the Appendix), while the mean SE and its intensity values tended to increase with the management intensity, being lower in the organic orchards and higher in the conventional ones (Fig. 3 and Table 6 in the Appendix).

Interestingly, the surveyed olive orchards produced an average of 6655.79 Kg olive fruit ha^{-1} (±3520.13), with organic ones having the higher mean production (7293 Kg ha^{-1}, ±3284), followed by conventional (6587 Kg ha^{-1}, ± 3791) and integrated (6087 Kg ha^{-1}, ± 3359) (Table 3). Similar yields were found by another study in Crete, Greece, for both organic and conventional systems (Volakakis et al., 2011; N. 2017), while a study in Spain (Alonso and Guzmán, 2010) have found lower performance, in terms of organic olive oil production, by 14% when compared to conventional. It should be also noticed that the average olive fruit yield of the olive orchards studied appears to be more than three times higher when compared to the Greek national average yield, estimated as 2157 kg ha^{-1} (Eurostat, 2014; Russo et al., 2016).

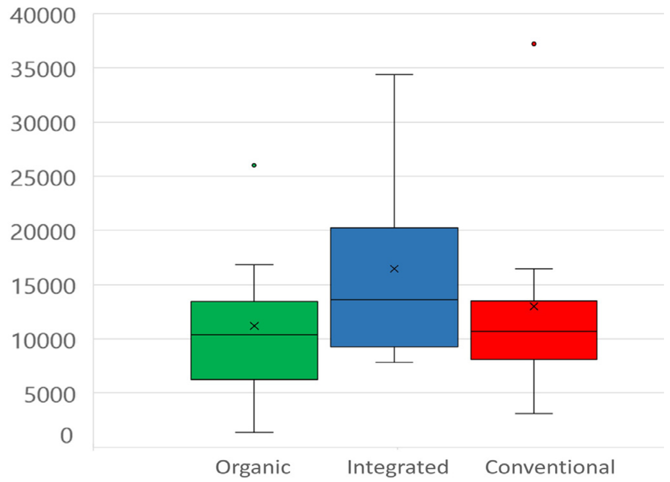


Fig. 3. Energy use (MJ/ha) in organic, integrated and conventional orchards. Boxplots show medians (lines), the 25th to 75th percentiles (boxes), means (asterisks), non-outlier ranges (whiskers) and outliers (dots).

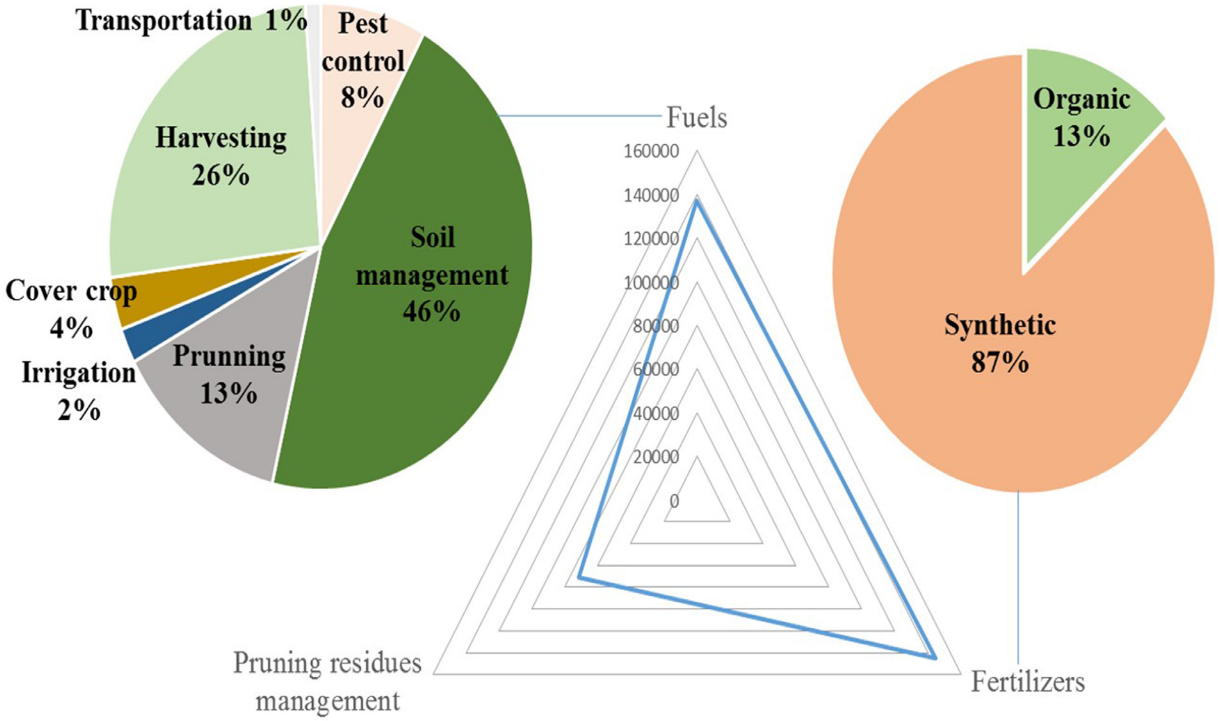


Fig. 4. Greenhouse Gas (GHG) emissions (CO_2-eq/ha), with regard to the use of resources and the management practices in the olive orchards (two-year period).

3.2. GHG emissions

The sum GHG emissions and the emissions intensity of the surveyed olive orchards are presented in the Appendix (Table 7). The total emissions over the two-year monitoring period for all orchards was 352,831 CO_2-eq ha^{-1}. (Year 1: 206,000 CO_2-eq ha^{-1}; year 2: 146,831 CO_2-eq ha^{-1}). The main sources of GHG emissions (Fig. 4) were ranked accordingly and fertilization was the main emitting factor, with 144,686 CO_2-eq ha^{-1} (year 1: 98,527 CO_2-eq ha^{-1}; year 2: 46,159 46,159 CO_2-eq ha^{-1}), followed closely by use of fossil fuels: 136,875 CO_2-eq ha^{-1} (year 1: 71,242 CO2-eq ha^{-1}; year 2: 65,633 CO2-eq ha^{-1}) and burning of pruning residues: 71,270 CO_2-eq ha^{-1} (year 1: 36,232 CO_2-eq ha^{-1}; year 2: 35,038 CO_2-eq ha^{-1}). Emissions due to the use of fossil fuels (Fig. 4) were mainly related to soil management practices and olive harvest, pruning works, pest control, as well as to cover crops \ green manure, irrigation and transportation, following a similar pattern as for energy use. Synthetic fertilizers contributed as well the major portion of total emissions, with respect to fertilization inputs.

Organic orchards, when compared to conventional ones, had significantly lower sum GHG emissions, burning of pruning residues emissions and emissions intensity in the 2nd harvest year (Table 8 in the Appendix). When the whole study period was considered, organic orchards were found to have significantly lower i) sum emissions when compared to the integrated ones; ii) emissions due to burning of pruning residues when compared to the conventional ones and iii) emissions intensity when compared to both integrated and conventional orchards (Fig. 5 and Table 8 in the Appendix).

Kaltsas et al. (2007) found emissions not to be affected by farming systems, but mentions that organic olive orchards tended to have lower emissions, as found by other authors studying arable crops (Haas et al., 2001). Taxidis et al. (2015) also found that GHG emissions were not affected either by farming or by olive varieties cultivated, with the specific exception of N_2O-emissions, appearing significantly lower in the organic than the conventional olive orchards, for a specific Greek olive variety (“Kolovi”).

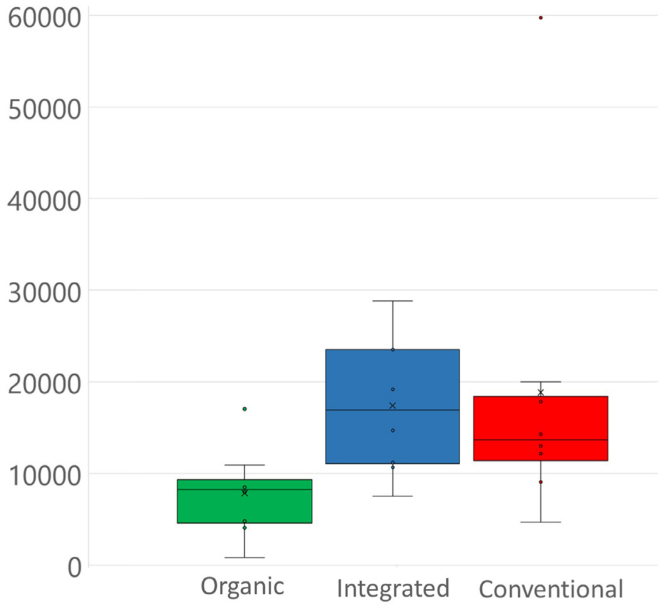


Fig. 5. GHG emissions (CO_2-eq ha^{-1}) in organic, integrated and conventional orchards. Boxplots show medians (lines), the 25th to 75th percentiles (boxes), means (asterisks), non-outlier ranges (whiskers) and outliers (dots).

3.3. Description of CO_2MPUTOLIV 1.0 development

Based on this study and on previous research, a software-based, decision support tool (DST), named “CO_2MPUTOLIV 1.0′′, and a complementary set of guidelines related to sustainable olive pro-

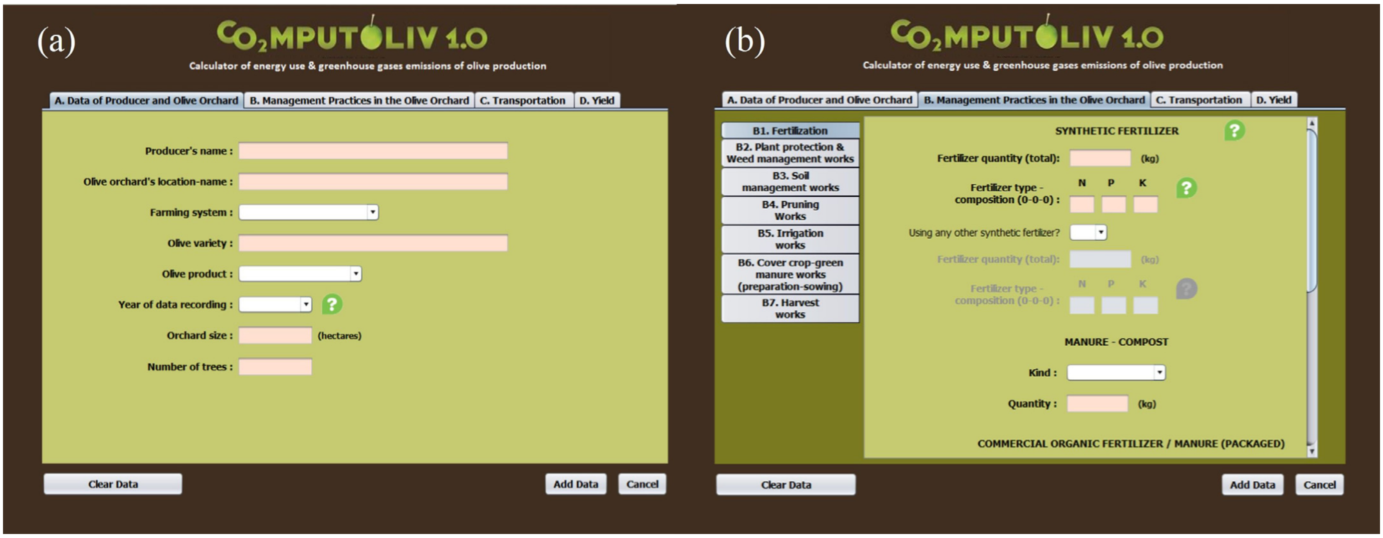
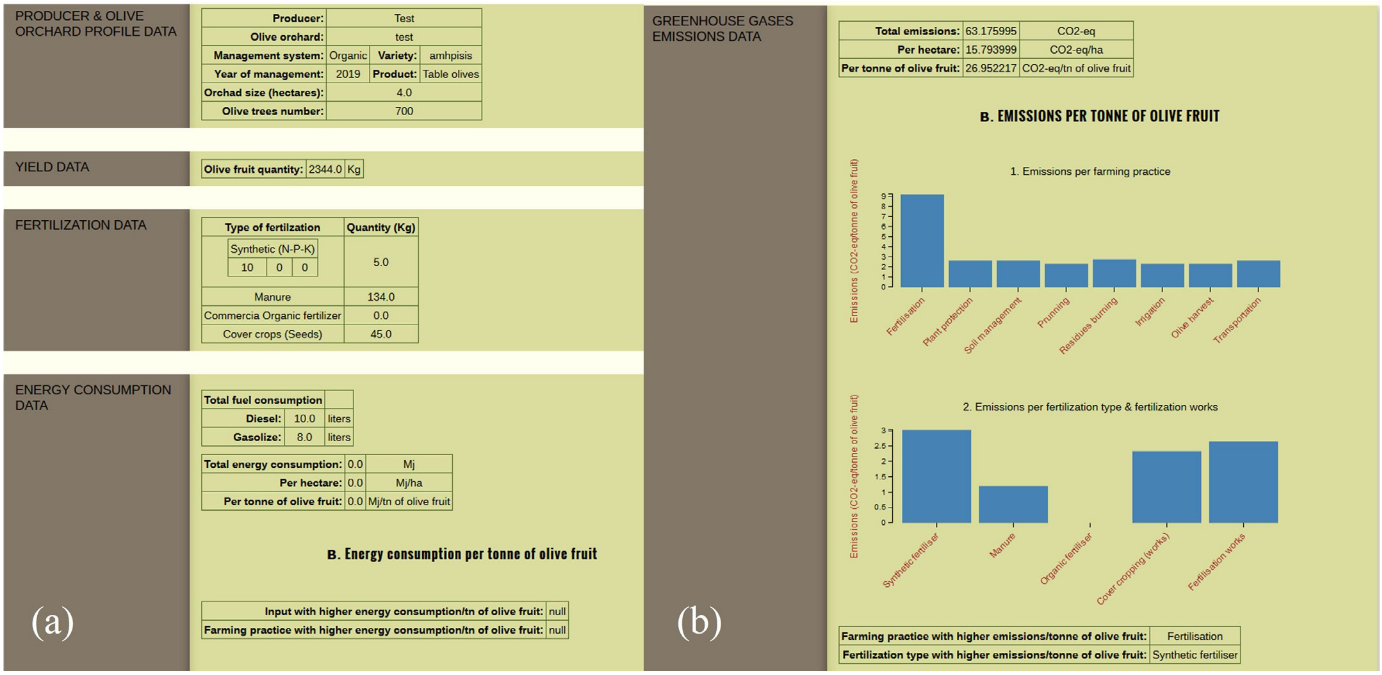


Fig. 6. Interface of the CO_2MPUTOLIV 1.0 software including sections of data registration. The displayed pages involve data of producer and olive orchard (a) and management practices (b).



PRODUCER & OLIVE ORCHARD PROFILE DATA

Producer:	Test		
Olive orchard:	test		
Management system:	Organic	**Variety:**	amhpisis
Year of management:	2019	**Product:**	Table olives
Orchad size (hectares):	4.0		
Olive trees number:	700		

YIELD DATA

Olive fruit quantity:	2344.0	Kg

FERTILIZATION DATA

Type of fertilzation	**Quantity (Kg)**
Synthetic (N-P-K) 10 0 0	5.0
Manure	134.0
Commercia Organic fertilizer	0.0
Cover crops (Seeds)	45.0

ENERGY CONSUMPTION DATA

Total fuel consumption		
Diesel:	10.0	liters
Gasolize:	8.0	liters

Total energy consumption:	0.0	Mj
Per hectare:	0.0	Mj/ha
Per tonne of olive fruit:	0.0	Mj/tn of olive fruit

B. Energy consumption per tonne of olive fruit

Input with higher energy consumption/tn of olive fruit:	null
Farming practice with higher energy consumption/tn of olive fruit:	null

GREENHOUSE GASES EMISSIONS DATA

Total emissions:	63.175995	CO2-eq
Per hectare:	15.793999	CO2-eq/ha
Per tonne of olive fruit:	26.952217	CO2-eq/tn of olive fruit

Farming practice with higher emissions/tonne of olive fruit:	Fertilisation
Fertilization type with higher emissions/tonne of olive fruit:	Synthetic fertiliser

Fig. 7. Interface of the output provided by CO_2MPUTOLIV 1.0 (a and b). The displayed output example represents an organic olive orchard producing table olives.

duction were developed. The tool is freely available in the webpage www.computoliv.eu where users may access the site and download the English and Greek version of the software, together with instructions for installation (the international version can be downloaded here). The tool is under the Creative Commons public copyright license CC BY-NC–ND 3.0 (Attribution-NonCommercial-NoDerivs 3.0 Unported Attribution) implying its use and distribution is free for non-commercial purposes, on condition that appropriate credit is given, a link is provided to the license, and any changes implemented are clearly indicated.

3.3.1. Input parameters

A data registration interface was developed in the DST, in order to accumulate all input parameters related to the productivity of an olive orchard. The parameters input required by the users included the input of i) the data of the producer and the olive orchard; ii) the management practices applied; iii) the transportation data, and iv) the olive orchard's yield (Fig. 6).

In all parameters listed, the input of data related to the fossil fuel use (type and quantity), as well as human labour are required. A "Help" button is available during all steps of the data registration, in order to guide users through the process. The data input is internally processed using generated formulas that convert input parameters to energy use and GHG emissions-related outputs. The conversion formulas created used inventories of values encountered in literature and in technical reports, as listed in Table 1 and Table 2.

The software output interface (Fig. 7) was developed to visualize in a comprehensive way the results of energy use and emissions of the olive orchard under analysis, together with auxiliary data. It is accompanied by an attached file, available for download, containing respective guidelines of best practices for sustainable olive production, based on the current findings and previous research (Kabourakis, 1999).

The CO_2MPUTOLIV tool was validated in both its initial draft form and the accomplished software, using the data registered during the two-year monitoring period supported by open consultation and informal trials by olive farmers. A sensitivity analysis (SA) was also performed, using the "What-if" data analysis (Data table) in Excel for Windows®, as a recommended process to assess quantitatively the most important parameters included in the guidelines for their suitability and performance (Mateus and Franz, 2015). Several best practices were evaluated as variables for their effect on olive orchard processes, inputs and outputs (Table 9 in theAppendix) using a simple simulation model based on empirical agronomic data, serving to parameterize these interactions. The choice of best practices was eventually supported by the appropriate response of important olive orchards processes including pest control, soil fertility, inputs of fertilization, irrigation, machinery use and yield output (Table 9 in the Appendix).

4. Conclusions

This study demonstrates the importance of less intensive olive production systems, for olive and other tree crops, in line with previous ones. Significantly lower GHG emissions were presented in organic olive orchards, with certain farming practices, such as the management pruning residues, making a major contribution. The non-significant effect of management systems on the energy use intensity and efficiency was attributed mainly to the high variability in the practices applied in the olive orchards under study. This was especially evident for the organic orchards, where the intensity of management practices, such as the soil management, is not explicitly controlled by organic regulations. The olive orchards under study were shown to have significant potential for energy consumption improvement and reduction of the GHG emissions. The development of the CO_2MPUTOLIV tool could be considered a simple, but well targeted and user-friendly, means to support strategic decision making and to educate stakeholders on the improvement of input use and management practices. It is thus expected that it will contribute, in a holistic manner and by considering agroecological principles, to the initial phases of the transition towards truly sustainable olive production systems in Greece and the broader Mediterranean area (Table 3)

Table 3
Olive fruit yield of organic (code names: 1O to 8O), integrated (1I to 8I) and conventional orchards (1C to 8C), including summary information of mean and standard error (S.E.) values for each management system.

	Olive fruit yield (kg ha^{-1})		
Olive orchards codes	Year 1	Year 2	Total
1O	5000	1700	6700
1C	1000	3027	4027
1I	1300	3100	4400
2O	220	2200	2420
2C	0	100	100
2I	830	1170	2000
3O	2250	4560	6810
3C	4400	500	4900
3I	3460	5747	9207
4O	0	9485	9485
4C	0	9000	9000
4I	3600	4350	7950
5O	9370	3000	12,370
5C	2000	2500	4500
5I	4000	2300	6300
6O	10,000	1000	11,000
6C	3850	70	3920
6I	8000	2500	10,500
7O	1150	2050	3200
7C	8750	500	9250
7I	500	1200	1700
8O	1860	4500	6360
8C	9000	4000	13,000
8I	9300	1340	10,640
Organic			
Mean	3731	3562	7293
SE	1319	897	1161
Integrated			
Mean	3874	2713	6587
SE	1122	635	1152
Conventional			
Mean	3625	2462	6087
SE	1164	617	1315

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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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.spc.2020.07.003.

Appendix

Table 4, Table 5, Table 7, Table 8, Table 9

Table 4
Farming practices and inputs in the organic, integrated and conventional olive orchards investigated, over the two-year study period.

Farming practices	Methods, inputs quantitative data and comments		
	Organic	Integrated	Conventional
Soil management	Rotavator (Rotary tiller) in five orchards, annually (in four orchards) or every 2nd year (one orchard), in spring (April). Field cultivator in two orchards, annually (April), for strip-tilling between olive trees. No tillage applied in one orchard. Mean proportion (%) of orchard surface tilled: 76 ± 31% (year 1) and 64 ± 38% (year 2). Machinery’s mean fuel consumption (diesel): 39.94 ± 13.72 l ha^{-1} (year 1) and 31.42 ± 18.77 l ha^{-1} (year 2)	Rotavator (Rotary tiller) in three orchards, annually, in spring (April). Field cultivator in three orchards annually (April). No tillage applied in two orchards. Mean proportion (%) of orchard surface tilled: 70 ± 41% (year 1) and 71 ± 42% (year 2). Machinery’s mean fuel consumption (diesel): 34.74 ± 20.26 l ha^{-1} (year 1) and 26.65 ± 16.61 l ha^{-1} (year 2).	Rotavator (Rotary tiller) in three orchards, annually (two orchards) or every 2nd year (one orchard), in spring (April). Field cultivator in five orchards, annually (April) or every 2nd year (one orchard). No tillage applied in one orchard. Mean proportion (%) of orchard surface tilled: 10 ± 13.23% for both years. Machinery’s mean fuel consumption (diesel): 32.79 ± 14.46 l ha^{-1} (year 1) and 30.90 ± 16.12 l ha^{-1} (year 2).
Pest control	No use of pesticides. Installation of self-made bait traps (plastic bottles with water and ammonia source) in two orchards over the study period (installed in May and maintained/refilled periodically until October). Consumption of approx. 6.7 l ha^{-1} of fuel (gasoline) for preparation and installation / maintenance of traps. Weed control applied through soil management practices, as described above. No application of herbicides.	Bait spray against olive fly by the Regional Government twice or three times per year. Use of insecticide [Dimethoate or Spinosad (0.3%)] with protein. Herbicide application (Glyphosate) in two orchards. Machinery’s mean fuel consumption (diesel): 13.90 ± 10.16 l ha^{-1} (year 1) and 10.99 ± 5.64 l ha^{-1} (year 2).	Same practices as for integrated orchards. Herbicide application (Glyphosate) in two orchards. Machinery’s mean fuel consumption (diesel): 11.48 ± 9.55 l ha^{-1} (year 1) and 8.02 ± 4.69 l ha^{-1} (year 2)
Fertilization	Application of sheep and goat manure (in three orchards), every 2nd year (2 orchards) or annually (one orchard), with mean quantity 4.16 ± 1.94 t ha^{-1}. Application of packaged bio-fertilizers (in three orchards) every 2nd year: 500 ± 260 kg ha^{-1}, PatentKali® (in two orchards): 263 ± 44 kg ha^{-1} and Boron (one orchard): 37 kg ha^{-1}. Use of legumes (Vicia sativa sub. species sativa) as green manure in four orchards (mainly combined with sheep & goat manure or bio-fertilizer) every 2nd year: 19 ± 44 Kg ha-1 of seeds sowed. No fertilizer application in one orchard. Machinery’s mean fuel consumption (diesel): 2.57 ± 3.29 l ha-1 (year 1) and 0.82 ± 1.29 l ha-1 (year 2).	Application of 100 ± 60 kg of Nitrogen ha^{-1}, 17 ± 7 kg Phosphorus ha^{-1} and 44 ± 28 kg Potassium ha^{-1} as synthetic fertilizers, as well as of urea (two orchards): 22.59 ± 5.99 Kg ha^{-1}, PatentKali® (one orchard): 333 kg ha^{-1}, and sheep and goat manure (one orchard): 8.4 t ha^{-1} every 2nd year. No fertilizer application in one orchard. Machinery’s mean fuel consumption (diesel): 6.10 ± 3.10 l ha-1 (year 1) and 1.50 ± 0.51 l ha-1 (year 2).	Application of 61 ± 28 kg Nitrogen ha^{-1}, 42 ± 21 kg Phosphorus ha^{-1} and 49 ± 19 kg Potassium ha^{-1} as synthetic fertilizers, as well as PatentKali® (one orchard): 67,09 kg ha^{-1} and sheep and goat manure (two orchards): 4.46 ± 3.03 t ha^{-1} every 2nd year. No fertilizer application in three orchards. Machinery’s mean fuel consumption (diesel): 6.13 ± 3.08 l ha-1 (year 1) and 1.50 ± 0.50 l ha-1 (year 2).
Pruning	Performed annually in all orchards, except one, including heavy pruning in one year and thinning out of annual branches on the other. Use of tools such as chainsaws and pruning scissors. Pruning residues are chipped by branch destroyer (adapted to the tractor) and later incorporated to the soil by use of rotavator of cultivator, as described in soil management, except one orchard where burning occurred in year 1 (80 kg ha^{-1} of residues). Pruning equipment’s mean fuel consumption (gasoline): 8 ± 5 l ha^{-1} (year 1) and 6.59 ± 5.50 l ha^{-1} (year 2).	Same practices. Burning of residues performed in four orchards (1511 ± 1451 kg ha^{-1} of residues burnt) in year 1. Pruning equipment’s mean fuel consumption (gasoline): 10.50 ± 10.15 l ha^{-1} (year 1) and 14.63 ± 19.40 l ha^{-1} (year 2).	Same practices. Burning residues performed in all orchards (3428 ± 3041 kg ha^{-1} of residues burnt). Pruning equipment’s mean fuel consumption (gasoline): 16.70 ± 12.23 l ha^{-1} (year 1) and 10.76 ± 9.54 l ha^{-1} (year 2).
Irrigation	Drip irrigation 5–15 times per year, from April to October, depending on precipitation and water availability. Use of municipal irrigation network, except one orchard (use of pump consuming an average of 200 l diesel / year). Irrigation quantity: 827.87 ± 514.80 m^3 ha^{-1} (year 1) and 692.24 ± 360.76 m^3 ha^{-1} (year 2).	Same practices. Irrigation quantity: 1359.86 ± 801.96 m^3 ha^{-1} (year 1) and 1590.00 ± 1428.54 m^3 ha^{-1} (year 2).	Same practices. Irrigation quantity: 1359.86 ± 801.96 m^3 ha^{-1} (year 1) and 1590.00 ± 1428.54 m^3 ha^{-1} (year 2). Two orchards use pump consuming an average of 130 L diesel / year). Irrigation quantity: 1375.63 ± 1021.13 m^3 ha^{-1} (year 1) and 1189.67 ± 999.07 m^3 ha^{-1} (year 2).
Harvesting	Use of vibrating rakes and harvesting nets laid under olive canopy. Harvest equipment’s mean fuel consumption (gasoline): 23.66 ± 19.09 l ha^{-1} (year 1) and 15.32 ± 4.11 l ha^{-1} (year 2).	Same practices. Harvest equipment’s mean fuel consumption (gasoline): 35.77 ± 24.83 l ha^{-1} (year 1) and 18.01 ± 13.44 l ha^{-1} (year 2).	Same practices. Harvest equipment’s mean fuel consumption (gasoline): 28.77 ± 25.85 l ha^{-1} (year 1) and 14.93 ± 6.64 l ha^{-1} (year 2).

Table 5

Embodied energy of machinery and infrastructure in the olive orchards monitored.

Machinery / infrastructure	Unit	Weight (kg)	Useful life	Embodied energy (MJ/Unit)	Source
Tractor	h	4700	16,000	28.1	Guzmán and Alonso (2008) adapted
Rotavator (Rotary tiller)	h	310	2500	17.7	Michos et al. (2017)
Cultivator	h	300	2500	17.1	Michos et al. (2017)
Branch destroyer	h	300	2500	17.7	Michos et al. (2017)
Sprayer	h	200	1500	19.1	Guzmán and Alonso (2008)
Chainsaw	h	10	2000	0.48	Guzmán and Alonso (2008)
Pump	h	200	12,000	2.4	Michos et al. (2017)
Harvesting tools	h	50	9000	1.5	Litskas et al. (2011)
Sprayer tank	h	100	1500	6.2	Guzmán and Alonso (2008) adapted
Pruning tools	h			0.05	Taxidis et al. (2015)
Electricity	kWh			12.1	Jarach (1985)

Table 6

Energy use in the olive orchards under study for the two-year monitoring period, including sum energy (SE) and its intensity and efficiency, non-renewable energy (NRE) and its efficiency, and summary information of mean and standard error (S.E.) values for each management system (organic, integrated, conventional).

	Year 1					Year 2					Total				
Olive orchards	SE use	NRE use	SE intensity	SE efficiency	NRE efficiency	SE use	NRE use	SE intensity	SE efficiency	NRE efficiency	SE use	NRE use	SE intensity	SE efficiency	NRE efficiency
1O	6930	5990	1.39	9.65	11.16	19,461	5204	11.45	1.17	4.37	26,391	11,195	3.94	3.39	8.00
1I	20,012	4180	15.39	0.87	4.16	14,405	1984	4.65	2.88	20.89	34,416	6163	7.82	1.71	9.54
1C	1492	1477	1.49	8.96	9.05	2443	1944	0.81	16.57	20.82	3935	3422	0.98	13.68	15.74
2O	562	496	2.56	5.23	5.92	855	698	0.39	34.39	42.13	1418	1195	0.59	22.82	27.08
2I	6750	5790	8.13	1.64	1.92	4401	3630	3.76	3.55	4.31	11,151	9421	5.58	2.40	2.84
2C	3119	2716	N.C.	N.C.	N.C.	1004	740	10.04	1.33	1.81	4123	3456	40.82	0.33	0.39
3O	6891	4734	3.06	4.37	6.35	4923	4669	1.08	12.38	13.06	11,814	9403	1.73	7.71	9.68
3I	17,595	4384	5.09	2.63	10.55	1752	1333	0.30	43.86	57.65	19,347	5717	2.10	6.36	21.53
3C	5647	5126	1.28	10.42	11.48	4642	4202	9.28	1.44	1.59	10,289	9328	2.10	6.37	7.02
4O	8877	5638	N.C.	N.C.	N.C.	3759	3319	0.40	33.74	38.21	12,636	8957	1.33	10.04	14.16
4I	2825	2482	0.78	17.04	19.40	5561	4593	1.28	10.46	12.66	8386	7074	1.05	12.68	15.02
4C	6355	2565	N.C.	N.C.	N.C.	5105	4305	0.57	23.57	27.95	11,460	6870	1.27	10.50	17.52
5O	6834	6293	0.73	18.33	19.91	10,239	9403	3.41	3.92	4.27	17,074	15,696	1.38	9.69	10.54
5I	18,557	11,740	4.64	2.88	4.56	7868	7221	3.42	3.91	4.26	26,425	18,961	4.19	3.19	4.44
5C	3384	3107	1.69	7.90	8.61	14,230	13,944	5.69	2.35	2.40	17,614	17,051	3.91	3.42	3.53
6O	7715	6379	0.77	17.33	20.96	1830	1266	1.83	7.30	10.56	9546	7645	0.87	15.41	19.24
6I	9474	7036	1.18	11.29	15.20	4091	3748	1.64	8.17	8.92	13,565	10,785	1.29	10.35	13.02
6C	14,024	5632	3.64	3.67	9.14	3501	3124	50.02	0.27	0.30	17,525	8756	4.47	2.99	5.99
7O	3321	3172	2.89	4.63	4.85	3331	3183	1.62	8.23	8.61	6652	6355	2.08	6.43	6.73
7I	6628	3116	13.26	1.01	2.15	3501	3281	2.92	4.58	4.89	10,129	6397	5.96	2.24	3.55
7C	14,962	8055	1.71	7.82	14.52	24,281	23,904	48.56	0.28	0.28	39,243	31,959	4.24	3.15	3.87
8O	3263	3087	1.75	7.62	8.06	3062	2827	0.68	19.65	21.28	6325	5914	0.99	13.44	14.38
8I	6266	5715	0.67	19.84	21.76	4010	3863	2.99	4.47	4.64	10,276	9578	0.97	13.84	14.85
8C	6201	5585	0.69	19.40	21.55	5230	4145	1.25	10.72	12.90	10,959	9730	0.84	15.86	17.86
Organic															
Mean	5074	4307	1.88	9.59	11.03	5933	3821	2.61	15.10	17.81	11,482	8295	1.61	11.12	13.73
S.E.	943	686	0.34	2.08	2.36	2035	899	1.23	4.28	4.91	2531	1398	0.35	2.00	2.23
Integrated															
Mean	10,668	5555	6.14	7.15	9.96	5699	3707	2.62	10.23	14.78	16,712	9262	3.62	6.60	10.60
S.E.	6229	2720	1.88	2.57	2.64	1299	586	0.47	4.57	6.04	3086	1434	0,87	1.66	2.21
Conventional															
Mean	7618	4283	1.75	8.31	10.62	7554	7038	15.78	7.07	8.51	14,394	11,321	7.38	7.04	8.99
S.E.	2084	2035	0.37	1.96	1.87	2591	2613	6.95	2.95	3.57	3729	3102	4.55	1.87	2.30

Energy intensity: Ratio of sum energy used (MJ ha-1) to olive fruit yield (kg ha-1)].

Energy efficiency: Ratio of sum (SE) and non-renewable (NRE) energy used (MJ ha^{-1}) to energy content of olive fruit yield (MJ ha^{-1}).

Olive orchards / management systems abbreviations: organic (code names: 1O to 8O), integrated (1I to 8I) and conventional (1C to 8C).

N.C.: value not counted due to zero olive yield, resulting in non-comparable values.

Table 7
Emissions (CO_2-eq ha^{-1}) and emissions intensity of the olive orchards under study for the two-year monitoring period, as well as summary information of mean and standard error (S.E.) values for each management system (organic, integrated, conventional).

	Year 1		Year 2		Total	
Olive orchards	Sum emissions	Emissions intensity	Sum emissions	Emissions intensity	Sum emissions	Emissions intensity
1O	5636	1,13	5310	3,12	10,946	1,63
1I	18,496	14,23	5039	1,63	23,535	5,35
1C	829	0,83	3869	1,28	4698	1,17
2O	340	1,54	470	0,21	810	0,33
2I	3886	4,68	7312	6,25	11,198	5,60
2C	1584	N.C.	10,570	105,70	12,154	121,54
3O	5369	2,39	3128	0,69	8496	1,25
3I	28,107	8,12	698	0,12	28,805	3,13
3C	5349	1,22	3709	7,42	9058	1,85
4O	6575	N.C.	2222	0,23	8797	0,93
4I	4586	1,27	2956	0,68	7542	0,95
4C	2811	N.C.	15,043	1,67	17,854	1,98
5O	4297	0,46	12,740	4,25	17,037	1,38
5I	18,798	4,70	4715	2,05	23,513	3,73
5C	1658	0,83	11,334	4,53	12,992	2,89
6O	4710	0,47	3289	3,29	7999	0,73
6I	15,934	1,99	3258	1,30	19,193	1,83
6C	16,839	4,37	3165	45,21	20,004	5,10
7O	2107	1,83	2667	1,30	4774	1,49
7I	9113	18,23	1569	1,31	10,682	6,28
7C	31,015	3,54	28,693	57,39	59,709	6,45
8O	2195	1,18	1873	0,42	4068	0,64
8I	11,654	1,25	3026	2,26	14,679	1,38
8C	4111	0,46	10,177	2,54	14,289	1,10
Organic						
Mean	3903	1.29	3962	1.69	7866	1.05
S.E.	706	0.25	1258	0.53	1623	0.15
Integrated						
Mean	13,822	6.81	3571	1.95	17,393	3.53
S.E.	2698	2.09	690	0.62	2489	0.68
Conventional						
Mean	8025	1.87	10,820	28.22	18,845	17.76
S.E.	4405	0.62	2783	12.64	5684	13.27

Emissions intensity: Ratio of sum emissions (CO_2-eq ha^{-1}) to olive fruit yield (kg ha^{-1}).
Olive orchards / management systems abbreviations: organic (code names: 1O to 8O), integrated (1I to 8I) and conventional (1C to 8C).
N.C.: value not counted due to zero olive yield, resulting in outlier values.

Table 8
Results of the Kruskall-Wallis statistical test applied for the comparison of management systems (organic, integrated and conventional) in terms of energy use for different inputs, sum energy (SE), its intensity and efficiency, non-renewable energy (NRE) and its efficiency, GHG emissions in terms of fossil fuels and fertilizer inputs, pruning residues management and emissions intensity.

Input / management practice		Year 1	Year 2 $\chi^2(p)$	Total
Energy use	SE	2.34	0.64	1.12
	NRE	1.18	0.42	0.18
	Fossil fuels	1.21	0.81	0.15
	Fertilizers	2.70	0.70	2.62
	Pesticides	16.63**	13.81**	16.12**
	Labour	0.84	5.78	3.45
	SE intensity	0,21	3.30	2.88
	SE efficiency	0.24	3.03	2.89
	NRE efficiency	0.02	3.78	1.62
Emissions	Sum emissions	5.71	7.28*	7.44*
	Fossil fuels	0.50	0.81	0.46
	Fertilizer use	3.73	0.37	4.18
	Pruning residues burn	3.31	21.81**	13.27**
	Emissions intensity	3.01	7.03**	9.38**

Level of significance: * $p < 0.05$; ** $p < 0.01$.

Table 9
Results of the What-if (sensitivity) analysis simulating the effect of best management practices included in the CO_2MPUTOLIV guidelines, on the olive orchard processes, inputs and outputs; Ranging values (1 to 10; 1: Reduction, 5: No change, 10: Increase) represent the response of processes to an increasing intensity of best practices application.

Management parameters		Effect on olive orchards processes, inputs and outputs					
Category	Best practice	Pest control	Soil fertility	Fertilizer use	Machinery use	Irrigation	Yield
Soil management	Soil cover	5	8	3	3	3	5
	Minimum soil tillage	7	1	7	9	9	5
Fertilization	Rational fertilizer application	6	2	9	6	7	8
Plant protection	Olive pests monitoring & rational control	10	5	5	6	5	9
Irrigation	Efficient irrigation methods	5	5	6	5	8	9
Canopy management	Regular tree pruning and residues management	7	5	5	7	5	7
Biodiversity	Biodiversity conservation & enhancement	7	7	4	4	4	6
Equipment	Rational use of equipment	5	5	5	8	5	6
Harvest	Appropriate harvest date & climate conditions	5	5	5	5	6	7

References

Altieri, M.A., 1999. The ecological role of biodiversity in agroecosystems. Agric. Ecos. Environ. 74, 19–31. doi:10.1016/S0167-8809(99)00028-6.

Alonso, A.M., Guzmán, G.J., 2010. Comparison of the efficiency and use of energy in organic and conventional farming in Spanish agricultural systems. J. Sustain. Agr. 34 (3), 312–338. doi:10.1080/10440041003613362.

Angevin, F., Fortino, G., Bockstaller, C., Pelzer, E., Messéan, A., 2017. Assessing the sustainability of crop production systems: toward a common framework? J. Crop Prot. 97, 18–27. doi:10.1016/j.cropro.2016.11.018.

Audsley, E., Alber, S., Clift, R., Cowell, S., Crettaz, P., Gaillard, G., Hausheer, J., Jolliet, O., Kleijn, R., Mortensen, B., Pearce, D., Roger, E., Teulon, H., Weidema, B., van Zeijts, H., 1997. Final Report, Concerted Action AIR3-CT94-2028, European Commission DG VI, Brussels, Belgium https://www.researchgate.net/profile/Eric_Audsley/publication/258966401_EU_Concerted_Action_report_HARMONISATION_OF_ENVIRONMENTAL_LIFE_CYCLE_ASSESSMENT_FOR_AGRICULTURE_Final_Report_Concerted_Action_AIR3-CT94-2028/links/00463529865607368b000000/EU-Concerted-Action-report-HARMONISATION-OF-ENVIRONMENTAL-LIFE-CYCLE-ASSESSMENT-FOR-AGRICULTURE-Final-Report-Concerted-Action-AIR3-CT94-2028.

Barker, J.C., Hodges, S.C., Walls, F.R., 2002. Livestock manure production rates and nitrogen content. North Carolina Department of agriculture and Consumer Services, http://ipmwww.ncsu.edu/agchem/chptr10/1011.pdf.

Bernoux, M., Branca, G., Carro, A., Lipper, L., Smith, G., Bockel, L., 2010. Ex-ante greenhouse gas balance of agriculture and forestry development programs. Sci. Agr. 67 (1), 31–40.

Bouat, A., 1974. Physiologie de l'olivier en relation avec son amélioration culturale. CIHEAM, Options Mediterr. 24, 63–68. https://om.ciheam.org/om/pdf/r24/CI010569.pdf.

Bouwman, A.F., 1995. Compilation of a global inventory of emissions of Nitrous oxide Ph.D. thesis. University of Wageningen, the Netherlands.

Carof, M., Godinot, O., 2018. A free online tool to calculate three nitrogen-related indicators for farming systems. Agric. Syst. 162, 28–33. doi:10.1016/j.agsy.2018.01.015.

Chatzisymeon, E., Foteinis, S., Mantzavinos, D., Tsoutsos, T., 2013. Life cycle assessment of advanced oxidation processes for olive mill wastewater treatment. J. Clean. Prod. 54, 229–234. doi:10.1016/j.jclepro.2013.05.013.

Corinair, E.,1996. Guide inventory guidebook. B810, other mobile sources and machinery. https://www.eea.europa.eu/publications/EMEPCORINAIR5/page017.html.

Davis, J., 1999. Life cycle inventory (LCI) of fertiliser production: fertiliser products used in Sweden and Western Europe. SIK Institutet för livsmedel och bioteknik, Göteborg, Sverige.

Dyer, J.A., Desjardins, R.L., 2003. Simulated farm fieldwork, energy consumption and related greenhouse gas emissions in Canada. Biosyst. Eng. 85 (4), 503–513. doi:10.1016/S1537-5110(03)00072-2.

EIP-AGRI, 2017. EIP-AGRI Workshop on Tools for environmental farm performance: Final report. EIP-AGRI Agriculture & Innovation https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/eip-agri_ws_tools_for_environmental_farm_performance_final_report_2017_en.pdf.

EPA, U., 2014. Emission factors for greenhouse gas inventories. Stationary combustion emission factors," US Environmental Protection Agency 2014, https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf.

Espadas-Aldana, G., Vialle, C., Belaud, J.P., Vaca-Garcia, C., Sablayrolles, C., 2019. Analysis and trends for life cycle assessment of olive oil production. Sustain. Prod. Consum. 19, 216–230. doi:10.1016/j.spc.2019.04.003.

Eurostat. Agriculture, Forestry and Fishery Statistics, 2014 ed.; Eurostat: Luxembourg City, Luxembourg, 2015.

Fluck, R.C., 1992. Energy in Farm Production. Elsevier, the Netherlands.

Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Zaks, D.P., 2011. Solutions for a cultivated planet. Nature 478 (7369), 337–342. doi:10.1038/nature10452.

France, G.D., Thompson, D.C., 1993. An overview of efficient manufacturing processes. In: Proceedings of the fertilizer Society n° 337. Greenhill House, Peterborough.

Gellings, C.W., Parmenter, K.E., 2004. Energy efficiency in fertilizer production and use. Efficient Use and Conservation of Energy, Encyclopedia of Life Support Systems. Eolss Publishers, Oxford, UK https://sswm.info/sites/default/files/reference_attachments/GELLINGS%20et%20al%202004%20Energy%20Efficiency%20in%20Fertiliser%20Production.pdf.

Genitsariotis, M., Stougioti, O., Tsarouhas, B., Chlioumis, G., 1996. Alternative farming practices in integrated olive groves. Aristotle University of Thessaloniki, Greece (in Greek).

Georgiou, K., Mentzis, A., Papadopoulos, A., Vageloglou, V., Papadakis, G.A., 2006.TASK 3.1 implementation of life cycle inventory in Voukolies /PolemarchiRegion of Crete (No. 3.1). Technical University of Crete, Crete, Greece.

Georgopoulou, E., Mirasgedis, S., Sarafidis, Y., Vitaliotou, M., Lalas, D.P., Theloudis, I., ..., Zavras, V., 2017. Climate change impacts and adaptation options for the Greek agriculture in 2021–2050: a monetary assessment. Clim. Risk Manag. 16, 164–182. doi:10.1016/j.crm.2017.02.002.

Gomiero, T., Pimentel, D., Paoletti, M.G., 2011. Environmental impact of different agricultural management practices: conventional vs. organic agriculture.. Crit. Rev. Plant Sci. 30 (1–2), 95–124. doi:10.1080/07352689.2011.554355.

Gosling, J. (2000). The Java language specification. Addison-Wesley Professional.

Guarino, F., Falcone, G., Stillitano, T., De Luca, A.I., Gulisano, G., Mistretta, M., Strano, A., 2019. Life cycle assessment of olive oil: a case study in southern Italy. J. Environ. Manag. 238, 396–407. doi:10.1016/j.jenvman.2019.03.006.

Guzmán, G.I., Alonso, A.M., 2008. A comparison of energy use in conventional and organic olive oil production in Spain. Agric. Syst. 98 (3), 167–176. doi:10.1016/j.agsy.2008.06.004.

Haas, G., Wetterich, F., Köpke, U., 2001. Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment. Agric. Ecosyst. Environ. 83 (1–2), 43–53. doi:10.1016/S0167-8809(00)00160-2.

Haverkort, A.J., Hillier, J.G., 2011. Cool farm tool–potato: model description and performance of four production systems. Potato Res. 54 (4), 355–369. doi:10.1007/s11540-011-9194-1.

Hemmati, A., Tabatabaeefar, A., Rajabipour, A., 2013. Comparison of energy flow and economic performance between flat land and sloping land olive orchards. Energy J. 61, 472–478. doi:10.1016/j.energy.2013.09.006.

IOR Energy (2008). List of common conversion factors (Engineering conversion factors).

IPCC (1996). Guidelines for national greenhouse gas inventories. In: Greenhouse Gas Inventory Reference Manual. Intergovernmental Panel on Climate Change, Paris.

ISO 14040 (2006a). Environmental management. Life cycle assessment. Principles and framework. International Standard of Organization, Geneva.

ISO 14044 (2006b). Environmental management. Life cycle assessment. requirements and guidelines. International Standard of Organization, Geneva.

Jarach, M., 1985. Sui valori di equivalenza per l'analisi e il bilancio energetici in agricoltura. Riv. Ing. Agr. 2, 102–114.

Kabourakis, E., 1999. Code of practices for ecological olive production systems. Olivae 77, 46–55.

Kaltsas, A.M., Mamolos, A.P., Tsatsarelis, C.A., Nanos, G.D., Kalburtji, K.L., 2007. Energy budget in organic and conventional olive groves. Agric. Ecosyst. Environ. 122 (2), 243–251. doi:10.1016/j.agee.2007.01.017.

Kavargiris, S.E., Mamolos, A.P., Tsatsarelis, C.A., Nikolaidou, A.E., Kalburtji, K.L., 2009. Energy resources' utilization in organic and conventional vineyards: energy flow, greenhouse gas emissions and biofuel production. Biomass Bioenergy 33 (9), 1239–1250. doi:10.1016/j.biombioe.2009.05.006.

Kroeze, C., Bogdanov, S., 1997. Application of two methods for N_2O emission estimates to Bulgaria and the Netherlands. Idöjárás. Q. J. Hung. Meteorol. Serv. 101, 239–260.

Litskas, V.D., Mamolos, A.P., Kalburtji, K.L., Tsatsarelis, C.A., Kiose-Kampasakali, E., 2011. Energy flow and greenhouse gas emissions in organic and conventional sweet cherry orchards located in or close to Natura 2000 sites. Biomass Bioenergy 35 (3), 1302–1310. doi:10.1016/j.biombioe.2010.12.023.

Mateus, M.D., Franz, G., 2015. Sensitivity analysis in a complex marine ecological model. Water (Basel) 7 (5), 2060–2081. doi:10.3390/w7052060.

Michos, M.C., Mamolos, A.P., Menexes, G.C., Tsatsarelis, C.A., Tsirakoglou, V.M., Kalburtji, K.L., 2012. Energy inputs, outputs and greenhouse gas emissions in organic, integrated and conventional peach orchards. Ecol. Indic. 13 (1), 22–28. doi:10.1016/j.ecolind.2011.05.002.

Michos, M.C., Menexes, G.C., Kalburtji, K.L., Tsatsarelis, C.A., Anagnostopoulos, C.D., Mamolos, A.P., 2017. Could energy flow in agro-ecosystems be used as a "tool" for crop and farming system replacement? Ecol. Indic. 73, 247–253. doi:10.1016/j.ecolind.2016.09.050.

Michos, M.C., Menexes, G.C., Mamolos, A.P., Tsatsarelis, C.A., Anagnostopoulos, C.D., Tsaboula, A.D., Kalburtji, K.L., 2018. Energy flow, carbon and water footprints in vineyards and orchards to determine environmentally favourable sites in accordance with Natura 2000 perspective. J. Clean. Prod. 187, 400–408. doi:10.1016/j.jclepro.2018.03.251.

Mobtaker, H.G., Akram, A., Keyhani, A., 2012. Energy use and sensitivity analysis of energy inputs for alfalfa production in Iran. Energy Sustain. Dev. 16 (1), 84–89. doi:10.1016/j.esd.2011.10.009.

Mudahar, M.S., Hignett, T.P., 1987a. Energy in plant nutrition and pest control. In: Helsel, Z.R. (Ed.). In: Energy in World Agriculture, 2. Elsevier, Amsterdam, pp. 1–23 AmsterdamOSTI ID: 5289491.

Mudahar, M.S., Hignett, T.P., 1987b. Energy requirements, technology, and resources in the fertilizer sector. In: Helsel, Z.R. (Ed.). In: Energy in World Agriculture, 2. Elsevier, Amsterdam, pp. 25–61 OSTI ID: 5289491.

Murphy, P., Crosson, P., O'Brien, D., Schulte, R.P., 2013. The carbon navigator: a decision support tool to reduce greenhouse gas emissions from livestock production systems. Animal 7 (s2), 427–436. doi:10.1017/S1751731113000906.

Pimentel, D., 1980. CRC Handbook of Energy Utilization in Agriculture. CRC press, inc, Boca Raton FL. 1980.

Pimentel, D., Hepperly, P., Hanson, J., Douds, D., Seidel, R., 2005. Environmental, energetic, and economic comparisons of organic and conventional farming systems. Bioscience 55 (7), 573–582 10.1641/0006-3568(2005)055[0573:EEAECO]2.0.CO;2.

Power, A.G., 2010. Ecosystem services and agriculture: trade-offs and synergies. Philosophical transactions of the royal society. J. Biol. Sci. 365 (1554), 2959–2971. doi:10.1098/rstb.2010.0143.

Rockström, J., Steffen, W.L., Noone, K., Persson, Å., Chapin III, F.S., Lambin, E., Foley, J., 2009. Planetary boundaries: exploring the safe operating space for humanity. http://archives.pdx.edu/ds/psu/8946.

Rose, D.C., Sutherland, W.J., Parker, C., Lobley, M., Winter, M., Morris, C., Twining, S., Ffoulkes, C., Amano, T., Dicks, L.V., 2016. Decision support tools for agriculture: towards effective design and delivery. Agric. Syst. 149, 165–174. doi:10.1016/j.agsy.2016.09.009.

Russo, C., Cappelletti, G.M., Nicoletti, G.M., Di Noia, A.E., Michalopoulos, G., 2016. Comparison of European olive production systems. Sustain 8, 1–11. doi:10.3390/su8080825.

Schader, C., Grenz, J., Meier, M.S., Stolze, M., 2014. Scope and precision of sustainability assessment approaches to food systems. Ecol. Soc. 19 (3), 42. doi:10.5751/ES-06866-190342.

Schader, C., Baumgart, L., Landert, J., Muller, A., Ssebunya, B., Blockeel, J., Weisshaidinger, R., Petrasek, R., Mészáros, D., Padel, S., Gerrard, C., Smith, L., Lindenthal, T., Niggli, U., Stolze, M., 2016. Using the sustainability monitoring and assessment routine (SMART) for the systematic analysis of trade-offs and synergies between sustainability dimensions and themes at farm level. Sustain 8 (3), 274–294. doi:10.3390/su8030274.

Strapatsa, A.V., Nanos, G.D., Tsatsarelis, C.A., 2006. Energy flow for integrated apple production in Greece. Agric. Ecosyst. Environ. 116 (3–4), 176–180. doi:10.1016/j.agee.2006.02.003.

Taxidis, E.T., Menexes, G.C., Mamolos, A.P., Tsatsarelis, C.A., Anagnostopoulos, C.D., Kalburtji, K.L., 2015. Comparing organic and conventional olive groves relative to energy use and greenhouse gas emissions associated with the cultivation of two varieties. Appl. Energy 149, 117–124. doi:10.1016/j.apenergy.2015.03.128.

Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., Polasky, S., 2002. Agricultural sustainability and intensive production practices. Nature 418 (6898), 671–677. doi:10.1038/nature01014.

Tsarouhas, P., Achillas, C., Aidonis, D., Folinas, D., Maslis, V., 2015. Life cycle assessment of olive oil production in Greece. J. Clean. Prod. 93, 75–83. doi:10.1016/j.jclepro.2015.01.042.

Volakakis, N., Stergiadis, S., Papamanolioudaki, A., Stefanoudaki, E., Kiritsakis, A., Eyre, M.D., ... Kabourakis, E., 2011. Effect of management system and geographic position on olive oil quality in Crete, Greece. In: Proceedings of the 4th International Conference Olivebiotech 2011: Olive Culture and Biotechnology of Olive Tree Products. Newcastle University.

Volakakis, N., Kabourakis, M.E., Leifert, C., 2017. Conventional and organic cultivation and their effect on the functional composition of olive oil. In: Kiritsakis, A., Shahidi, F. (Eds.), Olives and Olive Oil As Functional Foods: Bioactivity, Chemistry and Processing. Wiley, Oxford, pp. 35–43.

Wells, L., 2001. The Curing Season. Grand Central Publishing.

Wibbelmann, M., Schmutz, U., Wright, J., Udall, D., Rayns, F., Kneafsey, M., Trenchard, L., Bennett, J., Lennartsson, M., 2013. Mainstreaming agroecology: implications for global food and farming systems. Centre for agroecology and food security discussion paper. Coventry: Centre for Agroecology and Food Security. ISBN: 978-1-84600-0454.

Zafiriou, P., Mamolos, A.P., Menexes, G.C., Siomos, A.S., Tsatsarelis, C.A., Kalburtji, K.L., 2012. Analysis of energy flow and greenhouse gas emissions in organic, integrated and conventional cultivation of white asparagus by PCA and HCA: cases in Greece. J. Clean. Prod. 29, 20–27. doi:10.1016/j.jclepro.2012.01.040.