Evaluation of sustainable innovations in olive growing systems: A Life Cycle Sustainability Assessment case study in southern Italy.

Evaluation of sustainable innovations in olive growing systems: a Life Cycle Sustainability Assessment case study in southern Italy

Anna Irene De Luca[a], Giacomo Falcone[a], Teodora Stillitano[a], Nathalie Iofrida[a*], Alfio Strano[a] and Giovanni Gulisano[a]

[1]Department of Agriculture (AGRARIA), Mediterranean University of Reggio Calabria, Feo di Vito, 89122 Reggio Calabria, Italy

[*]Corresponding author. Tel.: +39 (0)965 1694230; E-mail address: nathalie.iofrida@unirc.it

ABSTRACT

Innovations are increasingly needed by companies to engage in new market competitiveness. Conscientious consumers are demanding sustainable products and services, and “new qualities” are requested, such as environmental protection, social equitability and economic viability. To satisfy this demand, companies are struggling to find innovative solutions to sustainability concerns.

The present paper proposes an innovative and integrated approach, i.e., the Life Cycle Sustainability Assessment, a methodology that is still under development within the conceptual framework of Life Cycle Thinking (Kloepffer, 2008). Life Cycle Assessment, Life Cycle Costing and social Life Cycle Assessment are integrated here by means of a multicriterial and participative method, the Analytic Hierarchy Process.

This case study is about growing Calabrian olives, which is the most important crop in terms of surface area at a regional level. The study focuses on an important agronomic practice, i.e., weeding. The functional unit is 1 hectare of cultivated surface, and the system boundary is “from cradle to farm gate”. The time boundary considered here is the expected life of an olive tree corresponding to 50 years. All of the primary data have been gathered through specific in-field surveys with semi-structured questionnaires to farmers and workers.

Nine impact categories and quantitative indicators, direct and/or proxy, cover the three primary sustainability dimensions, i.e., environment, economy and society. Three scenarios have been chosen for their relevance to the Calabrian panorama as follows:

- a control scenario (CS), which is represented by the conventional and traditional farming system, that commonly recurs according to the use of chemicals for weed and pest control;
- a low-dosage/no-tillage (LDNT) scenario, as represented by a reduced use of chemicals; and
- a zero chemical weeding (ZCW) scenario, representing the organic farming system.

The results of the multicriterial analysis revealed that the greatest stakeholder concerns are environmental and social sustainability, especially in terms of toxicity and worker health. According to these preferences, low-dosage/no-tillage was the best scenario, with better performance for all of the selected categories except for job opportunities.

Holistic sustainability assessments, especially those involving relevant stakeholders, are essential strategies for successfully satisfying and retaining customers, and the present epistemological hybrid proposal to the Life Cycle Sustainability Assessment could serve this purpose.

Keywords: Agricultural innovations; Olive growing systems; Life Cycle Sustainability Assessment; Multi Criteria Decision Analysis; Participative techniques

1. Introduction

Sustainability has become the leading paradigm of current policies, management practices, and research themes in many fields. Consumers have become more conscientious, and they have oriented their preferences towards healthy and low-impact products. Therefore, companies are increasingly needing to re-engineer their production systems to satisfy this demand for products and services with

these “new qualities” (Ghobadian et al., 1994; Buzzell and Gale, 1987; Zeithaml, 2000; Enquist and Edvardsson, 2007; Annunziata and Vecchio, 2016; Silva et al., 2017).
Agriculture is one of the primary responsible sectors in terms of sustainability concerns, and it is directly involved in the use and consumption of natural resources such as water and soil through the emission of GHGs and the use of pesticides and fertilizers, with impacts on human well-being in terms of food quality, access to resources, and rural economies (Benis and Ferrao, 2016).
The so-called green products, i.e., those demonstrating (e.g., by means of certifications and labels) more environmental friendliness, have largely attracted a consensus in recent years in the global markets. Environmentally friendly behaviours among consumers have increased, with notable improvements within the food category (Greendex, 2014; Paul et al., 2016). Green consumers are not only concerned about environmental issues, but they are also socially responsible consumers who account for the socioeconomic consequences of their private consumption and trust that their purchasing power can bring about social change (Moisander, 2007; Joshi and Rahman, 2015).
In recent decades, agriculture has been shown to be able to tolerate the challenge of the sustainable paradigm, with producers implementing principles of agro-ecological production, alternative food networks, and local food systems, together with productivist systems that have adhered to the principles of sustainability (Faure et al., 2013). These innovative agricultural systems not only consist of new technical or organizational solutions; the core issue in sustainable innovation is about how knowledge is produced and shared. Processes should be innovated by connecting scientific research, stakeholders, local actors and policy makers and fostering participation and collaboration between these different types of actors (Triomphe and Rajalahti, 2013).
Entrepreneurship is considered to have great responsibility for sustainable innovations by putting into practice any analytical insights provided by research and by fostering processes that are socially inclusive and ecology oriented (Sarkar and Pansera, 2015). Companies are therefore requested to innovate and adapt to new market challenges; in turn, they could become economically resilient and gain more market shares (Klewitz and Hansen, 2014). Figure 1 illustrates some examples of possible innovations in agriculture according to three primary concerns of sustainability, i.e., the environment, the economy and the people.

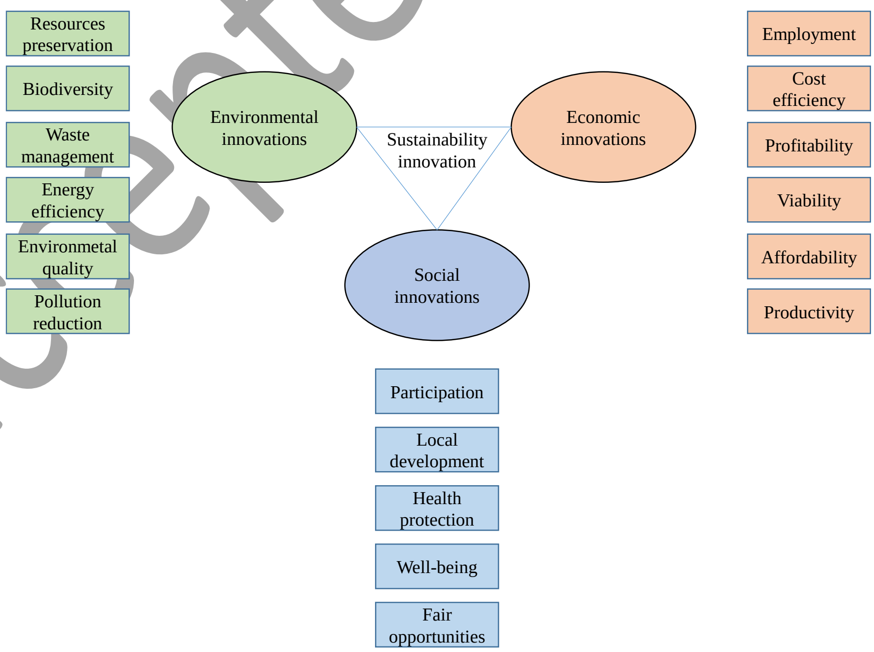


Figure 1 - Sustainability innovations in agriculture, primary examples.

Even if this trinomial conception of sustainability has been strongly criticized because it does not catch interrelations between these and other dimensions, it remains the most frequently applied concept because it is easily adapted to management and accounting contexts (Iofrida et al., 2016; De Luca et al., 2017).

Defining and measuring innovation performances towards sustainability goals in the real world requires reliable evaluation tools to understand the direction in which any changes should be oriented. In fact, sustainable innovation is considered to be “any new or significant improvement of products, services, technological or organizational processes, commercialized or internally implemented, that not only provide economic benefits but also generate positive social and environmental impacts” (Calik and Barbudeen, 2016:449). Assessment practices are required to collect all these factors and account for several conflicting criteria, over a long-term perspective, while accounting for the foreground and background aspects of the system under scrutiny.

Recently, the Life Cycle Sustainability Assessment (LCSA) has been conceived as an integrative and holistic methodology that can comply with these different issues. In taking into account environmental, economic and social constraints, the life cycle perspective enables an understanding of how impacts can shift among life cycle phases and which hotspots occur, and it can allow for comparisons among different solutions (scenarios) and therefore show how innovations can be successful. This approach has been conceived to help decision-making processes, to orient management practices and to communicate information to users such as stakeholders, shareholders, consumers, local actors, etc. The methodology is not yet standardized because it is still under development. The primary difficulties derive from the integration of different disciplines and their inherent epistemologies (Iofrida et al., 2016).

The aim of the present study is to try to overcome this integration difficulty by means of a multicriterial method, the AHP by Saaty (1990). In fact, according to De Luca et al. (2017), many Life Cycle practitioners use the MCDA that, thanks to its flexibility, can help address subjective assumptions in an objective way, to consider the actors’ concerns and to resolve the trade-offs among the different dimensions of sustainability (Cinelli et al., 2014). The choice of the most appropriate MCDA method to apply is not obvious; for the purpose of this research, AHP has been chosen because it allows the user to obtain a set of relative weights without absolute assertions, to discard inconsistent answers and therefore preserve objectivity.

The object of analysis is weeding management, one of the most important agronomic practices in the Mediterranean area, because it strongly influences the soil quality, water management and yields. This case study is about Calabrian olives growing (in particular, the hilly area of Gioia Tauro and its neighbours), the most important cultivation area at the regional level, and a representative crop of the entire Mediterranean area. Calabria is the second region in Italy in terms of olives growing area, with approximately 186,000 ha, representing the most important agro-food supply chain, contributing to economic development, especially in rural areas (Stillitano et al., 2016). However, the olive growing systems are characterized by obsolete productive structures that have high production costs (Strano et al., 2014) and low productivity, due to the lack of mechanized agricultural practices such as pruning and harvesting (Bernardi et al., 2016). This economic weakness has also repercussions with on the social sphere; for example, agricultural workers generally receive low wages, and they are often illegally employed. The environment is also affected by the use of pesticides, fertilizers and other chemicals, with repercussions on workers health, as well. These failures make farms less competitive on the market. To increase their profitability, they must rationalize their management practices, by optimizing their resource use in a more effective and sustainable way. Different weeding practices are therefore compared to find the most (probably) sustainable solution.

2. Life Cycle Sustainability Assessment (LCSA): theoretical background

The Life Cycle Sustainability Assessment (LCSA) appeared in the life cycle discourse quite early. Kloepffer (2008) first discussed the problem of integrating multiple aspects (such as environmental, economic and social ones) into the Life Cycle (LC) perspective, especially when referring to the use of a functional unit, cut-off criteria and system boundaries. Since the beginning, there has been a specific and persistent reference to the “three pillars” approach of sustainability, i.e., environmental

protection, economic viability and social equity, and the LCSA has been proposed as the LC-oriented solution (Kloepffer, 2008; Finkbeiner et al., 2010; Valdivia et al., 2013; Hall, 2015).
The first attempts at merging LC tools were written by O'Brien et al. (1996), who discussed an approach to jointly assess the social and environmental impacts (SELCA), while Zhou et al. (2007) combined the Life Cycle Assessment (LCA) with Life Cycle Costing (LCC). After them, Kloepffer (2008) provided the first definition of the LCSA. The author focused on the consensus gathered by the "three pillar model", or Triple Bottom Line (TBL) when using business language (Elkington, 1997), and defined the LCSA as the sum of all the LC tools. Therefore, LCSA = LCA + LCC + sLCA, with LCA as the environmental LCA, LCC as an LCA-type LCC, and social LCA (sLCA) as their social pair (Finkbeiner et al., 2010). Guinée et al. (2011) describe the LCSA as an LCA with a broadened scope from environmental impacts to the other "dimensions of sustainability", but also a broadened object of analysis, from products and services to sectors, economic and social behaviours, physical and technological relations.
The integration of the three methodologies requires new knowledge and research programs because the LCSA "is a transdisciplinary integration framework of models rather than a model in itself" (Guinée et al., 2011:90). Therefore, the primary challenge of the LCSA is to integrate different disciplines, with each one having its own epistemological questions, models and practices (De Luca et al., 2015c).
However, upon reviewing the literature on this subject, a very different perspective emerges. To analyse the available scientific literature, publications were gathered using the Scopus research engine and ScienceDirect website under the keywords "Life Cycle Sustainability Assessment" AND "LCSA" for article titles, abstracts and article keywords. As a result, 69 scientific contributions fitting the topic were selected, and they were published from 2007 to 2016. The inclusion criteria were about a clear statement of conducting or discussing an LCSA methodology; the exclusion criteria concerned the absence of scientific indexing (doi).
In trying to understand which concept of LCSA was primarily applied, the review found that 45% of the studies referred to a "holistic perspective" (Onat et al., 2014) as well as a "system analytic tool" (Finkbeiner et al., 2010) or "system wide approach" (Sala et al., 2013a, 2013b). Some authors report that most of the approaches have a reductionist nature, addressing the complexity of a broad evaluation by combining the final results instead of applying a truly merged methodology at the modelling phase (Stefanova et al., 2014). In confirming this argument, most of the analysed papers (60%) referred to the three pillars approach to justify the application of three separate evaluations (LCA, LCC, and sLCA). Furthermore, some authors clearly declared that the development of the LCSA lay in the improvement of each LC method, underlying the decline of sustainability in three separate dimensions (Klöpffer and Ciroth, 2011; Pesonen and Horn, 2013); therefore, the LCSA is never a hybrid methodology but primarily a sum of methodologies (Ren et al., 2015). The primary difficulty involved in integrating different assessment tools lies in the epistemological bases of these disciplines, which is the way that reality is intended and in how facts are analysed or interpreted (Phoenix et al., 2013; Iofrida et al., 2016).
To resolve this issue, many authors applied separate LC tools and resorted to other methods to integrate the final LC results. As highlighted in a previous study by De Luca et al. (2017), the Multicriteria Decision Analysis (MCDA) methods are the most frequently applied to aggregate the final LC results, as highlighted by the fact that 65 scientific studies can be found for the period from 1997-2016.
Generally, the MCDA can represent an efficient tool in all the cases in which there is a need to guarantee several conditions. First, the goal is to achieve a rational and comprehensive comparison of alternatives that respond differently to various dimensions; then, it is to manage multiple conflicting objectives systematically, with several criteria or indicators that are characterized by incomparable units (Pohekar and Ramachandran, 2004). Finally, another condition is to identify widely acceptable solutions that are able to reconcile, balance, aggregate and/or integrate all the different objectives under consideration.

In that their study, De Luca et al (2017) found different typologies of integration between the MCDA and LC tools. In the first group, the MCDA methods were applied as a part of an LC framework, to complement the significance of evaluation results or to allow the combination and synthesis of different types of insights. In a second group, the LC results were considered as parts (indicators) of a wider multicriterial framework, while a third group considered the LC tools and MCDA methods on the same level and with the same importance, and therefore, they were fully merged.
According to De Luca et al. (2017), the primary use of the MCDA method in LC studies has been to identify scenarios, to select impact categories, and, very often, to weight and assign scores to results or indicators. Furthermore, the MCDA methods have participative purposes, promoting the roles of stakeholders in the decision-making process, eliciting directly their preferences and, thus, providing transparent and unbiased information potentially useful for political actions based on contextual knowledge (De Luca et al., 2015b). Among all MCDA methods, AHP is a measurement method, based on the judgements of experts, that enable to derive priority scales based on relative weights (Saaty, 2008), generally used to evaluate alternatives and to solve complex decisional problems.

3. Material and methods

3.1. Case study description

The object of analysis in this study is olive orchard management in the hilly area of "Gioia Tauro Plain" (GTP), one of the most representative olive growing areas of the Calabria region. It includes 16 municipalities that are located on the western mountainside of "Aspromonte"; even if traditional olive groves remain the most widespread cultivation system (Bernardi et al., 2016), especially in hilly and mountainous areas, increasing attention is being paid to intensive systems (Stillitano et al., 2017).
A preliminary territorial survey consisting of both desk and field research was performed to outline the olive growing peculiarities in the analysed area. Specifically, at the desk level, current official statistics have been used as reference, as well as previous studies by the same authors; while, at field level, privileged witnesses involved in olive growing operations have been consulted. As a result, the territorial analysis allowed us to highlight that the biggest concern about growing olives in the hills is related to weed control. This farming operation can have critical consequences from environmental, economic and social points of view. For example, mechanical weeding in hilly areas can be dangerous for tractor drivers and can contribute to soil degradation, the pauperization of nutritional reserves, GHG emissions due to root damage (Cerutti et al., 2015; Deytieux et al., 2012) and problems for the local population due to erosion and landslides.
Chemical weeding might seem preferable, but this technique is not always suitable (e.g., in organic farming), and it has heavy effects in terms of human toxicity and ecotoxicity due to herbicide emissions and to soil degradation because it removes the grass cover. Furthermore, according to many authors, strong associations have been found between agricultural chemicals and diseases such as cutaneous melanoma, non-Hodgkin's lymphoma, renal cell carcinoma, and Parkinson's disease (Hu et al., 2002; Fritschi et al., 2005; Elbaz et al., 2009; Fortes et al., 2016).
Commonly, weed control consists of the use of chemical herbicides with the mechanical removal of grass cover (Stillitano et al., 2016), therefore combining the above-mentioned negative effects.
All of the primary data about inputs and outputs are derived from specific in field surveys that were conducted by means of custom-fitted questionnaires and face-to-face interviews with farmers.
For the purpose of this study, a group of 30 farms, who were characterized as having an average surface of 5 ha, were analysed through a semi-structured questionnaire to gather data about ordinary olive grove management. In particular, this data collection was related to farm production, farm inputs, machinery use for farm management, direct and indirect cost items (wages, quotas, interests and land rent). Direct interviews with local entrepreneurs have allowed the measurement of potential social effects in these contexts.
The farms included in this sample were chosen for their productive significance (representativeness of the territory) and their distribution in the area along the hilly side of the GTP. After the collection

of input and output data (Table 1, Supplemental Material 1), a standard management system was planned, and it defined the average farm inputs (types and quantities of agricultural inputs), machinery use for farm management (e.g., fertilizer application, tillage, pruning, etc.), working hours and other factors.

Given all the farming operations, and with the objective of defining a more sustainable weeding technique, three different scenarios were designed as follows:

- a control scenario (CS), as represented by the conventional and traditional farming system, that commonly involves the use of chemicals for weed and pest control;
- a low-dosage/no-tillage (LDNT) scenario, as represented by a reduced use of chemicals and machinery; and
- a zero chemical weeding (ZCW) treatment, representing the organic farming system in which weed control is only performed mechanically.

The CS is characterized by the use of a high quantity of glyphosate (up to 6 Kg ha^{-1}). The LDNT scenario entails a reduced quantity of herbicide (0.5 Kg ha^{-1}), which is distributed only under the trees, drawing a 4-m-wide strip (2 m per side) and a respect strip of 3 m. The ZCW scenario consists of the use of a rotary cultivator, which removes the whole grass cover, in addition to the other mechanical operations.

This study considered the entire agricultural life cycle, with a time boundary of 50 years (average data from interviews) and four primary phases (De Luca et al., 2014; Cerutti et al., 2015) as follows:

- planting, which considers all the operations from the olive grove design to the planting of trees;
- the growing phase, from the 1st to the 4th years, which includes all the operations necessary for the training system formation;
- the production phase from the 5th to the 50th years, which includes different sub-phases consisting of increasing production (from the 5th to 15th years), constant production (from the 16th to 45th years) and decreasing production (from the 46th to 50th years); and
- the end of life (50th year).

An experimental plan was set up with a farm in the municipality of San Giorgio Morgeto (512 m a.s.l) as follows: three plots of 5 ha each were selected to apply the three different weeding scenarios. The plots were defined to reproduce an average ordinary farm in the area under study. The experimental management plan was applied for 4 seasons (2013-2016) to evaluate the potential effects of the weed control on the yield by also considering the natural alternation of olive yields. The experiments (with a weeding control) were performed during the constant production stage.

Table 1 – Foreground Life Cycle Inventory

Life cycle phase	Operation	Input/Output	Unit	CS	LDNT	ZCW
Environmental	Tillage	Diesel	l ha-1 year-1	60.00	-	60.00
	Supplemental irrigation	Electicity	kw ha-1 year-1		266.00	
		Water	m3 ha-1 year-1		500.00	
	Fertilization	11-22-16 (N-P-K)	Kg ha-1 year-1		1440.00	
		Diesel	l ha-1 year-1		15.00	
	Weed Control	**Glyphosate**	**Kg ha-1 year-1**	**6.00**	**0.50**	**-**
		Diesel	**l ha-1 year-1**	**13.91**	**3.00**	**40.00**
		Water	**m3 ha-1 year-1**	**2.00**	**1.00**	**-**
	Pest Control	Dimethoate 37.70 %	l ha-1 year-1		4.50	
		Diesel	l ha-1 year-1		18.00	
		Water	m3 ha-1 year-1		6.00	
		Copper oxycloride 37.50 %	Kg ha-1 year-1		12.00	
		Diesel	l ha-1 year-1		12.00	
		Water	m3 ha-1 year-1		4.00	
	Pruning	Gasoline	l ha-1 year-1		20.00	
	Mechanical harvesting	Diesel	l ha-1 year-1		150.70	
	Machinery maintenance	Lubricant	l ha-1 year-1		3.50	
		Grease	Kg ha-1 year-1		2.00	
Econ	Tillage	Diesel	€ ha-1 year-1	60.00	-	60.00

		Labor	€ ha-1 year-1	47.36	-	47.36
	Supplemental irrigation	Electicity	€ ha-1 year-1		79.80	
		Water	€ ha-1 year-1		60.00	
	Fertilization	11-22-16 (N-P-K)	€ ha-1 year-1		748.80	
		Diesel	€ ha-1 year-1		15.00	
		Labor	€ ha-1 year-1		10.93	
	Weed Control	**Glyphosate**	**€ ha-1 year-1**	**36.00**	**3.00**	**-**
		Diesel	**€ ha-1 year-1**	**13.91**	**3.00**	**40.00**
		Water	**€ ha-1 year-1**	**0.24**	**0.12**	**-**
		Labor	**€ ha-1 year-1**	**25.50**	**10.93**	**25.50**
	Pest Control	Dimethoate 37.70 %	€ ha-1 year-1		40.50	
		Diesel	€ ha-1 year-1		18.00	
		Water	€ ha-1 year-1		0.72	
		Copper oxycloride 37.50 %	€ ha-1 year-1		78.00	
		Diesel	€ ha-1 year-1		12.00	
		Water	€ ha-1 year-1		0.48	
		Labor	€ ha-1 year-1		54.64	
	Pruning	Gasoline	€ ha-1 year-1		29.00	
		Labor	€ ha-1 year-1		699.00	
	Mechanical harvesting	Diesel	€ ha-1 year-1		150.70	
		Labor	€ ha-1 year-1		670.00	
	Machinery maintenance	Lubricant	€ ha-1 year-1		42.00	
		Grease	€ ha-1 year-1		16.00	
Social	Tillage	Hour of exposure to psychosocial risks factors	hours ha-1 year-1	585.00	-	900.00
		Hours of potential employment	hours ha-1 year-1	195.00	-	300.00
		Working needs imbalance	dimensionless	*0.33*	-	*0.33*
	Supplemental irrigation	Hour of exposure to psychosocial risks factors	hours ha-1 year-1		-	
		Hours of potential employment	hours ha-1 year-1		-	
		Working needs imbalance	dimensionless	0.33	0.35	0.33
	Fertilization	Hour of exposure to psychosocial risks factors	hours ha-1 year-1		135.00	
		Hours of potential employment	hours ha-1 year-1		45.00	
		Working needs imbalance	dimensionless	*0.33*	*0.35*	*0.33*
	Weed Control	**Hour of exposure to psychosocial risks factors**	**hours ha-1 year-1**	**525.00**	**15.75**	**-**
		Hours of potential employment	**hours ha-1 year-1**	**105.00**	**3.15**	**-**
		Working needs imbalance	dimensionless	***0.33***	***0.35***	**0.33**
	Pest Control	Hour of exposure to psychosocial risks factors	hours ha-1 year-1		1125.00	
		Hours of potential employment	hours ha-1 year-1		225.00	
		Working needs imbalance	dimensionless	*0.33*	*0.35*	*0.33*
	Mechanical aided harvesting	Hour of exposure to psychosocial risks factors	hours ha-1 year-1		9660.00	
		Hours of potential employment	hours ha-1 year-1		2520.00	
		Working needs imbalance	dimensionless	*0.33*	*0.35*	*0.33*
	Pruning	Hour of exposure to psychosocial risks factors	hours ha-1 year-1	14070.00		8400.00
		Hours of potential employment	hours ha-1 year-1		3990.00	
		Working needs imbalance	dimensionless	*0.33*	*0.35*	*0.33*
	Machinery maintenance	Hour of exposure to psychosocial risks factors	hours ha-1 year-1		1635.00	
		Hours of potential employment	hours ha-1 year-1		911.25	
		Working needs imbalance	dimensionless	*0.33*	*0.35*	*0.33*

3.2. Life Cycle Assessment (LCA) as applied to the case study

The environmental results were obtained through an LCA that was applied according to ISO norms (ISO, 2006). The functional unit (FU) was 1 ha of cultivated surface, and the system boundary consisted of the agricultural production “from cradle to farm gate”.

In the Life Cycle studies, the choice of FU is at the discretion of the practitioner, but it strongly depends on the objectives of the assessment, the addressees of the study, and the typology of the investigation. According to a review by Cerutti et al. (2015), surface FUs are preferred when management practices are under discussion.

The temporal horizon encompassed the expected life of the olive growth over 50 years. Data for foreground processes were directly collected from the experimental design and included the fuel, lubricants and water consumption, typology of water distribution and related energy consumption, quantity, type, period and distribution modality of fertilizers and pesticides, distances of transport and masses of products dislocated, waste typology, mass and disposal modality, and all the inputs and outputs linked to weed control. Data on nitrous oxide and ammonia emissions were estimated according to Brentrup et al. (2000). The herbicide emissions were estimated as 100% of the active ingredient (Nemececk and Kägi, 2007). Data on the background processes were obtained from the Eco-invent V. 3.2 database (Wernet et al., 2016), and they were related to the fuel, lubricant, energy, fertilizers, pesticides, herbicides and capital goods production as well as waste processes. LCA elaborations were performed with SimaPro software (PRè, 2016). To identify the environmental impacts of each weeding operation, three impact categories were selected. First, the Climate Change from the IPCC 100a - 2013 method to highlight the impact related to the mechanical operations. The Toxicity (the sum of human, fresh water aquatic, marine aquatic and terrestrial ecotoxicity) was found using the CML baseline V3.03 method to uncover the effects of chemical herbicide use and Land Use (the sum of agricultural and urban land occupations) from the ReCiPe midpoint method to consider the area that was subjected to alterations during the orchard life cycle. Other impact categories should be considered, but the selection was limited to three to harmonize the integration of the different life cycle tools. A sensitivity analysis was performed by varying the principal inputs connected to the weeding operation. For the CS, the minimum dosage of glyphosate (4 Kg ha^{-1}) was hypothesized for the ZCW scenario with a reduction of 25% of the fuel consumption, and the LDNT was a pejorative scenario with an increasing herbicide dosage of up to 1 Kg ha^{-1}.

3.3. Life Cycle Costing (LCC) as applied to the case study

To identify the economic insights, a Conventional LCC (Ciroth et al., 2016) was applied. The system boundary and the functional unit were similar to those of the LCA. This approach is based on a cash flow model (ISO, 2008), and it allows for the rationalization of the long-term decision-making process when different investment alternatives are available. Because the study followed a farms perspective, only the real money flows were considered (Swarr et al., 2011; Martínez-Blanco et al., 2014).

As a first step in the analysis, all of the costs occurring over the life cycle of each weeding scenario were calculated (Supplemental Material 1). For this purpose, an economic inventory was created through the monetization of all the collected inputs and outputs. This collection was performed by multiplying the measured quantities by the unit prices of the last year. Therefore, this economic inventory was fully complementary to the environmental one, because each unitary process cost was split into its elementary components (Falcone et al., 2016); in particular, costs related to the planting (investment costs) and operating costs of each production stage and disposal costs were analysed. The total cost was classified into variable and fixed costs. The following variable costs were accounted for in the production process: fertilizers, pesticides, herbicides, fuels and lubricant consumption by machinery, human labour costs needed during agricultural operations, outsourced cost items (e.g., expert consultancies, transport and outsourced cultivation practices), and interests on advanced capital. The fixed costs included the ownership costs of the machinery and land investments (i.e., the depreciation, insurance and maintenance), rent for land use, interests on capital goods, taxes and administrative overheads (De Luca et al., 2015b; Falcone et al., 2015; Stillitano et al., 2017).

Here, the input cost was calculated according to the current market prices (i.e., 2015). The family labour cost was estimated in terms of the opportunity cost and was equalized to the employment of casual workers according to the local current wage. The rental cost for land use was deduced from

the average local rental prices while accounting for the interests on advance capital and capital goods, where interest rates of 4.5% and 2% were applied, respectively. The administrative overheads were estimated to be 5% of the gross production value, which corresponds to the annual total revenues (Stillitano et al., 2016). The total revenues for the entire life cycle of each scenario were then calculated by multiplying the olive yield by its market price, which referred to the last harvest season (De Gennaro et al., 2010; Mohamad et al., 2014), i.e. 2015/2016, including EU Agricultural Policy subsidies. In particular, the olive prices were provided by the investigated farmers and they reflected the market prices in the province of Reggio Calabria.
All of the costs and revenues were discounted for the entire life cycle of 50 years. To select a discount rate, the opportunity cost approach in terms of alternative investments with a similar risk and time was used. Specifically, we assumed a discount rate equal to 1.8%, which was similar to the average return rate of Italian government bonds in 2014. During the life cycle, we assumed constant prices, and therefore, we could exclude adjustments for inflation (Emblemsvåg, 2003; Hussain et al., 2005). Thus, three economic categories were identified, i.e., Profitability, Life cycle costs and Investment feasibility, which corresponded to the following indicators: the Gross Margin (GM), Discounted Life Cycle Costs (DLCC) and Net Present Value (NPV). The first indicator was calculated by subtracting the variable costs from the total revenues. The discounted life cycle costs were determined by summing up the investment costs, the present value of the operating costs of each production phase, and disposal costs; this indicator has been applied to estimate the overall cost of the different scenarios, with the purpose of recognizing the primary processes responsible for most of the economic impacts. The cash flow assessments generated at different stages of the project lifespan can provide information on its viability; thus, the NPV was chosen as an indicator of the investment feasibility and represents the sum of discounted future cash flows incurred during the whole life cycle. It is also one of the most frequently applied and appropriate indicators in the LCC literature (Foolmaun and Ramjeawon, 2013; Hossaini et al., 2014; Yu and Halog, 2015).
The selected indicators were able to assess the primary economic hotspots during the entire life of the olive growing systems, and therefore, they provided information on more effective management for long-term sustainability.
As a final step, sensitivity analyses were performed by changing the olive selling prices, the discount rate, and the primary input used in the experimentation phase (weed control) to demonstrate how the economic results are related to these variables. The sensitivity analysis concerning the olive price change was performed by assuming a range between 0.50 and 0.80 € Kg^{-1} and by excluding public subsidies, to reflect the market price dynamics in a free market. To explore the effect on the economic indicators from the discount rate fluctuations, a range of ±0.4 percentage points (p.p.) was used. Finally, a sensitivity analysis of the results to the variation in inputs used in the weed control operation (see section 3.2) was conducted.

3.4. Social Life Cycle Assessment (sLCA) as applied to the case study

The LCA and LCC have their roots in disciplines belonging to the so-called "hard sciences", and therefore, post-positivist paradigms are predominant (Iofrida et al., 2016). This approach is probably the primary reason why the LCA and LCC first reached a methodological consensus, and standardized procedures were established in ISO 14040:2006 and ISO 14044:2006 for LCA and in ISO 15686-5:2008 and Norwegian standard NS 3454 for LCC, but only for buildings and constructed assets. This is not the case for sLCA, which, despite being proposed during the nineties, did not yet have a common methodological procedure. A broad number of different methodological proposals have been set up with attention to the most diverse aspects, such as company responsibilities or impacts derived from the very nature of the life cycle, a local perspective or global one, with lists of primarily static indicators that were chosen according to very different criteria.
The sLCA proposed here has been conceived to be epistemologically near the other methodologies, to facilitate their integration from a holistic perspective. Therefore, the assessment methodology chosen here belongs to mixed-methods research (Tashakkori and Teddlie, 2010), i.e., it combines an

"impact pathway" (Feschet et al., 2013; Macombe et al., 2013; Silveri et al., 2014; Bocoum et al., 2015; Iofrida, 2016) and a type 1 impact assessment (e.g., UNEP-SETAC, 2009; De Luca et al., 2015b). Both positive and negative indicators have been chosen (Di Cesare et al., 2016).
In detail, the "social health" impact category is used for people who are directly involved in the life cycle, i.e., all types of workers, such as farmers, experts, employees, and labourers. Consumers have been excluded in accordance with the system boundaries of the other LC tools. Here, the source of impacts under consideration is the very nature of the life cycle, and farm responsibilities (organization, management, decisions, and internal policies) are not taken into account. The impacts found here are assessed in terms of psychosocial risk factors (Cox et al., 2000; Gasnier, 2012; Silveri et al., 2014; Amiri et al., 2015), i.e., the hours of potential exposure when someone works under conditions that can lead to health problems. These risks are measured in terms of the odds ratio (OR) and are classified by the strength of association. For each life cycle phase, an inventory sheet reported how many hours of work were necessary (the average of the interview data) for each task. Each task was then related to one or more working condition (noise, vibrations, stress, open-air work, and use of chemicals) (Callea et al., 2014). A literature review has been conducted to gather those studies and correlate these conditions with the psychosocial risks (see Supplemental Material 1). Only psychosocial risk factors with strong associations were taken into account ($1.7<OR<8$).
The second impact category enlarges the perspective and evaluates the impact on local employment by means of studying the employment hours during the whole life cycle. This is also one of the most accepted and applied indicators. It was calculated by taking averaged data from interviews with farmers from the case study. As in other agricultural sectors, olive growing is represented by small farms with a low capacity for long-term hiring; most of the workers involved here are seasonal or temporary for a specific task (such as harvesting, pruning, etc.).
The third impact category has a wider perspective and refers to the impact on the national welfare, in terms of social security contributions paid by farmers. Here, the category reveals the behaviour of the farmer, who in some cases might resort to contracting illegal work to save money; other times, they might hire fictitious workers to provide them with social aid and subsidies to the detriment of national revenues. The indicator applied here is the ratio between the working hours declared by the farmers and the working needs available in the literature. If the ratio is less than 1, it probably means that the farmers use illegal work. Even if this indicator represents a personal behaviour, it is also an indirect evaluation of the overall assets of olive growers in the Calabria region, as determined by farmers.

3.5. Life Cycle Sustainability Assessment (LCSA) as applied to the case study by means of Multi-Criteria Decision Analysis (MCDA)

In conducting sustainability assessment studies, the greater the complexity of the system, the more several factors will have to be taken into account. This is the case for the multifaceted feature and several functions of the agricultural contexts (De Luca et al., 2015c) in which the composite set of farming operations requires consideration of all the different typologies of impacts within the environmental, economic and social domains and in accordance with a holistic approach. In an attempt to identify the best way to combine the sustainability assessment tools, such as the LCA, LCC and sLCA, the MCDA methods are attracting a great amount of interest for their several potential abilities to support choices and improve their quality in difficult contexts. Specifically, they support the overcoming of subjective elements as well as support for the interpretation phase represented by other benefits of combining the MCDA and LC methodologies (Falcone et al., 2016; Gaudreault et al., 2009; Hermann et al., 2007). An in-depth and extensive overview of MCDA approaches that were applied to LC studies can be found in De Luca et al. (2017), which highlight the primary synergies and advantages of the approaches in combination in terms of the LCSA methodological advances. Among all the different methods belonging to the general umbrella of the MCDA, the Analytic Hierarchy Process (AHP) introduced by Saaty (1980) is a well-known technique that was widely implemented in many scientific fields and is applicable for valuing the different criteria, when the nature of alternatives is non-continuous.

AHP allows organizing multi-objective real problems in a rational framework hierarchically configured, i.e. decomposing the problem in sublevels more easily comprehensible and subjectively evaluable (Bushan and Rai, 2004). This method was created to better organise and transfer the viewpoints by the decision-makers. Indeed, to consider all of the components of a complex choice could be arduous and, consequently, to prioritise alternative solutions for assuming rational decisions becomes complicated for decision-makers.

The primary phases of AHP method can be explained as follow. First, the hierarchical tree of the problem have to be structured, with criteria and alternatives to evaluate. The general objective of the analysis represents the main root of this capsized tree, while each criterion is a node with possible sub-criteria at a descendant level. At the bottom of the tree, all alternatives are assigned to every criterion, depending by its mutual correspondence, i.e. by the performances of each solution in respect to each evaluation criterion. The second phase consists of formulating and collecting judgments by experts and/or decision makers. Essentially, the AHP assigns a value/weight for each criterion according to the decision maker's preferences expressed through *pairwise comparisons* of criteria (Saaty, 1980). The decision-makers state their subjective opinion expressing the value of one single pairwise comparison at a time (Triantaphyllou and Mann, 1995). The preference - or relative importance - for each criterion is formulated in qualitative terms according to a scale of rating that attributes numerical values from 1 to 9 to the follow opinions: equally important, weakly more important, strongly more important, very strong more important, extremely more important (Saaty, 1980). The third phase is the building of a square matrix with rank equal to the number of criteria considered. The matrix elements a_{ij} are obtained comparing the criterion i with criterion j according to the above-mentioned scale as reported in the Table 2. Finally, in the last phase, the criteria weights and the scenarios performance scores are combined, and an overall score for each alternative is determined by a weighted sum of the scores obtained for each criterion. Then a ranking of scenario analysed is performed by prioritizing the sequence of alternatives.

Table 2 - Scale of rating for pairwise comparison (Saaty, 1980; 2008).

Relative importance of *i*th criterion in respect to the *j*th criterion	**Meaning**	**Description**
1	Criterion *i* and *j* have equal importance	Two criteria contribute equally to the overall goal
3	Criterion *i* is weakly more important than *j*	Subjective experience and knowledge slightly prefer one criterion over another
5	Criterion *i* is strong more important than *j*	Subjective experience and knowledge strongly prefer one criterion over another
7	Criterion *i* is very strong more important than *j*	Subjective experience and knowledge very strongly prefer one criterion over another; its dominance is demonstrated
9	Criterion *i* is extremely more important than *j*	The evidence favouring one criterion over another; is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgements	In case of compromise
Reciprocal values	If criterion *i* has one of the above values when compared with criterion *j*, then *j* has the reciprocal value when compared with *i*	Reflecting dominance of second alternative compared with the first

In the case study analysed in this paper, the first phase of the AHP, i.e., the creation of a hierarchical structure through the decomposition of the decisional problem into levels and sublevels, coincided with the framework of the sustainability dimensions (first level) and impact categories (second level) quantified through LC tools.

The second AHP phase consisted of pairwise comparisons at each level. Since AHP is based on subjective preferences, it is noteworthy to pay close attention to the participation of the actors consulted in the decision making process. The choice of which stakeholders include in the analysis is a critical phase that considerably influence the results of the research that, therefore, are strictly context-dependent (De Luca et al., 2015b). Indeed, the specific weights elaborated for each criterion accurately reveal the preferences of stakeholders about the relative importance of criteria and, then, reflect the classification of scenario analysed in multiple dimensions. Generally, the categories of stakeholders should be defined in accordance with specific characteristics coherently linked to the nature of the decisional problem. For example, they should have a direct and significant interest in the field under study, as well as they should be aware for the implications of changes of the context. Furthermore, they should have specific knowledge and technical expertise to state judgments about the specific issues treated.

For the purpose of this paper, 15 experts on olive farming systems of Calabria were involved to express their opinion on the value of impact categories considered for the sustainability assessment. The stakeholders were composed of three main typologies of actors directly affected to the olive-oil production chain: researchers, technicians, and producers (five people per typology). Within the group of researchers, individual interviews were administrated to exponents with specific expertise in scientific sectors of agronomy, arboriculture, agricultural mechanization, rural economy, and food industry. Among the technicians, agronomists with professional experience as consultants of olive farms have been consulted while, as producers, five olive growers have been chosen because of their managerial skills and aptitude to farming innovations witnessed by their participation with academic teams in several research projects. Each of them assigned a preference to the impact categories and sustainability dimensions according to the above-mentioned pairwise comparison approach (Saaty, 1980); in Table 3 an example of interview scheme used in the case study is provided and its equivalent square matrix to elaborate the weights of criteria.

Table 3 - Example of interview scheme and matrix for pairwise comparisons between sustainability impact categories

Using the following terms (1) equal, (3) weak, (5) strong, (7) very strong, (9) extreme, that express the relative importance of the category per row, compared to the other per column, please state your opinion on these comparison:			
Social dimension	**Social health**	**Job opportunities**	**Contribution to national welfare**
Social health	1	values from 1 to 9	values from 1 to 9
Job opportunities	reciprocal values	1	values from 1 to 9
Contribution to national welfare	reciprocal values	reciprocal values	1
Matrix (3 × 3)	**Social health**	**Job opportunities**	**Contribution to national welfare**
Social health	1	a_{12}	a_{13}
Job opportunities	$1/a_{12}$	1	a_{23}
Contribution to national welfare	$1/a_{13}$	$1/a_{23}$	1

In order to elaborate AHP weights, each element of each pairwise comparison matrix was normalized, and a consistency ratio (CR) was calculated (Saaty, 1980); answers with CR values greater than 10% were discarded to avoid incongruity of judgments. Each impact category weight has been re-weighted according to the values assigned by respondents to the three sustainability dimensions.

Simultaneously to the AHP analysis and once each LC tool was applied, according to the method illustrated in the previous sections, an assessment matrix was created by using the results of previous LC analysis and, then assembling all performances of the scenario per each criterion belonging to the environmental, economic and social dimensions. Not all of the indicators have the same direction,

some are positive, as for example, the gross margin and fair employees' treatment, and others are negatives, like such as all the environmental indicators or life cycle costs.
Therefore, to give all the data the same significance, the indicators were minimized or maximized, according to their negative or positive meaning. Then, such heterogeneous data were normalized, namely they were converted into a-dimensional indices through a min-max normalization function (De Luca et al., 2015b). Normalized data of sustainability performances quantified with LC analysis were weighted with AHP results to obtain the final evaluation of olive growing management scenarios.

4. Results

4.1. Environmental results

The results of the environmental analysis showed that, in term of GHGs, the LDNT scenario causes lower emissions, followed by the CW scenario (+1.23%) and then MW (+6.08%). In terms of toxicity, the results were very similar (better scenario: LDNT +0.66%, CW +0.94 MW), and most of the 1,4 dichlorobenzene eq. emissions were attributable to the "Marine aquatic ecotoxicity" sub-category, which represented approximately 99.9% of the total toxic emissions for all the scenarios. In terms of land use, the LDNT scenario was considerably better than that of CW and MW, using approximately 23% less land compared to the other scenarios. This result was due to the choice of considering occupied land as only the share of the surface affected by farming practices (Table 4).

Table 4 - Environmental assessment

Life Cycle tool	Impact Categories	Indicators	Unit of Measure	Positive or negative	Olive growing scenarios		
					CS	*LDNT*	*ZCW*
LCA	Climate change	GHGs	Kg CO2 eq ha^{-1} $50yr^{-1}$	-	3.65E+05	3.60E+05	3.82E+05
	Toxicity	Toxic emissions	Kg 1,4-DB eq ha^{-1} $50yr^{-1}$	-	4.67E+08	4.64E+08	4.68E+08
	Land Use	Land occupation	m^2yr ha^{-1} $50yr^{-1}$	-	6.49E+05	5.00E+05	6.50E+05

To evaluate the sensitivity of the results with regard to the weeding operation, a sensitivity analysis was performed by varying the physical quantity of inputs and outputs involved in the weeding. The results showed which variations introduced into the life cycle inventory could produce mild-intensity effects, with positive and negative deviations from the baseline scenarios that never exceeded 0.6% (in the CS scenario, the sensitivity result in terms of climate change was better with respect to the baseline at just 0.58%). Even though the variations in the CS and ZCW scenarios were ameliorative while being detrimental in the LDTN, the LDTN remains the best scenario (Table 5).

Table 5 - Environmental sensitivity analysis

Life Cycle tool	Impact Categories	Indicators	Unit of Measure	Positive or negative	Olive growing scenarios		
					CS	*LDNT*	*ZCW*
LCA	Climate change	GHGs	kg CO2 eq ha^{-1} $50yr^{-1}$	-	-0.580%	+0.047%	-0.198%
	Toxixity	Toxic emissions	kg 1,4-DB eq ha^{-1} $50yr^{-1}$	-	-0.094%	+0.042%	-0.177%
	Land Use	Land occupation	m2yr ha^{-1} $50yr^{-1}$	-	-0.014%	+0.001%	-0.004%

4.2. Economic results

From an economic perspective, the LDNT scenario achieved the best performance compared to the others for all the examined indicators, causing less overall impact throughout its life cycle. Since both the olive yields and market prices were similar for the three systems, the differences in margins and net present values were determined by finding the differences in the costs. The LDNT was the least costly system, due to the lower weed control cost (in terms of input) and no-tillage farming (in terms of lower labour cost), followed by the CS and ZCW systems. Conversely, the ZCW scenario had the highest labour cost because of the greater number of tillage operations performed to remove the grass cover as well as high fuel consumption. Thus, these results indicated that mechanical weed control was more expensive than herbicide application.

The lower costs incurred over the entire life of the LDNT system also led to increases in farm profitability and investment feasibility. The research results highlighted that this scenario was the most profitable and economically feasible alternative since it showed the higher values of the GM and NPV indicators, which were equal to 143,727.28 € ha^{-1} and 42,631.84 € ha^{-1}, respectively (Table 6, Supplemental Material 1).

Table 6 - Economic impacts results

Life Cycle tool	Impact Categories	Indicators	Unit of Measurement	Positive or negative	Olive growing scenarios		
					CS	*LDNT*	*ZCW*
LCC	Profitability	GM	€ ha^{-1} $50yr^{-1}$	+	141,391.04	143,727.28	141,006.35
	Life Cycle Costs	DLCC	€ ha^{-1} $50yr^{-1}$	-	184,174.96	181,838.72	184,559.65
	Investment feasibility	NPV	€ ha^{-1} $50yr^{-1}$	+	40,295.60	42,631.84	39,910.91

However, the simulations performed by excluding European subsidies and considering only the current olive market price (i.e., 0.50 € Kg^{-1}) revealed reduced economic returns and negative NPV values for all the systems (Table 7), suggesting that these scenarios were not economically suitable in the long-term. Conversely, an increase equal to 0.10 € Kg^{-1} in the olive price positively affected the viability of each investment; in the LDNT scenario, the GM and NPV indicators increased by approximately 0.38 p.p. and 3.5 p.p., respectively, while in the CS and ZCW systems, they increased by 0.39 p.p. and 2.8 p.p.

A sensitivity assessment of the discount rate variation showed a constant impact on all the indicators and for each scenario with respect to the base-case scenario (i.e., 1.8%). Specifically, by assuming a discount rate of 1.4%, increases of 19%, 9% and 23% were found for the GM, DLCC and NPV indicators, respectively. When considering a discount rate of 2.2%, decreases of 17%, 8% and 20% were achieved. This trend indicates that a small change in the discount rate leads to a strong impact from the discounting of future values on the present values.

With regard to the sensitivity analysis and the input used during the weed control operation, the following results were obtained:

- for the CS scenario, a decrease in the herbicide amount (i.e., 4 Kg ha^{-1} of glyphosate instead of 6 Kg ha^{-1}) led to a decrease of 0.13% for the DLCC indicator, while there were increases of 0.17% and 0.61% for GM and NPV, respectively;
- regarding the LDTN solution, a change in the herbicide input from 0.5 Kg ha^{-1} to 1 Kg ha^{-1} led to a 0.02% increase in the DLCC indicator and positive variations equal to 0.03% and 0.10% in the GM and NPV, respectively; and

in the case of the ZCW scenario in which a lower fuel consumption (i.e., 30 l ha^{-1} instead of 40 l ha^{-1}) was considered for the mechanical removal of the grass cover, the DLCC indicator decreases by 0.58%, while the GM and NPV increase by 0.76% and 2.6%, respectively.

Table 7 - Sensitivity analysis on economic results

	CS	LDNT	ZCW

Parameter change		GM	DLCC	NPV	GM	DLCC	NPV	GM	DLCC	NPV
		(€ ha^{-1} 50yr^{-1})			(€ ha^{-1} 50yr^{-1})			(€ ha^{-1} 50yr^{-1})		
Olive price (€ Kg^{-1})	0.50	88,932.10	-	-12,163.34	91,268.34	-	-9,827.10	88,547.41	-	-12,548.03
	0.60	123,220.11	-	22,124.66	125,556.35	-	24,460.90	122,835.42	-	21,739.97
	0.70	157,508.11	-	56,412.67	159,844.35	-	58,748.91	157,123.42	-	56,027.98
	0.80	191,796.11	-	90,700.67	194,132.36	-	93,036.91	191,411.43	-	90,315.98
Discount rate (%)	1.4	168,940.20	201,456.94	49,559.54	171,276.44	198,891.64	52,124.84	168,555.51	201,863.50	49,152.98
	2.2	117,300.40	168,930.96	32,270.00	119,636.65	166,796.29	34,404.68	116,915.72	169,296.10	31,904.87
Weed control input		141,638.37	183,927.63	40,542.92	143,682.87	181,883.13	42,587.42	142,081.68	183,484.32	40,986.24

4.3. Social results

To assess the "social health" impact category, 18 data sheets have been compiled, i.e., an inventory of working hours for each LC phase of each scenario. Working tasks, such as tillage, pruning, harvesting, fertilization, etc., have been associated with types of working conditions, including the noise, vibrations, high physical demand, temporary work, outdoor working environment, organophosphate insecticide exposure, high psychological demand (quantity of work, intellectual requirements, and time constraints), glyphosate exposure, and copper pesticide exposure. Upon updating a previous scientific literature review by Iofrida (2016), scientific references were found regarding the association (as expressed in an odds ratio, or OR) between one or more of these working conditions with health risks (Supplemental Material 2). In considering only the strong associations (1.7<OR<8), significant intensities of association were found for cardiovascular diseases, musculoskeletal diseases, lower self-esteem, psychological distress, disability, osteoarthritis, chronic bronchitis, cutaneous melanoma, non-Hodgkin's lymphoma, renal cell carcinoma, and Parkinson's disease. The strongest associations were found for the effort-reward imbalance and cardiovascular diseases with an OR of 6.15 (Siegrist, 1996) and the glyphosate and sun exposure with cutaneous melanoma with an OR of 4.68 (Fortes et al., 2016). In adding together all the working hours, it was found that 1 ha of olive growing over a life cycle of 50 years could potentially expose some people to a disease with strong associations at 58,801.9 hours in the CS scenario, 52,913.65 hours in the LDNT scenario (best performance), and 54,276.9 in the ZCW scenario (Table 8). However, it should also be clarified that, if considering only diseases with mortal courses, the ZCW scenario would be the most socially sustainable, because the chemicals have a serious impact on human health.

Table 8 - Social indicators results

Life Cycle tool	Impact Categories	Indicators	Unit of Measure	Positive or negative	Olive growing scenarios		
					CS	*LDNT*	*ZCW*
sLCA	Social health	Hours of risk exposure	hours ha^{-1} 50yr^{-1}	-	58,801.90	52,913.65	54,276.90
	Job opportunities	Employment hours	hours ha^{-1} 50yr^{-1}	+	12,103.08	11,758,33	12,103.08
	Contribution to national welfare	Fair employees treatment	dimensionless	+	0.665	0.646	0.665

The second impact category, "job opportunities", is intended to be the contribution of the olive growing sector to local employment and is measured in the hours of hired workers, according to the declarations of the interviewed farmers. The CS and ZCW scenarios showed the best performance, with approximately 12,103 hours of work per ha for the entire agricultural life cycle (50 years). There is little difference compared to the LDNT scenario, and it is primarily due to the mechanical farming operations. The third impact category is about the contribution of the farms to the national welfare by means of social security payments paid by farmers. This impact has been evaluated through a proxy indicator, i.e., the ratio between the hours of work declared by farmers and the average working hour requirements calculated according to the literature and local expert suggestions. A high value (>1) could indicate possible fictitious hiring (agricultural workers can receive national subsidies in particular conditions); a low value (<1) could indicate possible undeclared work. In the present case study, the CS and ZCW scenarios showed the best performances, at closer to 1 than the LDNT scenario.

4.4. LCSA results with AHP applications to reconcile conflicting aspects of sustainability in a participative way

After the measuring of all of the environmental, economic, and social indicators, the overall sustainability degree of olive growing management scenarios associated to innovative agronomic practices was evaluated using the multicriteria method with the AHP approach here presented. As already explained the AHP technique allowed for the weighting of each sustainability dimension and impact category according to the viewpoint of authoritative stakeholders in the area of study. Tables 9, 10, 11 and 12 show an example of pairwise comparison matrix fulfilled (corresponding to the answer of one interviewed) for each level of hierarchical framework (sustainability dimensions and impact categories) and the equivalent results about the average weights obtained. Single results for each level of AHP framework obtained from single interview to stakeholder are presented in Table 12. The AHP permitted for the transformation of qualitative judgements into quantitative elements (the weighting of each category), and, therefore, for the synthesizing of stakeholder priorities (De Luca et al., 2015c). Each impact category (level 2) weight has been re-weighted according to the values assigned by respondents to sustainability dimensions (level 1), as presented in Figure 2.

Table 9 - AHP weights of the three sustainability dimensions

Sustainability dimensions	Environmental	Economic	Social	**Average weights**
Environmental	1	5	3	0.452
Economic	1/5	1	1/5	0.171
Social	1/3	5	1	0.377

Table 10 - AHP weights of the environmental impact categories

Environmental dimension	Climate change	Toxicity	Land Use	**Average weights**
Climate change	1	5	3	0.323
Toxicity	1/5	1	1/5	0.437
Land Use	1/3	5	1	0.241

Table 11 - AHP weights of the economic impact categories

Economic dimension	Profitability	Life cycle costs	Investment feasibility	**Average weights**
Profitability	1	5	3	0.272
Life cycle costs	1/5	1	1/3	0.171
Investment feasibility	1/3	3	1	0.377

Table 12 - AHP weights of the social impact categories

Social dimension	Social health	Job opportunities	Contribution to national welfare	**Average weights**
Social health	1	5	3	0.509
Job opportunities	1/5	1	1/5	0.357
Contribution to national welfare	1/3	5	1	0.134

Table 13 - AHP results per stakeholder interviewed

	Sustainability dimensions	Stakeholders interviewed														
		S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**
Level 1 - AHP framework	Environmental	0.429	0.600	0.075	0.281	0.455	0.429	0.114	0.651	0.685	0.046	0.198	0.726	0.726	0.618	0.753
	Economic	0.143	0.200	0.602	0.135	0.091	0.143	0.405	0.223	0.080	0.167	0.076	0.076	0.076	0.086	0.063
	Social	0.429	0.200	0.324	0.584	0.455	0.429	0.481	0.127	0.234	0.787	0.726	0.198	0.198	0.297	0.184
LCA impact categories - Level 2	Climate change	0.223	0.460	0.600	0.180	0.161	0.460	0.067	0.221	0.067	0.234	0.067	0.701	0.715	0.618	0.067
	Toxicity	0.651	0.319	0.200	0.778	0.779	0.221	0.715	0.319	0.218	0.685	0.218	0.215	0.218	0.297	0.715
	Land Use	0.127	0.221	0.200	0.042	0.060	0.319	0.218	0.460	0.715	0.080	0.715	0.085	0.067	0.086	0.218
LCC impact categories - Level 2	Profitability	0.715	0.319	0.067	0.076	0.184	0.323	0.278	0.460	0.143	0.158	0.223	0.198	0.234	0.637	0.060
	Life cycle costs	0.067	0.221	0.715	0.726	0.063	0.110	0.391	0.221	0.429	0.766	0.651	0.726	0.080	0.105	0.779
	Investment feasibility	0.218	0.460	0.218	0.198	0.753	0.567	0.330	0.319	0.429	0.076	0.127	0.076	0.685	0.258	0.161
sLCA impact categories - Level 2	Social health	0.258	0.584	0.067	0.672	0.753	0.731	0.405	0.701	0.455	0.161	0.685	0.715	0.701	0.701	0.046
	Job opportunities	0.637	0.281	0.715	0.257	0.184	0.188	0.481	0.202	0.091	0.779	0.234	0.218	0.097	0.202	0.787
	Contribution to national welfare	0.105	0.135	0.218	0.070	0.063	0.081	0.114	0.097	0.455	0.060	0.080	0.067	0.202	0.097	0.167

Figure 2 -AHP weights for sustainability dimensions and "weighted weights" of impact categories

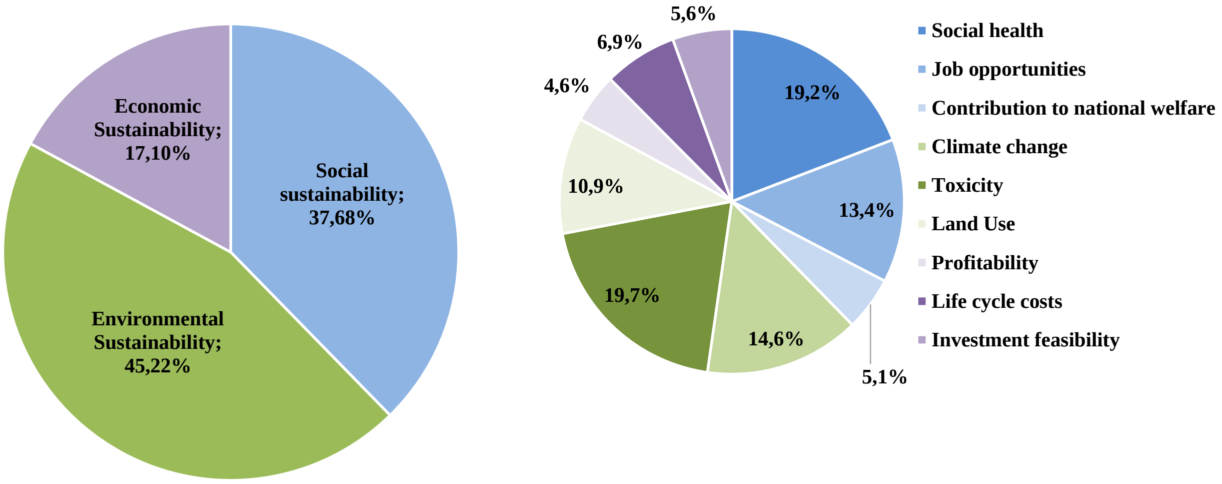
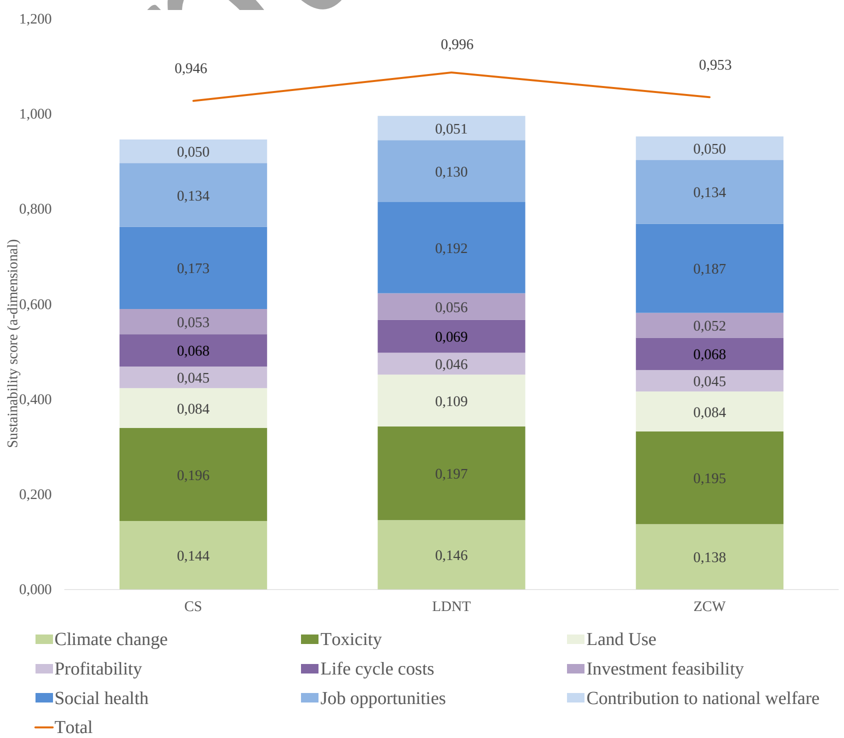


Figure 3 presents the results of the overall sustainability assessment carried out integrating LC tools and MCDA technique. As mentioned in the methodological paragraph, the sustainability score was obtained by multiplying normalized LC data per AHP weights. The LDNT scenario shows the best performance, which was probably influenced by the reduced mechanical operations. It is necessary to take into account that the use of chemical herbicides is the subject of a long scientific debate (Portier et al., 2016), and therefore, the results should be interpreted with caution. However, the LCSA methodology presented here showed its effectiveness in comparing farming practices, and it is suitable for assessing many types of innovations (in technology, processes, and management practices). Improvements are certainly possible because the methodology can be adapted to different contexts and actors.

Figure 3 - Integrated sustainability performance of olive growing scenarios



5. Discussion

Olive growing sustainability issues have been addressed by many Life Cycle practitioners, with a growing interest in recent years, with attention to all aspects of olive oil production and by-products, transportation, reuse and consumption (Notarnicola et al., 2017). In fact, Banias et al. (2017) published a systematic literature review about the use of environmental tools in the life cycle of olive oil, while taking into account the farming phase at the orchard level, the production of olive oil, and packaging, transportation and reverse logistics.

In general, the farming phase (with pesticide use and waste/by-product production being the most high-impact operations) and the production of olive oil are the phases with the highest environmental focus from the scientific community (Banias et al., 2017).

Romero-Gàmez et al. (2017) calculated and evaluated the potential environmental impacts associated with olive oil production from the extraction of the raw materials to the oil mill gate. They compared traditional systems with intensive and super-intensive systems and found that fertilizers were the highest contributors in all the impact categories, especially in the intensive but non-irrigated conventional system. Organic farming showed the lowest impacts but to the detriment of productivity; integrated production was the best olive production system from an overall environmental and productive point of view, especially the traditional mechanized systems (Romero-Gamez et al., 2017). Tsarouhas et al. (2015) analysed the olive oil production in Greece, and they found that the cultivation of olive trees and the production of olive oil are the sub-systems that are responsible for most of the environmental impacts. Christoforou and Fokaides (2016) investigated different scenarios for the torrefaction process of olive husks, finding a potential improvement in terms of environmental impacts by employing renewable energy sources for heating purposes. Hanandeh and Gharaibeh (2016) investigated olive oil production in northern Jordan, and they highlighted that soil management is the primary contributor to environmental impacts, and lower mechanization and solid waste use for energy purposes would reduce the impacts. Guermazi et al. (2017) affirmed that waste disposal is one of the primary environmental concerns, and therefore, olive oil by-products require specific management, especially mill wastewater, which is responsible for the emission of greenhouse gases. Benavente et al. (2017) analysed the hydrothermal carbonization (HTC) of olive mill waste, finding that thermal treatment is more environmentally advantageous than biological treatment, and incineration with energy recovery has a lower impact than HTC, but operational challenges remain.

Therefore, in the literature, few studies can be found about the joint use of life cycle tools and MCDA applied to olive oil production, except for Recchia et al. (2011) and De Luca et al. (2015c). Olive growing has attracted the attention of LCA practitioners who have analysed every aspect of environmental performance, but little attention has been paid to all the aspects of an integrated concept of sustainability (De Luca et al., 2016).

Many authors have affirmed that the farming phase is the most significant one, especially concerning the use of fertilizer and soil management. For this reason, this study focused on the use of chemicals in weed management.

Weed control represents a relevant issue in the LCA of agricultural productions because of its relevant influences on all areas of protection. In several LCA studies on herbaceous crops, weed control has emerged as the main contributor to environmental impacts (Deytieux et al., 2012; Bacenetti et al., 2016). In perennial crops, weed control is generally placed in the background analysis, and it is considered one of the principal hot-spots that characterize orchard management, along with fertilization, pest control and mechanical operations (Cerutti et al., 2015). This study, which is related to the whole life cycle of 1 ha of olives, showed the contribution of weed control to orchard management. In fact, weeding was the main farming operation discriminating the three olive growing scenarios. Although the environmental results confirmed that the principal hot-spots were represented by fertilization (for approximately 70% of the total impacts), mechanical harvesting and pest control, the differences in the eco-profiles of the different scenarios were attributed exclusively to weeding. Therefore, changing this farming operation could help to mitigate the environmental impacts of agricultural production and should not be neglected by LCA practitioners. As underlined by

Salomone et al. (2015), weed control represents a critical farming operation for LCA practitioners because of different issues. This is due for example to the lack of specific data on herbicide production, and the need to manage complex dispersion models, which could be the reasons why many authors exclude specific mentions about weeding from LCI (e.g., Avraamides and Fatta, 2008; Tsarouhas et al., 2015). Our findings confirmed the results of the few papers on olive groves that explicitly address weed control, such as for example Salomone and Ioppolo (2012), who highlighted that most of the ecotoxicity emissions could be attributed to "Marine aquatic ecotoxicity" due to the impact of fertilization, pest control and mechanical operations. Concerning GHG emissions, and by scaling down our results (from an average yield of 15,000 Kg ha^{-1} year^{-1} to 1000 Kg of harvested olives), the emission of CO_2 eq/1,000 Kg of olives was, on average, equal to 477.6 Kg, confirming the findings of Salomone and Ioppolo (2012). Likewise, in terms of toxicity, our results assume values that were considerably higher, in particular due to applying larger amounts of fertilizers and pesticides. The CS and ZCW scenarios could be compared with conventional and organic scenarios, respectively, as analysed by Mohamad et al. (2014). Contrary to their results, the CS scenario showed better performances than the ZCW. Our results could be explained by the lower dosage of glyphosate and a different mechanical weeding technique.

Similar results can be found in Iraldo et al. (2013), who attributed the relevant contribution of toxic emissions to weed control. From the land use point of view, the LDTN scenario yields better results, but, to perform a deeper land use assessment, the analyses should be integrated by specific indicators as suggested by Saad et al. (2013). The inclusion of other indicators such as the Soil Organic Content or Erosion Potential could considerably emphasize the results.

As expected from the results of this case study, the greatest contributors to the economic impact of olive production was the harvesting and pruning operations, which involve higher farm labour and machinery ownership costs, in accordance with other studies (Mohamad et al., 2014; Sgroi et al., 2015; Stillitano et al., 2016; 2017; Castillo-Ruiz et al., 2017). The other cost items with high impacts were fertilization and phytosanitary treatments in terms of input costs. In particular, to fight biotic factors, due to the humid microclimate of the orography and the high-density planting, a higher number of pesticide applications were necessary. Therefore, the weed control activity had a lower impact on the total orchard cost when performed through both tillage and chemical products.

However, the purpose of this study was to highlight the effects of different weed control techniques on the economic results. Thus, our results indicated that reducing the inputs for weed control associated with no-tillage management decreased the costs during the entire olive production cycle (LDNT scenario). Conversely, when chemical weed control (CS scenario) is considered, the results are poorer due to the higher use of herbicides. Where mechanical weed control (ZCW scenario) is assumed, the results are worse because of the high human labour requirements and fuel consumption involved in removing the grass cover. Several researchers have shown that human labour and fuel consumption are the most important cost items in soil management within agricultural production systems (Hemmati et al., 2013; Palese et al., 2013; Falcone et al., 2016).

Our results are not consistent with those reported by Mohamad et al. (2014), who found mechanical weed control to be better at reducing costs than the use of herbicides. As observed in the study by Pergola et al (2013), in which the authors considered that spontaneous weeds were mowed at least twice a year by using agricultural machinery (sustainable system scenario), weed control operations together with disease control and harvesting consumed the largest amount of inputs, endorsing the results obtained by our ZCW scenario.

The economic sensitivity analysis (Table 7) highlighted that each investigated scenario was strongly influenced by the uncertainty connected to the assumption of data invariance (i.e., the olive price, discount rate, and primary input used under experimental conditions) during the reference period. The economic findings showed that the investments in olive growing were not economically sustainable at the current market prices (De Gennaro et al, 2012) and when excluding EU subsides. These findings indicated that the olive groves under study were strictly dependent on public subsides, confirming the insights obtained by other studies (Xiloyannis et al., 2008; Oxouzi et al. 2012; Di Vita et al., 2015).

Sensible variations in the economic viability of the examined investments were achieved when a discount rate change was assumed. As noted by Hussain et al. (2005), a small percentage of variation in the discount rate can have a large impact on the present values.
On the other hand, only slight changes on results were obtained by considering variations of input used in the three different weeding scenarios. In both cases, LDNT scenario remained the best solution overall.
From a social point of view, the use of chemicals for weed management were found to potentially expose workers to fewer hours of work (and therefore, to an overall lower risk to their health), but from a qualitative point of view, it exposes them to worse conditions due to exposures to the risk of potentially mortal diseases. In all scenarios, harvesting and the use of tractors have a greater impact in terms of hours, but they principally expose workers to the risk of musculoskeletal disorders, while their exposure to chemicals, even if during fewer hours, exposes them to more dangerous diseases, such as cancers, non-Hodgkin lymphomas, and Parkinson's disease.
The involvement of stakeholders in weighting has been of the utmost importance for overcoming this trade-off among the sustainability dimensions and categories of impacts. The results have shown that the actors are strongly concerned with toxicity and the social health of workers. To improve their products and gain access to more markets by meeting these new requirements for ethics and environmentally friendly products, farmers and managers should take these "sustainability qualities" into account. These will also improve their economic and environmental performances.

6. Conclusions

The aim of this study was to assess innovations in terms of olive farming systems, by accounting for all aspects of sustainability through an integrated and participative LCSA proposal. The assessment was conducted by comparing three types of scenarios that were applied in a representative olive area. From the environmental point of view, the CS and ZCW scenarios had the worst results respectively due to the use of herbicide (CS) and diesel consumption (ZCW) for weeding operation. The LDNT represented the best solution, but, further research should be done by including other impact categories. In particular "land use assessment" would require the implementation of specific indicators that consider also the impacts on the "quality of soils". The sensitivity analyses demonstrated that also by reducing the input of the worst scenarios and increasing those of the better ones, the ranking did not change.
Future developments of the research could also include further weed control techniques, such as alternative herbicides and other mechanical weeding operations, in order to expand the range of possible choices, coherently with the agronomic techniques that can be actually implemented in the olive growing.
The economic assessment performed showed that although the weed control phase has not a sensible impact on the total orchard cost, the large use of herbicides (CS scenario) as well as mechanical weed control (ZCW scenario) negatively affected the results. Particularly, the removal of grass cover by using machines was the technique most responsible for the costs increasing because of the recur to human labour and fuel consumption. Therefore, weed management performed by using reduced herbicide applications in combination with no-tillage (LDNT scenario) is the less expensive solution. In addition, this study demonstrated how the economic feasibility of the olive growing investments in the study area strongly depends on public subsides, since, at the current market condition, olive price is not profitable for farmers. However, the economic sensitivity analysis proved how these results can be affected by the methodological choices and input data quality. In this sense, new weeding control techniques should be further investigated in order to explore more management models that could reduce costs and improve farm profitability.
From a social point of view, LDNT scenario is the best one only in terms of psychosocial risk factors, but it is highly recommended to reduce or eliminate chemicals for weeding and pest control, due to the possible risk of mortal disease.

The methodology applied here is an example of user-friendly tools that are applicable in many contexts and by many types of users with minimal knowledge about LC tools. Room for improvement remains, especially concerning the choice of indicators under consideration.
Sustainability is considered as the new total quality, and sustainable production is considered to be a means to create innovation while respecting the environment, preserving economic viability and satisfying social requirements (Germani et al., 2016). Therefore, integrative methodologies are highly suitable as decision-making support tools, especially when innovation strategies are requested. The participation of local actors allowed to make sustainability assessments consistent with local realities and to give an interpretive legitimization to the analysis. The originality of the present work also comes from the use of the "weighted weights" of each impact category according to the preferences of actors for one or another sustainability dimension. The MCDA methods enabled the LCSA here applied to deal with subjective assumptions in an objective way, to account for actor values and to overcome trade-offs among the different dimensions of sustainability. However, further improvements are possible, for example, by considering more indicators or by involving the actors in the construction of the methodology through the empowerment processes of social learning.

ACKNOWLEDGEMENTS

This research is funded by the Italian Ministry of University and Research (MIUR) within the research project "Distretto ad alta tecnologia agroindustrale della Calabria AGRIFOODTECH (PON03PE_00090_2) "Modelli sostenibili e nuove tecnologie per la valorizzazione delle olive e dell'olio extravergine di oliva prodotto in Calabria", coordinated by Department of Agriculture, Mediterranean University of Reggio Calabria, Italy.

REFERENCES

Amiri, D., Sann, L.M., Adon, M.Y., Mukhtar, H.F., Idris, K., Kuhn, K., Kamari, A.A., 2015. Relationship of psychosocial safety climate and workplace psychosocial risks: A randomized trail among personnel of an oil and gas company in Iran. Asian Soc. Sci. 11, 69–83.

Annunziata, A., Vecchio, R. 2016. Organic Farming and Sustainability in Food Choices: An Analysis of Consumer Preference in Southern Italy. Agriculture and Agricultural Science Procedia, 8, 193–200.

Avraamides M., Fatta D. 2008. Resource consumption and emissions from olive oil production: a life cycle inventory case study in Cyprus. Journal of Cleaner Production 16, 809-821. doi:10.1016/j.jclepro.2007.04.002

Bacenetti J., Fusi A., Negri M., Bocchi S., Fiala M. 2016. Organic production systems: Sustainability assessment of rice in Italy. Agriculture, Ecosystems and Environment, 225, 33–44. https://doi.org/10.1016/j.agee.2016.03.046

Banias, G., Achillas, C., Vlachokostas, C., Moussiopoulos, N., Stefanou, M. 2017. Environmental impacts in the life cycle of olive oil: a literature review. Journal of the Science of Food and Agriculture 97(6), 1686-1697.

Benavente, V. Fullana, A., Berge, N.D. 2017. Life cycle analysis of hydrothermal carbonization of olive mill waste: Comparison with current management approaches. Journal of Cleaner Production 142, 2637-2648.

Benis, K., Ferrao, P. 2016. Potential mitigation of the environmental impacts of food systems through Urban and Peri-Urban Agriculture (UPA) – A Life Cycle Assessment approach. Journal of Cleaner Production, 140, 1–12.

Bernardi, B., Benalia, S., Fazari, A., Zimbalatti, G., Stillitano, T. and De Luca, A.I. 2016. Mechanical harvesting in traditional olive orchards: Oli-picker case study. Agronomy Research 14(3), 683-688.

Bocoum, I., Macombe, C., Revéret, J.-P. 2015. Anticipating impacts on health based on changes in income inequality caused by life cycles. Int J Life Cycle Assess 20:405-417

Brentrup, F., Küsters, J., Lammel, J., Kuhlmann, H. 2000. Methods to estimate on-field nitrogen emission from crop production as an input to LCA studies in the agricultural sector. Int J Life Cycle Assess, 5 (6), 349-357.

Bushan, N., Rai, K. 2004. Strategic Decision Making. Applying the Analytic Hierarchy Process. Springer-Verlag London. Buzzell, R.D., Gale, B.T. 1987. The PIMS principles: Linking strategy to performance. Simon and Schuster.

Calik, E., Bardudeen, F. 2016. A Measurement Scale to Evaluate Sustainable Innovation Performance in Manufacturing Organizations. Procedia CIRP, 40, 449–454.

Callea, P., Zimbalatti, G., Quendler, E., Nimmerichter, A., Bachl, N., Bernardi, B., Smorto, D., Benalia, S. 2014. Occupational illnesses related to physical strains in apple harvesting. Ann Agric Environ Med, 21(2), 407-411 doi:10.5604/1232-1966.1108614.

Cappelletti, G.M., Grilli, L., Nicoletti, G.M., Russo, C. 2017. Innovations in the olive oil sector: A fuzzy multicriteria approach. Journal of Cleaner Production, 159, 95-105.

Castillo-Ruiz, F.J., Sola-Guirado, R.R., Castro-Garcia, S., Gonzalez-Sanchez, E.J., Colmenero-Martinez, J.T., Blanco-Roldán, G.L. 2017. Pruning systems to adapt traditional olive orchards to new integral harvesters. Scientia Horticulturae, 220: 122-129.

Cerutti, A.K., Beccaro, G.L., Bosco, S., De Luca, A.I., Falcone, G., Fiore, A., Iofrida, N., Lo Giudice, A., Strano, A. 2015. Life Cycle Assessment in the Fruit Sector, in: Notarnicola B, Salomone R, Petti L, Renzulli PA, Roma R, Cerutti AK (Eds.) Life Cycle Assessment in the Agri-food Sector Case Studies, Methodological Issues and Best Practices. Springer Publishing. Switzerland.

Christoforou, E.A., Fokaides, P.A. 2016. Life cycle assessment (LCA) of olive husk torrefaction. Renewable Energy, 90, 257-266.

Ciroth, A., Hildenbrand, J., Steen, B. 2016. Life cycle costing. In Sustainability Assessment of Renewables-Based Products: Methods and Case Studies, 1st ed.; Dewulf, J., De Meester, S., Alvarenga, R.A.F., Eds.; John Wiley and Sons: Chichester, UK, pp. 215-228.

Cox, T., Griffiths, A., Rial-Gonzalez, E., 2000. Research on Work-related Stress, Office for Official Publications of the European Communities. ISBN 92-828-9255-7.

De Gennaro, B., Notarnicola, B., Roselli, L., Tassielli, G. 2012. Innovative olive-growing models: an environmental and economic assessment, J. Clean. Prod., 28, 70-80.

De Luca A.I., G. Falcone, T. Stillitano, A. Strano, and G. Gulisano. 2014. Sustainability assessment of quality-oriented citrus growing systems in Mediterranean area. Quality Access to Success 15(141):103-108.

De Luca, A.I., Falcone, G., Iofrida, N., Stillitano, T., Strano, A., Gulisano, G., 2015a. Life cycle methodologies to improve agri-food systems sustainability. Rivista di Studi sulla Sostenibilità (1), 135-150. doi:10.3280/RISS2015-001009.

De Luca, A.I., Iofrida, N., Strano, A., Falcone, G., Gulisano, G., 2015b. Social life cycle assessment and participatory approaches: A methodological proposal applied to citrus farming in Southern Italy. Integr. Environ. Assess. Manag. 11(3), 383-96.

De Luca, A.I., Molari, G., Seddaiu, G., Toscano, A., Bombino, G., Ledda, L., Milani, M., Vittuari, M. 2015c. Multidisciplinary and innovative methodologies for sustainable management in agricultural systems. Environ Eng Manag J 14(7):1571-1581.

De Luca, A.I., Iofrida, N., Leskinen, P., Stillitano, T., Falcone, G., Strano, A., Gulisano, G. 2017. Life Cycle tools combined with multi-criteria and participatory methods for agricultural sustainability. Insights from a systematic and critical review. Science of Total Environment, 595, 352-370.

Deytieux V.,Nemecek T., Freiermuth Knuchel R., Gaillard G., Munier-Jolain N.M. 2012. Is Integrated Weed Management efficient for reducing environmental impacts of cropping systems? A case study based on life cycle assessment. European Journal of Agronomy, 36, 55–65. doi:10.1016/j.eja.2011.08.004

Di Cesare, S., Silveri, F., Sala, S., Petti, L. 2016. Positive impacts in social life cycle assessment: state of the art and the way forward. Int J Life Cycle Assess (in press). doi:10.1007/s11367-016-1169-7.

Di Vita, G., Chinnici, G., D'Amico, M. 2015. Sustainability of olive oil production in Sicilian marginal agricultural areas, Q. Access Success, 16(S1): 118-125.
El Hanandeh, A., Gharaibeh, M.A. 2016. Environmental efficiency of olive oil production by small and micro-scale farmers in northern Jordan: Life cycle assessment. Agricultural Systems 148, 169-177.
Elbaz, A., Clavel, J., Rathouz, P. J. 2009. Professional Exposure to Pesticides and Parkinson Disease. Annals of Neurology, 66(4), 494–504.
Elkington, J. 1997. Cannibals with Forks: the Triple Bottom Line of 21st Century Business. Conscientious Commerce.
Emblemsvåg, J., 2003. Life-cycle costing. Using Activity-Based Costing and Monte Carlo Methods to Manage Future Costs and Risks. John Wiley & Sons, Inc. Hoboken. New Jersey.
Enquist, B., Edvardsson, B., Sebhatu, S.P. 2007. Values-based service quality for sustainable business. Managing Service Quality: An International Journal, 17(4), 385-403.
Falcone, G., De Luca, A., Stillitano, T., Strano, A., Romeo, G., Gulisano, G., 2016 Assessment of Environmental and Economic Impacts of Vine-Growing Combining Life Cycle Assessment, Life Cycle Costing and Multicriterial Analysis. Sustainability 8, 793.
Falcone, G., Strano, A., Stillitano, T., De Luca, A.I., Iofrida, N., Gulisano, G., 2015 Integrated sustainability appraisal of wine-growing management systems through LCA and LCC methodologies. Chem. Eng. Trans. 44: 223-228.
Faure, G., Coudel, E., Soulard, C.T., Devautour, H. 2013. Reconsidering innovation to address sustainable development. In: Coudel, E., Devautour, H., Soulard, C. T., Faure, G., Hubert, B. (Eds). Renewing Innovation Systems in Agriculture and Food: How to Go Towards More Sustainability? Wageningen Academic Publishers, Ed., pp. 17-34
Feschet, P., Macombe, C., Garrabé, M., Loeillet, D., Saez, A.R., Benhmad, F., 2013. Social impact assessment in LCA using the Preston pathway. The case of banana industry in Cameroon. Int. J. Life Cycle Ass. 18(2), 490-503.
Finkbeiner, M., Schau, E.M., Lehmann, A., Traverso, M. 2010. Towards Life Cycle Sustainability Assessment. Sustainability, 2, 3309-3322.
Foolmaun, R.K., Ramjeawon, T. 2013. Life cycle sustainability assessments (LCSA) of four disposal scenarios for used polyethylene terephthalate (PET) bottles in Mauritius. Environ Dev Sustain 15:783-806.
Fortes, C., Mastroeni, S., Segatto, M. M., Hohmann, C., Miligi, L., Bakos, L., Bonamigo, R. 2016. Occupational Exposure to Pesticides With Occupational Sun Exposure Increases the Risk for Cutaneous Melanoma, 58(4).
Fritschi, L., Benke, G., Hughes, A. M., Kricker, A., Turner, J., Vajdic, C. M., Grulich, A. 2005. Original Contribution Occupational Exposure to Pesticides and Risk of Non-Hodgkin ' s Lymphoma, 162(9), 849–857.
Gabel, V.M., Meier, M.S., Köpke, U., Stolze, M., 2016. The challenges of including impacts on biodiversity in agricultural life cycle assessments. J. Environ. Manage. 181: 249-260.
Gasnier, C. 2012. Etude de l'impact des conditions de travail sur la santé dans la perspective de développer des pathways en ACV sociale. Bilan de recherche de stage (March - October 2012). Altran and IRSTEA
Gaziulusoy, A.I., Brezet, H. 2015. Design for system innovations and transitions: A conceptual framework integrating insights from sustainablity science and theories of system innovations and transitions. Journal of Cleaner Production, 108, 1–11.
Germani, M., Luzi, A. Marilungo, E., Papetti, A., Peruzzini, M. 2016. Investigating the sustainability of a high-energy consuming industrial process to achieve total quality, Int. J. Productivity and Quality Management, Vol. 18, Nos. 2/3, 2016
Ghobadian A, Speller S, Jones M 1994 Service quality: concepts and models. IJQRM, 11(9): 43-66.
Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., Trow, M. 1994. The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies. SAGE, ISBN: 8790803977938.

Gibson, R.B. 2006. Beyond the Pillars: Sustainability Assessment As a Framework for Effective Integration of Social, Economic and Ecological Considerations in Significant Decision-Making. Journal of Environmental Assessment Policy and Management, 8(3), 259–280.

Greendex 2014. Greendex 2014: Consumer Choice and the Environment - A Worldwide Tracking Survey, report, September. National Geographic, Globescan.

Guermazi, Z., Gharsallaoui, M., Perri, E., Gabsi, S., Benincasa, C. 2017. Integrated approach for the eco design of a new process through the life cycle analysis of olive oil: Total use of olive by-products. European Journal of Lipid Science and Technology (in press).

Guinée, J.B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., Ekvall, T., Rydberg, T. 2011. Life cycle assessment: Past, present and future. Environmental Science and Technology, 45 (1), 90–96.

Hall, M.R. 2015. A transdisciplinary review of the role of economics in life cycle sustainability assessment. Int. J. Life Cycle Assess. 20, 1625–1639.

Han, J., Kamber, M., Pei, J. 2011. Data mining: Concepts and techniques. 3rd ed. Waltham (MA): Morgan Kaufmann. 708 p.

Hemmati, A., Tabatabaeefar, A., Rajabipour, A. 2013. Comparison of energy flow and economic performance between flat land and sloping land olive orchards, Energy, 61: 472-478.

Hossaini, N., Kasun Hewage, K., Sadiq, R. 2014. Spatial life cycle sustainability assessment: a conceptual framework for net-zero buildings. Clean Techn Environ Policy, 17:2243-2253

Hu, J., Mao, Y., White, K., Canadian, T., Registries, C. 2002. Renal cell carcinoma and occupational exposure to chemicals in Canada, 52(3), 157–164.

Hussain, M., Mumma, G., Saboor, A. 2005. Discount rate for investments: some basic considerations in selecting a discount rate. Pak. J. life soc. Sci., 3(1-2), 1-5.

Iofrida N (2016) Paradigmatic stances and methodological issues in social life cycle assessment. Comparison of two different methodological proposals applied to agricultural products. PhD thesis, Mediterranean University of Reggio Calabria, Italy.

Iofrida, N., De Luca, A.I., Strano, A., Gulisano, G. 2016. Can social research paradigms justify the diversity of approaches in social Life Cycle Assessment? Int J LCA (in press) doi10.1007/s11367-016-1206-6

Iraldo F., Testa F., Bartolozzi I. 2014. An application of Life Cycle Assessment (LCA) as a green marketing tool for agricultural products: the case of extra-virgin olive oil in Val di Cornia, Italy, Journal of Environmental Planning and Management, 57:1, 78-103, DOI: 10.1080/09640568.2012.735991

ISO. 2006a. ISO 14040:2006 Environmental management - Life Cycle Assessment - Principles and framework. International Organization for Standardization (ISO), Geneva

ISO. 2006b. ISO, 2006b. ISO 14044:2006 Environmental management - Life Cycle Assessment - Requirements and guidelines. International Organization for Standardization. Geneva, Switzerland.

ISO. 2008. ISO 15686-5:2008 Buildings and Constructed Assets-Service Life Planning-Life Cycle Costing; International Organization for Standardization (ISO): Geneva, Switzerland.

Joshi, Y., Rahman, Z. 2015. Factors Affecting Green Purchase Behaviour and Future Research Directions. International Strategic Management Review (Vol. 3). Holy Spirit University of Kaslik.

Kleijn, D., Kohler, F., Báldi, A., Batáry, P., Conceptón, E.D., Clough, Y., Díaz, M., Gabriel, D., Holzschuh, A., Knop, E., Kovács, A., Marshall, E.J.P., Tscharntke, T., Verhulst, J. 2009. On the relationship between farmland biodiversity and land use intensity in Europe. R. Soc. 276: 903-909.

Klewitz, J., Hansen, E.G. 2014. Sustainability-oriented innovation of SMEs: a systematic review. Journal of Cleaner Production, 65:57-75.

Klöpffer, W. 2008. Life cycle sustainability assessment of products (with Comments by Helias A. Udo de Haes, p. 95). Int J Life Cycle Assess 13:89.

Klöpffer, W., Ciroth, A., 2011. Is LCC relevant in a sustainability assessment? Int. J. Life Cycle Assess. 16, 99–101.

Klöpffer, W., Renner, I. 2007. Lebenszyklusbasierte Nachhaltigkeitsbewertung von Produkten. TaTuP Zeitschrift des ITAS zur Technikfolgenabschätzung, 16 (3), 32–38

Macombe, C., Leskinen, P., Feschet, P., Antikainen, R. 2013. Social life cycle assessment of biodiesel production at three levels: a literature review and development needs. J. Clean. Prod. 52, 205-216

Martínez-Blanco, J., Lehmann, A., Muñoz, P., Antón, A., Traverso, M., Joan Rieradevall, J., Finkbeiner, M. 2014. Application challenges for the social Life Cycle Assessment of fertilizers within life cycle sustainability assessment. J. Clean. Prod. 69:34-48.

Mathur, V.N., Price, A.D.F., Austin, S. 2008. Conceptualizing stakeholder engagement in the context of sustainability and its assessment. Construction Management and Economics 26(6): 601-609.

Mohamad, R.S., Verrastro, V., Cardone, G., Bteich, M.R., Favia, M., Moretti, M., Roma, R. 2014. Optimization of organic and conventional olive agricultural practices from a Life Cycle Assessment and Life Cycle Costing perspectives. J. Clean. Prod., 70:78-89.

Moisander, J. 2007. Motivational complexity of green consumerism. International Journal of Consumer Studies, 31(4), 404-409.

Narasimhan, S., Kannan, V. 2011. Total quality management as the foundation of sustainability - Turning a new leaf. Eur. J. Soc. Sci., 24 (3), 444-451.

Nemecek, T., Kägi, T., 2007. Life Cycle Inventories of Swiss and European Agricultural Production Systems. Final Report Ecoinvent V2.0 No. 15a. Agroscope Reckenholz-Taenikon Research Station ART, Swiss Centre of Life Cycle Inventories: Zurich and Dübendorf, CH.

Notarnicola B., Tassielli, G., Renzulli, P.A., Castellani, V., Sala, S. 2017. Environmental impacts of food consumption in Europe. J. Clean. Prod., 140: 753-765.

O’Brien, M., Doig, A., Clift, R. 1996. Social and environmental life cycle assessment (SELCA). The International Journal of Life Cycle Assessment, 1(4), 231–237.

Oxouzi, E., Melfou, K., Galea M., Papanagiotou, E. 2012. Economic performance and crop farm efficiency in mountainous and other less favoured areas in Greece, Bulg. J. Agric. Sci., 18(6): 846-853.

Palese, A.M., Pergola, M., Favia, M., Xiloyannis, C., Celano, G. 2013. 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, 27: 81-90.

Paul, J., Modi, A., Patel, J. 2016. Predicting green product consumption using theory of planned behavior and reasoned action. Journal of Retailing and Consumer Services 29, 123-134.

Pesonen, H.L., Horn, S., 2013. Evaluating the Sustainability SWOT as a streamlined tool for life cycle sustainability assessment. Int. J. Life Cycle Assess. 18, 1780–1792.

Phoenix, C., Osborne, N. J., Redshaw, C., Moran, R., Stahl-Timmins, W., Depledge, M. H., Wheeler, B. W. 2013. Paradigmatic approaches to studying environment and human health: (Forgotten) implications for interdisciplinary research. Environmental Science and Policy.

Portier, C.J., Armstrong, B.K., Baguley, B.C., et al. 2016. Differences in the carcinogenic evaluation of glyphosate between the International Agency for Research on Cancer (IARC) and the European Food Safety Authority (EFSA). J Epidemiol Community Heal. 0, 1–5.

PRè - Product Ecology Consultants 2016. SimaPro Database Manual - Methods library. Netherlands.

Recchia, L., Boncinelli, P., Cini, E., Vieri, M., Garbati Pegna, F., Sarri, D. 2011. Olive Oil Production Chain. In: Multicriteria Analysis and LCA Techniques. With Applications to Agro-Engineering Problems. (Green Ener, pp. 99–128). Springer.

Ren, J., Manzardo, A., Mazzi, A., Zuliani, F., Scipioni, A., 2015. Prioritization of bioethanol production pathways in China based on life cycle sustainability assessment and multicriteria decision-making. Int. J. Life Cycle Ass. 20(6), 842-853.

Romero-Gàmez, M. Castro-Rodriguez, J., Suàrez-Rey, E.M. 2017. Optimization of olive growing practices in Spain from a life cycle assessment perspective. Journal of Cleaner Production 149, 25-37.

Saad R., Koellner T., Margni M. 2013. Land use impacts on freshwater regulation, erosion regulation, and water purification: a spatial approach for a global scale level. International Journal of Life Cycle Assessment, 18, 1253–1264. DOI 10.1007/s11367-013-0577-1

Saaty, T.L. 1980. The Analytic Hierarchy Process. McGraw-Hill, New York.
Saaty, T.L. 2008. Decision making with the analytic hierarchy process. Int. J. Services Sciences, 1, 1, 83-98.
Sala, S., Farioli, F., Zamagni, A. 2013a. Progress in sustainability science: Lessons learnt from current methodologies for sustainability assessment: Part 1. International Journal of Life Cycle Assessment, 18, 1653–1672.
Sala, S., Farioli, F., Zamagni, A. 2013b. Life cycle sustainability assessment in the context of sustainability science progress (part 2). International Journal of Life Cycle Assessment, 18, 1686–1697.
Salomone R., Cappelletti GM., Malandrino O., Mistretta M., Neri E., Nicoletti GM., Notarnicola B., Pattara C., Russo C., Saija G. 2015. Life Cycle Assessment in the Olive Oil Sector, In: Life Cycle Assessment in the Agri-food Sector Case Studies, Methodological Issues and Best Practices, Notarnicola B., Salomone R., Petti L., Renzulli P.A., Roma R., Cerutti A.K., Eds., Springer Publishing, 390. DOI 10.1007/978-3-319-11940-3.
Salomone, R., Ioppolo, G., 2012. Environmental impacts of olive oil production: a Life Cycle Assessment case study in the province of Messina (Sicily) Journal of Cleaner Production 28:88-100.
Sarkar, S., Pansera, M. 2015. Sustainability-driven innovation at the bottom: Insights from grassroots ecopreneurs. Technological Forecasting and Social Change, 114, 327–338.
Sgroi, F., Foderà, M., Di Trapani, A.M., Tudisca, S., Testa, R. 2015. Cost-benefit analysis: A comparison between conventional and organic olive growing in the Mediterranean Area, Ecol. Eng., 82: 542-546.
Silva, A.R.A., Bioto, A.S., Efraim, P., Queiroz, G. de C. 2014. Impact of Sustainability Labeling in purchase intention and quality perception of dark chocolate. 9th International Conference on Life Cycle Assessment in the Agri-Food Sector, 141 (October), 2–7.
Silveri F., Macombe C., Gasnier C., Grimbhuler S. 2014. Anticipating the psychosocial factors effects in social LCA. Proceedings of SETAC Europe 24th Annual Meeting, May 11-15, Basel.
Stefanova, M., Tripepi, C., Zamagni, A., Masoni, P., 2014. Goal and Scope in Life Cycle Sustainability Analysis: The Case of Hydrogen Production from Biomass. Sustainability 6, 5463–5475.
Stillitano, T., De Luca, A.I., Falcone, G., Spada, E., Gulisano, G., Strano A. 2016. Economic profitability assessment of Mediterranean olive growing systems, Bulg. J. Agric. Sci., 22(4):517-526.
Stillitano T., De Luca A. I., Iofrida N., Falcone G., Spada E., Gulisano G. 2017. Economic analysis of olive oil production systems in Southern Italy. Quality - Access to Success, 18:157 (in press).
Swarr, T.E., Hunkeler, D., Klöpffer, W., Pesonen, H-L., Ciroth, A., Brent, A.C., Pagan, R. 2011. Environmental life cycle costing: A code of practice. Int. J. Life Cycle Assess. 16:389-391.
Tashakkori A, Teddlie C (Eds) 2010 The SAGE Handbook of Mixed Methods in Social & Behavioral Research. SAGE Publications, Inc.
Triantaphyllou, E., Mann, S.H. 1995. Using the analytic hierarchy process for decision making in engineering applications: some challenges. International Journal of Industrial Engineering: Applications and Practice. 2, 1, 35-44.
Triomphe, B., Rajalahti, R. 2013. From concept to emerging practice: what does an innovation system perspective bring to agricultural and rural development? In: Coudel, E., Devautour, H., Soulard, C. T., Faure, G., Hubert, B. (Eds). Renewing Innovation Systems in Agriculture and Food: How to Go Towards More Sustainability? Wageningen Academic Publishers, Ed., pp. 57-76
Tsarouhas P., Achillas Ch., Aidonis D., FolinasD., Maslis V. 2015. Life Cycle Assessment of olive oil production in Greece. Journal of Cleaner Production, 93, 5119, 75-83.
UNEP-SETAC. 2013. The methodological sheets of sub-categories in Social Life Cycle Assessment (sLCA). Retrieved from: [http://www.lifecycleinitiative.org.www.estis.net/sites/lcinit/]

Valdivia, S., Ugaya, C. M. L., Hildenbrand, J., Traverso, M., Mazijn, B., Sonnemann, G. 2013. A UNEP/SETAC approach towards a life cycle sustainability assessment - Our contribution to Rio+20. International Journal of Life Cycle Assessment, 18(9), 1673–1685.

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., Weidema, B P. 2016. The ecoinvent database version 3 (part I): overview and methodology. Int J Life Cycle Assess, 1-3 (article in press) doi:10.1007/s11367-016-1087-8.

Xiloyannis, C., A. Martinez Raya, C. Kosmas and M. Favia 2008. Semi-intensive olive orchards on sloping land: Requiring good land husbandry for future development, J. Environ. Manag., 89: 110-119.

Yu, M., Halog, A. 2015. Solar Photovoltaic Development in Australia-A Life Cycle Sustainability Assessment Study. Sustainability 7, 1213-1247.

Zeithaml, V.A. 2000. Service quality, profitability, and the economic worth of customers: what we know and what we need to learn. Journal of the academy of marketing science 28(1), 67-85.

Zhou, Z., Jiang, H., Qin, L., 2007. Life cycle sustainability assessment of fuels. Fuel, 86(1-2), 256-263.