Eco-profiles and economic performances of a high-value fruit crop in southern Italy: a case study of bergamot (Citrus bergamia Risso)

A. Strano, G. Falcone, B. F. Nicolò, T. Stillitano, A. I. De Luca, F. S Nesci, and G. Gulisano

Department of Agriculture, Mediterranean University of Reggio Calabria, Reggio Calabria, Italy

ABSTRACT

This paper analyses the environmental and economic sustainability of bergamot, a citrus crop considered very significant for its long-standing peculiarities linked to a strong socio-economic role, a meaningful rooting in territorial heritage and an important function in environmental and landscape terms. A comparison between conventional and organic cropping systems has been carried out by means of life cycle assessment and life cycle costing tools in order to assess the impacts of different management practices. The results show positive performances of the organic production system, from both environmental and economic points of view. Furthermore, compared to similar studies of other citrus crops in the same area, bergamot cultivation can represent an economically sustainable choice for farmers with lower environmental impacts.

KEYWORDS

Bergamot; crop management; environmental impacts; financial analysis; investment feasibility; life cycle assessment; life cycle costing

1. Introduction

In 2013, Italy was the second largest citrus fruit producer in Europe, producing approximately 2.7 million tons (FAOstat 2016), as well as the main worldwide producer of bergamot (Citrus bergamia Risso), the production of which was mainly concentrated in the Calabria Region (southern Italy), representing more than 90% of the worldwide production. Grown almost exclusively in the Reggio Calabria province, this crop has found over the centuries a suitable breeding ground able to satisfy its exacting pedo-climatic requirements, resulting in a one-of-a-kind agroecosystem. Therefore, a very close relationship between this fruit and its territory has occurred for a very long time, making bergamot a remarkable and likely irreplaceable socio-economic asset.

Indeed, a recent survey conducted on the livelihood resilience of bergamot farmers restates the profitability of this cultivation in comparison with other typical permanent crops, as well as the capability to generate a significant source of income and job opportunities for rural populations in southern Calabria (Ciani, Huggard, and Zervas 2014). This is mainly explained by the commercial relevance of the bergamot essential oil (Grando 2008) that flavor and fragrance industries seek. Indeed, the international trading market has long and widely acknowledged the highest quality of the Bergamot oil produced in the province of Reggio Calabria (Sawamura et al. 2006), characterized by a peculiar composition and complex aroma features (Russo et al. 2012) and by the unique capability to fix and accord all other constituents of a scent. Additionally, the scientific community increasingly agrees on the numerous pharmacological properties of bergamot essential oil (e.g., antimicrobial, anti-inflammatory, and analgesic effects) (Navarra et al. 2015), as well as those of bergamot fruit components (peel, pulp, seed, and juice) as, for example, sources of nutraceuticals (Russo et al. 2016). From a territorial or scenery point of view, the bergamot trees create a unique and interesting landscape in the world (Barbera 2013), whose agroecosystem stability must be maintained by guaranteeing an acceptable environmental sustainability level through the preservation over time of the functionality of biological processes. This should assure constant orchard productivity and the economic competitiveness of production. In the meantime, the depletion of natural resources and the pollution due to emissions and waste generated by anthropogenic activities should be contained – or better yet, avoided – as much as possible through adequate management systems (Fenollosa et al. 2014; Nicolò et al. 2015). Therefore, in most cases, a change in farming practices is needed to guide agricultural entrepreneurs toward sustainability pathways, reconciling an efficient use of energy and natural resources and a viable trade-off level between costs and revenues. Therefore, to pursue this objective means that the appropriate knowledge must be usable by farmers, which, to answer to consumers' needs and to cope with the pressures of market competitors, have to be conscious of environmental impacts caused by their production as well as of the production costs dynamics (Fenollosa et al. 2014). In this sense, life cycle-based tools for the evaluation of environmental and economic performance of a product or process system are increasingly appreciated by both private companies for certification strategies (EPD, database 2016), and public bodies for green procurement (Brammer and Walker 2011; Cerutti et al. 2016; Smith et al. 2016). Such assessment methodologies, belonging to the life cycle management (LCM) framework, allow researchers to take into account all stages that contribute to the production of a good or service "from cradle to grave", throughout its entire life cycle, from design to recycling or final disposal, considering all input and output flows of materials and energy requirements of each production process (Guinée 2002). Focused on environmental and economic appraisals, life cycle assessment (LCA), and life cycle costing (LCC) are currently widely applied to different fields of study.

Furthermore, in recent years, increasing interest in combined applications of these approaches has occurred, so much so that an ever increasing number of scholars address integrated analysis of environmental and economic sustainability (e.g., among the most recent works: Auer, Bey, and Schäfer 2017; Dattilo et al. 2016; Petrillo et al. 2016; Yang et al. 2016). This urgency to reconcile different dimensions/indicators/methods is also strongly felt in the agro-food field (Cerutti et al. 2015, 2015a; De Luca et al. 2014, 2017b, 2017a, 2015b; Falcone et al. 2015, 2016; Ren et al. 2015; Strano et al. 2013; Tamburini et al. 2015). Notoriously, this production sector is simultaneously responsible for huge environmental problems (EEA 2012, 2015), but also vulnerable to market crises and price shocks, more so than other sectors.

LCA is a method standardized by the International Organization for Standardization (ISO) 14040 norm (ISO 2006a) that establishes the methodological framework to perform, correctly, an LCA study, while the ISO 14044 norm (ISO 2006b) describes the guidelines and the fundamental steps of the analysis.

With regard to the LCA studies on citrus-fruit cultivation and citrus-based production, numerous applications have been carried out. In particular, the LCA method has been implemented to compare several farming systems such as conventional, organic (Knudsen et al. 2011; Nicolò et al. 2015; Pergola et al. 2013; Ribal et al. 2016) and integrated production (De Luca et al. 2014), and to evaluate both specific citrus-fruit production systems (Basset-Mens et al. 2016; Bessou et al. 2016; Coltro et al. 2009; Logiudice et al 2013; Sanjuán et al. 2005) and citrus-based products, such as juices and essential oils (Beccali et al. 2010; Dwivedi, Spreen, and Goodrich-Schneider 2012), related to the different use of inputs and agricultural practices. More recently, Yan et al. (2016) have quantified the GHG emissions associated with China's orange production in order to calculate the carbon footprint. Moreover, a recent review on the criteria to implement an LCA in fruit production systems underlines that citrus fruit are the most evaluated systems (Cerutti et al. 2015).

The LCC method, as the economic "alter ego" of LCA (Klopffer 2003), is a methodological approach developed and originally applied in management accountability in order to estimate the total life cycle cost of an investment, including both the initial costs and other consecutive costs that will be incurred throughout the product's lifetime (Dhillon 1989). Over time, LCC has been subject to improvements aimed at harmonizing and standardizing the method (Hunkeler, Lichtenvort, and Rebitzer 2008; ISO 2008). However, especially in connection with LCA, LCC, inevitably, must be based on a systematic analysis, which can guarantee complementarity and coherence with parallel environmental assessments in order to avoid practical issues in implementing these methods contemporaneously.

For example, several scholars have noted problems with the integration of LCA and LCC methods (Hunkeler, Lichtenvort, and Rebitzer 2008; Norris 2001; Rebitzer and Hunkeler 2003; Schmidt 2003; Settanni 2008). The main issue regards the alignment of the computational structures between the two models because of their different frameworks: while the LCA method is based on steady-state models, LCC is a quasi-dynamic model. Therefore, this nonalignment makes a direct comparison between LCA and LCC results difficult (Huppes et al. 2004). Accordingly, considerable efforts have been undertaken by scholars to implement increasingly efficient frameworks to unify LCA and LCC (Ciroth and Franze 2009; Heijungs, Settanni, and Guinée 2013; Moreau and Weidema 2015).

Regarding agricultural production systems, some scholars (Falcone et al. 2015, 2016) have integrated LCC and LCA methods by means of a common database, the same functional unit and system boundary and the evaluation in monetary terms of the physical flows resulting from the life cycle inventory. The costs of the unitary processes have been summarized for all lifecycle phases during the whole lifetime.

Concerning LCC studies in citrus-fruit, few applications are available in the scientific literature. To the best of our knowledge, only De Luca et al. (2014) and Pergola et al. (2013) have evaluated the environmental and economic performances of different farming systems by coupling LCA and LCC. Several studies analyze the economic performance of citrus orchards by means of production cost analysis. Sgroi et al. (2015) and Testa et al. (2015) performed a financial analysis to compare conventional and organic lemon orchards in Sicily in order to evaluate if organic systems may represents a strategy to control the abandonment of many conventional Sicilian lemon orchards. Chinnici, Pecorino, and Scuderi (2013) analyzed a sample group of organic and conventional citrus farms from an economic and environmental point of view through the production cost and energy analyses, respectively. Peris Moll and Juliá Igual (2006) investigated the feasibility of the organic Clementine crop in Spain by using production cost analysis and comparing two irrigation systems.

The aim of the present work is to analyze the economic and environmental sustainability of conventional and organic bergamot production systems in the Reggio Calabria province (South Italy), in order to measure both the potential environmental impacts by means of LCA methodology and the economic performance by using the LCC approach and specific financial indicators. The results could be a useful starting point to undertake strategies of valorization of bergamot cultivation both in environmental terms through green marketing oriented tools, as environmental communication instruments, and in economic terms to support farmers by improving investment management. To the authors' knowledge, this work represents the first attempt at environmental and economic analysis of bergamot cultivation. The remainder of the paper consists of four sections. The next section describes “materials and methods” and focuses on the farming systems, data sampling method and methodological approaches used in the study.

The third section presents the main environmental and economic results. The fourth part discusses the primary implications in terms of socio-economic repercussions for farms and for the territory in general in terms of their interest in this peculiar citrus-fruit crop and provides some conclusions and directions of future work.

2. Materials and methods

2.1. Bergamot cultivation in the Calabria region: system description and data gathering

The bergamot (Citrus bergamia Risso) is an endemic citrus fruit to rural landscapes located along the Reggio Calabria coast, precisely from Villa San Giovanni on the Tyrrhenian coast to Monasterace on the Ionian coast in South Italy (Figure 1). The surface area cultivated with bergamot is estimated to be approximately 1,200 ha (Consorzio del Bergamotto 2012). This area represents the only natural range in Italy, accounting for over 90% of the worldwide bergamot production. Bergamot is also cultivated in small areas of Africa (Ivory Coast, Mali, Cameroon, Guinea) and South America (Argentina and Brazil), although at these locations, the fragrance reaches lower quality standards than Calabrian production (Nesci, Sapone, and Baldari 2011). As

Figure 1. Production area of the bergamot cultivation in Calabria region (southern Italy).

previously mentioned, the bergamot processing industry is a sector with key implications for employment and farmers′ incomes for the Reggio Calabria province. The bergamot fruit is mainly used in the perfumery industry because of the particular characteristics of its essential oil, which are able to fix the aromatic "bouquet" and degree of harmonization of other essences, imbuing notes of freshness and fragrance. Furthermore, the essential oil has novel applications in the pharmaceutical and cosmetic industries. Recently, bergamot juice, considered until a few years ago to be a waste product, has been successfully introduced in gastronomy, confectionery, liqueurs and medical science. The exhausted bergamot peel and pulp, which represent by-products of the citrus processing industry, have also been used for many years as animal feed considerably appreciated by pig farmers (Crispo 2014; Nesci, Sapone, and Baldari 2011).

From a preliminary territorial survey, it emerged that the main bergamot farming system is an organic one due to production subsidies that represent a basic support to the farmers. The conventional farming system is scarcely present because bergamot is a crop that requires no special pest control interventions. However, in order to perform our study a comparative analysis between the two above mentioned management systems (conventional and organic) was carried out.

A group of eight farms was selected for data gathering and equally distributed between the analyzed scenarios. These farms are characterized by an average area between 5 and 10 ha, with an average plant density of 400 trees/ha. The average yield per plant is 45 kg via conventional systems and 40 kg for organic ones. The prevalent cultivar is “Fantastico”, derived from hybridization between two ancient cultivars, “Femminello” and “Castagnaro”, with high resistance to adversity as well as high fruit yield and quality. Bergamot fruits are normally harvested by hand between November and December. The choice of these farms allowed us to reconstruct the entire life cycle of each scenario due to the prevalence of unevenly aged trees (Stillitano et al. 2016) and dynamic management, with bergamot orchards under different production stages over the course of the survey.

Environmental and economic data were collected through face-to-face interviews by means of a custom-made questionnaire. The collected data belonged to three production seasons (2012, 2013, and 2014) in order to reduce both the degree of uncertainty related to seasonality (extraordinary operations due to biotic and abiotic factors) and subjectivity of farm management, and to attenuate production fluctuations (Falcone et al. 2016).

In particular, data gathering concerned production yields; types and doses of agricultural inputs; fuel and energy consumption for all field operations (tillage, fertilization, irrigation, pest and weed control, pruning and harvesting); and all expenses associated with use of human labor (i.e., remuneration), mechanical means (i.e., maintenance and insurance), services (e.g., expert consultancies, transport and outsourced cultivation operations), taxes, and land capital use. Averaged data were processed for both LCC and LCA implementation. Data pertaining to downstream processes (transport and transformation) were excluded.

2.2. Environmental analysis

According to LCA guidelines (ISO 14040:2006a; ISO 14044:2006b), the first phase of the LCA analysis was the identification and definition of the system functions through the determination of the functional unit (UF) and system boundary. A UF equal to 1 hectare of bergamot cultivation was identified and used in the LCC implementation (De Luca et al. 2015b; Falcone et al. 2015; Strano et al. 2013), to jointly interpret the environmental and economic results. Successively, the system boundary “from cradle to farm gate” was defined, considering only the bergamot production – from the plantation to bergamot uprooting – excluding the nursery stage, bergamot processing, distribution and consumption.

The useful life of the bergamot cultivation (40 years) was divided into four main stages (Figure 2): i. planting stage (year 0), in which the operations to design and plant the bergamot orchard were needed; ii. training stage (from 1st to 4th years), where there is both an increase of input applications to support the growing of young trees and an unproductive condition; iii. production

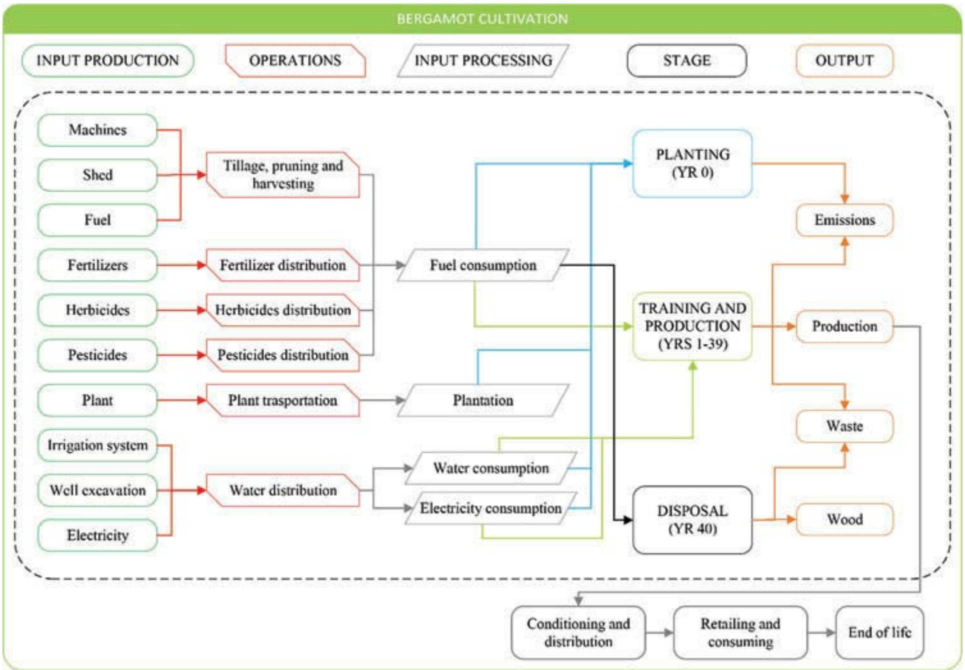

Figure 2. System boundaries flow chart for the production of bergamot.

stage (from 5th to 40th years), partitioned into three different sub-stages: increasing production stage (from 5th to 10th year) in which the trees reach maturity, constant production stage (from 11th to 30th year) in which the trees are fully developed and ensure a full production, and decreasing production stage (from 31th to 40th year), in which the average fruit yield decreases; iv. disposal stage (40th year), in which the plant is uprooted.

In the life cycle inventory (LCI) analysis, data related to background and foreground processes were gathered. Data pertaining to background processes, that is, the production of fuel, lubricant, energy, fertilizers, pesticides and capital goods, and waste processes, were obtained from the Eco-invent V. 3.1 database (Product Ecology Consultants 2010). Data associated with foreground processes related to water, energy, fuel and lubricant consumption, doses and method of fertilizers and pesticides distribution, waste typology, and mass and disposal scenarios were directly gathered by interviews. Fertilizers emissions were estimated according to Brentrup et al. (2000), and pesticide fate was modeled according to the assumptions of Margni et al. (2002). Allocation criteria were defined for machinery maintenance by using lubricant and grease consumption per real hours of use as reference criterion. The inventory data were processed using SimaPro 8.0.5 software and the Ecoinvent V.3.1 database (Product Ecology Consultants (PRè) 2010). To elaborate the results from each scenario, the ReCiPe Midpoint method (Goedkoop et al. 2013) was used. In particular, 18 impact categories were considered to characterize the environmental performance of organic and conventional bergamot cultivation. A detail description of these impact categories is listed in the Appendix.

2.3. LCC implementation and financial analysis

To carry out an economic analysis that allows us to obtain compatible results with environmental ones, the LCC approach was implemented. In particular, each environmental input and output considered in the LCA analysis was monetized; farm labor remuneration, capital goods and land capital were also considered (De Luca et al. 2014), allowing us to realize inventory costs complementary to LCA ones (Notarnicola, Settanni, and Tassielli 2009) both in terms of system boundary and FU (De Luca et al. 2014; Falcone et al. 2015; Strano et al. 2013). The monetization of each single component of data inventory was obtained by multiplying their average quantity (over the three-year period) by the unit price for the last year (2014).

The LCC approach adopted in this study was implemented according to an equation suggested by De Luca et al. (2014), through which both initial investment (design and plantation costs) and operating costs for each lifecycle stage were estimated. More specifically, operating costs included all inputs related to agricultural process, that is, seeds, fertilizers, pesticides, fuel and lubricants consumption of machinery ownership, and the labor cost needed during cultivating practices. To calculate the annual total operating cost of each single process the following cost items not directly attributable to specific growing operations were also considered: quotas of maintenance and insurance connected to capital goods (the quota of depreciation was not considered because the purchase cost of the capital goods has been accounted for in the planting stage); interests on advance capital (with an interest rate equal to 4.5%); remuneration of intellectual work (wages), obtained as percentage equal to 5% of the gross production value (GPV); land capital use; external technical services; and taxes.

To evaluate the feasibility of the two bergamot systems in terms of farm investments, the following financial indices were determined: the net present value (NPV) and the internal rate of return (IRR) (De Luca et al. 2014; Sgroi et al. 2015; Testa et al. 2015). For this purpose, it was also necessary to calculate the annual total revenues corresponding to the GPV. This latter value was evaluated by multiplying the average bergamot production by its market price from the last harvesting season (2013–2014) and by adding European subsidies. To actualize the cash flows (costs and revenues) of the investments, a discount rate equal to 1.8% (Mohamad et al. 2014; Pergola et al. 2013) was used, taking into account the low risk and long-term features of agricultural investments.

3. Results

3.1. Results of environmental performances

Analyzing the environmental impacts by use of a ReCiPe Midpoint characterization from a hierarchical perspective reveals that the organic scenario shows the best performance in all impact categories, except for “Terrestrial acidification” and “Particulate matter formation” due to the increased use of machinery for soil and weed management (Table 1). Comparing the environmental impacts of the organic and conventional systems for the “Climate Change” category, organic cultivation is more sustainable because of lower emissions of CO_2, equal to approximately 300% compared to conventional systems. These emissions are mainly generated during chemical fertilizer production and nitrogen fertilizer distribution (Figure 3).

Focusing on conventional systems, chemical fertilization represents the most polluting agricultural operation in all categories, where the gap with respect to the organic scenario reaches the highest values. For example, in the categories “Ozone depletion”, “Human toxicity” and “Freshwater eutrophication” a gap of more than 800% was estimated.

Table 1. Results of the impact categories of the bergamot cultivation systems (ReCiPe Midpoint method).

Impact category	Unit	Organic bergamot system	
Climate change	kg CO_2 eq	164967.46	54244.79
Ozone depletion	kg CFC-11 eq	0.02	0.01
Human toxicity	kg 1,4-DB eq	43135.48	7234.77
Photochemical oxidant formation	kg NMVOC	747.30	446.63
Particulate matter formation	kg PM_{10} eq	351.19	374.06
Ionizing radiation	kBq U^{235} eq	14748.83	4453.19
Terrestrial acidification	kg SO_2 eq	1423.52	2485.85
Freshwater eutrophication	kg P eq	42.07	4.89
Marine eutrophication	kg N eq	504.43	292.33
Terrestrial ecotoxicity	kg 1,4-DB eq	27.27	16.64
Freshwater ecotoxicity	kg 1,4-DB eq	828.94	126.57
Marine ecotoxicity	kg 1,4-DB eq	1069.78	122.61
Agricultural land occupation	m^2*yr	427712.58	426297.11
Urban land occupation	m^2*yr	883.43	189.34
Natural land transformation	m_2	40.25	23.45
Water depletion	m_3	160228.40	157856.35
Minerals depletion	kg Fe eq	17194.37	1135.40
Fossil depletion	kg oil eq	36612.12	15041.82

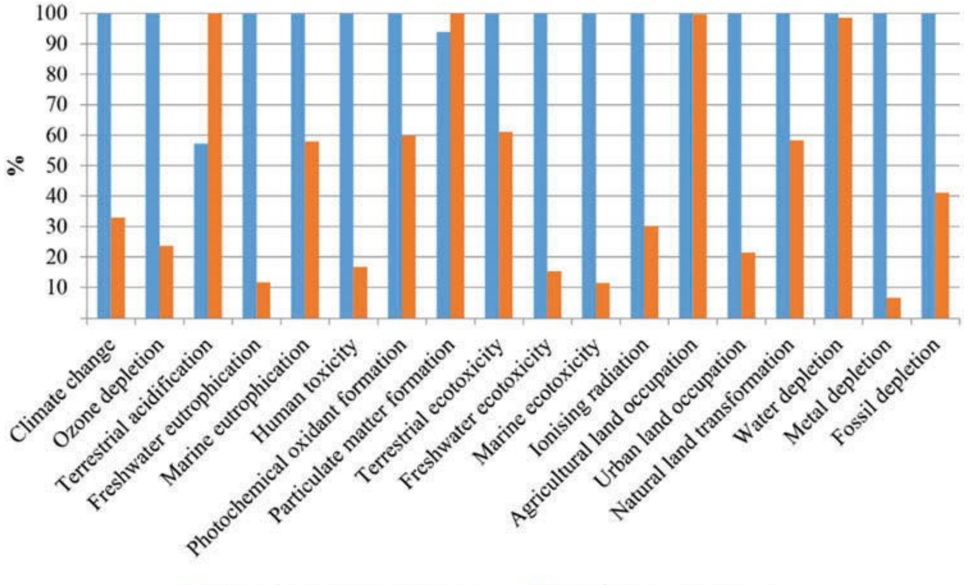

Figure 3. Environmental profiles of the conventional and organic bergamot cultivations.

3.2. Results of economic performances

A comparison between economic performance of conventional and organic bergamot systems is presented in Figure 4. Conventional cultivation is the most expensive method in terms of FU by recording a total life cycle cost of 126,061.85 € ha^{-1}, while the organic one has a value of 118,755.82 € ha^{-1}. This is mainly due to the increased employment of human labor in terms of

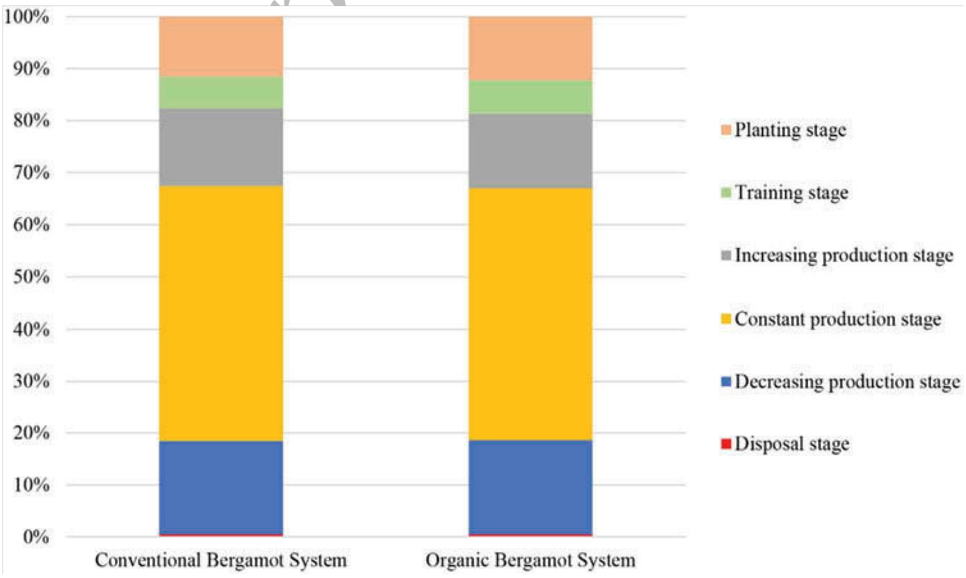

Figure 4. Total life cycle costs of the bergamot systems per life cycle stages.

working hours in the conventional farm management. Summing all working hours for the entire agricultural life cycle, a total of 1,242.33 h ha^{-1} was determined, higher by 27% compared to organic cultivation.

For both systems, 50% of the total life cycle cost is mainly concentrated in the Constant production stage, in which higher operating costs are generated by the harvesting and pruning operations in terms of labor costs (Figure 5). Specifically, in the conventional system harvesting absorbs around the 56% of the total cost but only accounts for 44% in the organic system. This difference is mainly due to a higher number of working hours required for conventional methods, owing to its great productivity in terms of bergamot fruits yield. Indeed, total hours of work per hectare needed during harvesting operation are estimated as 240.0 for the conventional system, which has an average yield of 18,000 kg ha^{-1}, and 192.0 h of work for the organic system, with 16,000 kg ha^{-1}.

For the same reasons, the pruning cost reaches values ranging from 18% in the conventional cultivation to 13% in the organic one. In the first farming system, working hours per hectare are equal to 112.0, while in the second system, this value amounts to 64.0. The higher pruning cost of the conventional scenario is also affected by employing qualified workers for performing this agricultural operation, assuming a compensation of 9.46 € h^{-1} against 5.87 € h^{-1} adopted for casual workers which are employed for the other agricultural activities (such as harvesting, tillage, irrigation, fertilization, and pest and weed control).

Concerning fertilization treatments, the greater economic impact in the organic management (58%) compared to conventional (42%) is caused by the major input use.

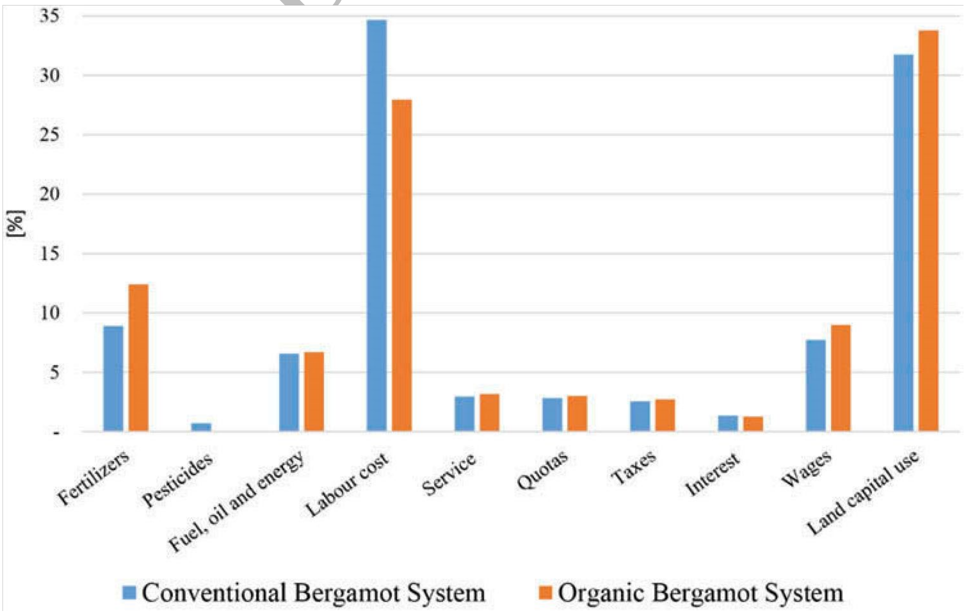

Figure 5. Incidence of each cost item on the production cost in the constant production stage.

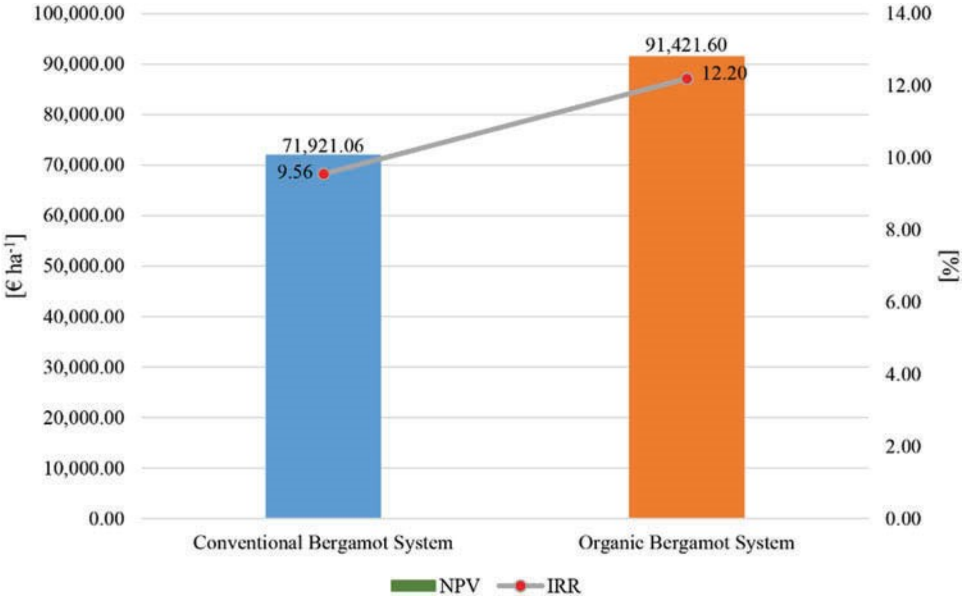

Figure 6. Financial analysis results.

Concerning the financial analysis of the two bergamot scenarios investigated, the results show their economic convenience in terms of long-term investments. However, organic systems exhibit the best performance by recording an NPV of 91,421.60 € ha^{-1}, rather than conventional systems, which register a value of 71,921.06 € ha^{-1} (Figure 6). In this scenario, the economic components that have a significant effect on feasibility are the lower total life cycle costs and the higher revenues because of the subsidy to organic farms. Furthermore, the better performance of the organic bergamot cultivation is also confirmed by an IRR value of 28% greater than conventional methods.

4. Discussion and conclusions

This paper has investigated the environmental and economic profiles of bergamot cultivation in the Reggio Calabria province by the joint use of LCA and LCC tools. The analysis showed the main hotspots within the bergamot life cycle, in order to realize the improvement of agricultural practices and decrease the environmental loads. Both LCA and LCC highlight that organic systems obtain the better performance.

With regard to the environmental aspects, in accordance with the results obtained in other studies on citrus fruits (De Luca et al. 2014; Knudsen et al. 2011; Nicolò et al. 2015; Pergola et al. 2013; Ribal et al. 2016), conventional bergamot cultivation resulted in greater environmental impacts than organic cultivation, chiefly due to the production and use of fertilizers and pesticides. However, the difference in yield between conventional and organic cultivation techniques (lower in the organic ones) could influence the findings, especially comparing different FU. Indeed, while the use of an area-based FU allows for the higher environmental impacts in conventional systems versus organic ones, the use of a mass-based FU could favor the conventional scenarios. Also, Ribal et al. (2016) declared that when the results are expressed by means a mass-based FU, the difference in the environmental performance is lower because mean yields under conventional production are higher.

Expressing our results by using 1 kg of bergamot citrus-fruit as FU, for example the total contribution to the GWP amounted to 0.102 kg CO_2 eq. and 0.271 kg CO_2 eq. in organic and conventional systems, respectively, showing that the conventional system represents once again the most impacting scenario although the gap between the two systems is reduced. These results are consistent with those obtained from Ribal et al. (2016), though the average yield (kg bergamot ha^{-1} year^{-1}) both in organic and conventional systems is low with respect to citrus fruit. Similarly, other studies (Dwivedi, Spreen, and Goodrich-Schneider 2012; Nicolò et al. 2015; Sanjuan et al. 2005) reported values similar to our estimates. However, even when considering double yields in the conventional system, the organic scenario reaches once again the best performance. This kind of result must be exclusively considered for bergamot cultivation because, by even minimizing farm inputs (water, fertilizers and pesticides), the yields remain high due to its greater adaptation to local pedo-climatic conditions.

Furthermore, comparing the environmental impacts in terms of “Climate Change” with organic clementine systems in the Reggio Calabria province, organic bergamot cultivation generates only 1356 kg CO_2 eq. ha^{-1} compared to the 2311 kg CO_2 eq. ha^{-1} for the clementine cultivation (De Luca et al. 2014).

In terms of water use, the cultivation of bergamot is less expensive than that of other citrus fruit. In our results, water depletion was 20% less than the better scenario analyzed by De Luca et al. (2014).

Similar trends can be observed comparing our results whit other studies that used similar indicators; however, bergamot cultivation is not always better. For example, considering the acidification potential in kg SO_2 eq ha^{-1} year^{-1}, Ribal et al. (2016) obtained the best results for organic cultivation (26.90 kg SO_2 eq ha$_{1}$ $^{-1}$

year), in opposition to our results in which the best scenario was the conventional with an impact higher than Ribal et al. (2016) (35.59 kg SO_2 eq ha^{-1} year^{-1}). These differences could be explained both in different cultivation techniques and, in particular, different LCIA methods used, which implies different impact characterization factors.

LCC and financial analysis results are comparable with those of other citrus fruits; nevertheless, there are specific peculiarities that characterize bergamot cultivation in this area. Similar results have been reached by Pergola et al. (2013) for orange and lemon orchards and by Testa et al. (2015) for lemons. Indeed, the conventional system presented a total life cycle cost higher than organic, in which the constant production stage is the most impactful due to the higher operating costs in terms of labor costs for manual harvesting and pruning operations.

Comparing the profitability of organic bergamot cultivation with other typical Calabrian citrus-fruits, bergamot remains the most profitable crop by recording a profit equal to 5,200.50 € ha^{-1} versus a Clementine system with a value of 2,248.12 € ha^{-1} (Gulisano et al. 2012).

A crucial role for improving bergamot farming profitability has been performed by the "Consortium of the Bergamot", which has stabilized the high volatility of the market price of fruits destined for transformation, guaranteeing to the farmers a unit price of approximately 0.52 € kg^{-1} for organic fruit and 0.50 € kg^{-1} for conventional.

Furthermore, a key role has been played by the Agricultural Department of the Calabria Region, who in March 2013 launched a series of measures to support the sector. The organic farming systems take advantage of production subsidies and, especially, the poor agronomic needs that allow them to maintain low operating costs.

From a territorial and social point of view, bergamot cultivation plays a key role by generating an economic activity that allows farmers to maintain a sustainable income. Currently, the strong increase in demand of bergamot for fresh consumption has led to an efficient solution of commercial differentiation and an enlargement of the area cultivated. Furthermore, the consumption of fresh fruit is increasing due to the beneficial properties of bergamot to human health, which have led the market to identify a price of approximately 2.50 € kg^{-1}. Therefore, decision-makers should plan marketing strategies to incentivize the cultivation of bergamot, through the protection of the national production and support measures for farmers. This study may contribute to enhancing knowledge on the achievement of sustainability levels of bergamot cultivation systems in order to reach higher environmental and economic profiles through the improvement of farm management.

Notes on contributors

Alfio Strano: Researcher in Agricultural Economics and Policy, Department of Agriculture, Mediterranean University of Reggio Calabria; address: Feo di Vito, 89124 Reggio Calabria, Italy; e-mail: astrano@unirc.it

Giacomo Falcone: Postdoc Fellowship in Agricultural Economics and Policy, Department of Agriculture, Mediterranean University of Reggio Calabria; address: Feo di Vito, 89124 Reggio Calabria, Italy; e-mail: giacomo.falcone@unirc.it

Bruno Francesco Nicolò: Postdoc Fellowship in Agricultural Economics and Policy, Department of Agriculture, Mediterranean University of Reggio Calabria; address: Feo di Vito, 89124 Reggio Calabria, Italy; e-mail: giacomo.falcone@unirc.it

Teodora Stillitano: Postdoc Fellowship in Agricultural Economics and Policy, Department of Agriculture, Mediterranean University of Reggio Calabria; address: Feo di Vito, 89124 Reggio Calabria, Italy; e-mail: teodora.stillitano@unirc.it

Anna Irene De Luca: Researcher in Agricultural Economics and Policy, Department of Agriculture, Mediterranean University of Reggio Calabria; address: Feo di Vito, 89124 Reggio Calabria, Italy; e-mail: anna.deluca@unirc.it

Francesco Saverio Nesci: Full Professor in Agricultural Economics and Policy, Department of Agriculture, Mediterranean University of Reggio Calabria; address: Feo di Vito, 89124 Reggio Calabria, Italy; e-mail: francesco.nesci@unirc.it

Giovanni Gulisano: Full Professor in Agricultural Economics and Policy, Department of Agriculture, Mediterranean University of Reggio Calabria; address: Feo di Vito, 89124 Reggio Calabria, Italy; e-mail: ggulisano@unirc.it

ORCID

A. I. De Luca http://orcid.org/0000-0002-8716-8177

References

Auer, J., N. Bey, and J.-M. Schäfer. 2017. Combined life cycle assessment and life cycle costing in the eco-care-matrix: A case study on the performance of a modernized manufacturing system for glass containers. Journal of Cleaner Production 141:99–109. doi:10.1016/j.jclepro.2016.08.096.

Barbera, G. 2013. Calabria. In Italian historical rural landscapes. cultural values for the environment and rural development, ed. M. Agnoletti, 489–508. Dordrecht, The Netherlands: Springer Science+Business Media.

Basset-Mens, C., H. Vannière, D. Grasselly, H. Heitz, A. Braun, S. Payen, P. Koch, and Y. Biard. 2016. Environmental impacts of imported and locally grown fruits for the French market: A cradle-to-farm-gate LCA study. Fruits 71(2):93–104. doi:10.1051/fruits/2015050.

Bayart, J. B., C. Bulle, L. Deschênes, M. Margni, S. Pfister, F. Vince, and A. Koehler. 2010. A framework for assessing off-stream freshwater use in LCA. International Journal of Life Cycle Assessment 15:439–53. doi:10.1007/s11367-010-0172-7.

Beccali, M., M. Cellura, M. Iudicello, and M. Mistretta. 2010. Life cycle assessment of Italian citrus-based products. Sensitivity analysis and improvements scenarios. Journal of Environmental Management 91(7):1415–28. doi:10.1016/j.jenvman.2010.02.028.

Bessou, C., C. Basset-Mens, C. Latunussa, A. Vélu, H. Heitz, H. Vannière, and J.-P. Caliman. 2016. Partial modelling of the perennial crop cycle misleads LCA results in two contrasted case studies. International Journal of Life Cycle Assessment 21(3):297–310. doi:10.1007/s11367-016-1030-z.

Brammer, S., and H. Walker. 2011. Sustainable procurement in the public sector: An international comparative study. International Journal of Operations and Production Management 31(4):452–76. doi:10.1108/01443571111119551.

Brentrup, F., J. Küsters, J. Lammel, and H. Kuhlmann. 2000. Methods to estimate on-field nitrogen emission from crop production as an input to LCA studies in the agricultural sector. International Journal of Life Cycle Assessment 5(6):349–57. doi:10.1007/BF02978670.

Cerutti, A. K., G. L. Beccaro, S. Bosco, A. I. De Luca, G. Falcone, A. Fiore, N. Iofrida, A. Lo Giudice, and A. Strano. 2015. Life cycle assessment in the fruit sector. In Life cycle assessment in the agri-food sector case studies, methodological issues and best practices, ed. B. Notarnicola, R. Salomone, L. Petti, P. A. Renzulli, R. Roma, and A. K. Cerutti, 333–88. Switzerland: Springer International Publishing.

Cerutti, A. K., S. Contu, F. Ardente, D. Donno, and G. L. Beccaro. 2016. Carbon footprint in green public procurement: Policy evaluation from a case study in the food sector. Food Policy 58:82–93. doi:10.1016/j.foodpol.2015.12.001.

Chinnici, G., B. Pecorino, and A. Scuderi. 2013. Environmental and economic performance of organic citrus growing. Quality - Access to Success 14(S1):106–12.

Ciani, F., J. Huggard, and T. Zervas. 2014. The Resilience of Bergamot Farmers in the Reggio Calabria Province of Southern Italy. Working Paper Economics 25/2014. DISEI Università degli Studi di Firenze.

Ciroth, A., and J. Franze. 2009. Life cycle costing in SimaPro. Berlin: GreenDeltaTC. http://www.simapro.de/uploads/media/LCCinSimaPro_english.pdf.

Coltro, L., A. L. Mourad, R. M. Kletecke, T. A. Mendonça, and S. P. M. Germer. 2009. Assessing the environmental profile of orange production in Brazil. The International Journal of Life Cycle Assessment 14(7):656–64. doi:10.1007/s11367-009-0097-1.

Consorzio del Bergamotto. 2012. Il Bergamotto di Reggio Calabria. Reggio Calabria: Laruffa Editore S.R.L.

Crispo, F. 2014. Bergamot in the Calabrian Economy and the Role of Consorzio del Bergamotto. In Citrus bergamia Bergamot and Its derivatives, ed. G. Dugo, and I. Bonaccorsi. Boca Raton, FL: CRC Press.

Dattilo, C. A., M. Delogu, L. Berzi, and M. Pierini. 2016. A sustainability analysis for Electric Vehicles batteries including ageing phenomena. IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), Florence, accessed June 7–10, 2016.

De Luca, A. I., G. Falcone, N. Iofrida, T. Stillitano, A. Strano, and G. Gulisano. 2015a. Life Cycle Methodologies to improve agri-food systems sustainability. Rivista Di Studi Sulla Sostenibilità 1:135–50. doi:10.3280/riss2015-001009.

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):103–08.

De Luca, A. I., N. Iofrida, G. Falcone, T. Stillitano, and G. Gulisano. 2017b. Olive growing scenarios of soil management: Integrating environmental, economic and social indicators in a life cycle perspective. Acta Horticulturae. (In Press).

De Luca, A. I., N. Iofrida, P. Leskinen, T. Stillitano, G. Falcone, A. Strano, and G. Gulisano. 2017a. Life Cycle tools combined with multi-criteria and participatory methods for agricultural sustainability. Insights from a systematic and critical review. Science of the Total Environment 595:352–70. doi:10.1016/j.scitotenv.2017.03.284.

De Luca, A. I., N. Iofrida, A. Strano, G. Falcone, and G. Gulisano. 2015b. Social life cycle assessment and participatory approaches: A methodological proposal applied to citrus farming in Southern Italy. Integrated Environmental Assessment and Management 11 (3):383–96. doi:10.1002/ieam.1611.

Dhillon, B. S. 1989. Life cycle costing: Techniques, models, and applications. New York, USA: Gordon and Breach Science Publishers.

Dwivedi, P., T. Spreen, and R. Goodrich-Schneider. 2012. Global warming impact of Florida's NotFrom-Concentrate (NFC) orange juice. Agricultural Systems 108:104–11. doi:10.1016/j.agsy.2012.01.006.

European Environment Agency (EEA). 2012. Environmental indicator report 2012 - Ecosystem resilience and resource efficiency in a green economy in Europe. Copenhagen, Denmark: Publications Office of the European Union.

European Environment Agency (EEA). 2015. Technical Report No 15/2015. Annual European Community greenhouse gas inventory 1990–2013 and inventory report 2015. Submission to the UNFCCC Secretariat. Copenhagen, Denmark: Publications Office of the European Union. Version 27.

Falcone, G., A. I. De Luca, T. Stillitano, A. Strano, G. Romeo, and G. Gulisano. 2016. Assessment of environmental and economic impacts of vine-growing combining life cycle assessment, life cycle costing and multicriterial analysis. Sustainability 8(8):793. doi:10.3390/su8080793.

Falcone, G., A. Strano, T. Stillitano, A. I. De Luca, N. Iofrida, and G. Gulisano. 2015. Integrated sustainability appraisal of wine-growing management systems through LCA and LCC Methodologies. Chemical Engineering Transactions 44:223–28. doi:10.3303/ CET1544038.

Fenollosa, M. L., J. Ribal, A. Lidon, I. Bautista, R. Juraske, G. Clemente, and N. Sanjuan. 2014. Influence of management practices on economic and environmental performance of crops. A case study in Spanish horticulture. Agroecology and Sustainable Food Systems 38:365– 659. doi:10.1080/21683565.2014.896302.

Food and Agriculture Organization of the United Nations (FAO). 2016.Faostat. Accessed March 9, 2016. http://faostat.fao.org/

Frischknecht, R., A. Braunschweig, P. Hofstetter, and P. Suter. 2000. Human health damages due to ionising radiation in life cycle impact assessment. Environmental Impact Assessment Review 20:159–89. doi:10.1016/S0195-9255(99)00042-6.

Goedkoop, M., R. Heijungs, M. A. J. Huijbregts, A. De Schryver, J. Struijs, and R. Van Zelm. 2013. ReCiPe 2008, A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. In Report I: Characterisation, First (revised). Ministry of Housing Spatial Planning and Environment (VROM), Netherlands. Available online at: http://www.leidenuniv.nl/cml/ssp/publications/recipe_characterisation.pdf

Grando, S. 2008. New market channels for a non-food agricultural product. The development of an alternative supply chain for the bergamot citrus in Calabria, Italy. World Review of Entrepreneurship, Management and Sust. Development 4(4):291–304. doi:10.1504/ WREMSD.2008.020113.

Guinée, J. B. 2002. Handbook on life cycle assessment - Operational guide to the ISO standards. Dordrecht, the Netherlands: Kluwer Academic Publishers.

Gulisano, G., A. I. De Luca, A. Strano, and G. Falcone. 2012. Valutazioni tecnico-economiche ed ambientali della clementinicoltura in Calabria. In Acta Italus Hortus, 9. SOI, Firenze, Italy. ISBN: 978-88-905628-8-4.

Heijungs, R., E. Settanni, and J. Guinée. 2013. Toward a computational structure for life cycle sustainability analysis: Unifying LCA and LCC. International Journal of Life Cycle Assessment 18(9):1722–33. doi:10.1007/s11367-012-0461-4.

Helmes, R. J. K., M. A. J. Huijbregts, A. D. Henderson, and O. Jolliet. 2012. Spatially explicit fate factors of phosphorous emissions to freshwater at the global scale. International Journal of Life Cycle Assessment 17:646–54. doi:10.1007/s11367-012-0382-2.

Hunkeler, D., K. Lichtenvort, and G. Rebitzer. 2008. Environmental life cycle costing. Pensacola, USA: CRC Press.

Huppes, G., M. Van Rooijen, R. Kleijn, R. Heijungs, A. De Koning, and L. Van Oers. 2004. Life Cycle Costing and the Environment. Report of a project commissioned by the Ministry of VROM-DGM for the RIVM Expertise Centre LCA.

International Organization for Standardization. 2006a. ISO 14040:2006–life cycle assessment–principles and framework. Geneva, Switzerland: International Organization for Standardization.

International Organization for Standardization. 2006b. ISO 14044:2006–life cycle assessment–requirements and guidelines. Geneva, Switzerland: International Organization for Standardization.

International Organization for Standardization. 2008. ISO 15686-5:2008 Buildings and constructed assets-Service life planning-Life Cycle Costing. Geneva, Switzerland: International Organization for Standardization.

IPCC. 2013. Climate change 2013: The physical science basis. In Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change, ed. T. F. Stocker, D. Qin, G. K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. M. Midgley, 1535. Cambridge: Cambridge University Press. doi:10.1017/CBO9781107415324.

Klopffer, W. 2003. Life-cycle based methods for sustainable product development. International Journal of Life Cycle Assessment 8(3):157–59. doi:10.1007/BF02978462.

Knudsen, M. T., G. Fonseca De Almeida, V. Langer, L. Santiago De Abreu, and N. Halberg. 2011. Environmental assessment of organic juice imported to Denmark: A case study on oranges (Citrus sinensis) from Brazil. Organic Agriculture 1(3):167–85. doi:10.1007/s13165011-0014-3.

Lo Giudice, A., C. Mbohwa, M. T. Clasadonte, and C. Ingrao. 2013. Environmental assessment of the citrus fruit production in Sicily using lca. Italian Journal of Food Science 25(2):202–12.

Margni, M., D. Rossier, P. Crettaz, and O. Jolliet. 2002. Life cycle impact assessment of pesticides on human health and ecosystems. Agriculture, Ecosystems & Environment 93(1–3):379–92. doi:10.1016/S0167-8809(01)00336-X.

Mohamad, R. S., V. Verrastro, G. Cardone, M. R. Bteich, M. Favia, M. Moretti, and R. Roma. 2014. Optimization of organic and conventional olive agricultural practices from a life cycle assessment and life cycle costing perspectives. Journal of Cleaner Production 70:78– 89. doi:10.1016/j.jclepro.2014.02.033.

Moreau, V., and B. P. Weidema. 2015. The computational structure of environmental life cycle costing. The International Journal of Life Cycle Assessment 20(10):1359–63. doi:10.1007/s11367-015-0952-1.

Navarra, M., C. Mannucci, M. Delbò, and G. Calapai. 2015. Citrus bergamia essential oil: From basic research to clinical application. Frontiers in Pharmacology 6(MAR):1–7. doi:10.3389/fphar.2015.00036.

Nesci, F. S., N. Sapone, and M. Baldari. 2011. Tutela e Sviluppo del Bergamotto Reggino. Paper presented at the XXXII Conferenza Scientifica Annuale AISRe, accessed September 15-17, Torino, Italy.

Nicolò, B. F., M. C. De Salvo, C. Ramírez-Sanz, A. V. Estruch, N. Sanjuán, G. Falcone, and A. Strano. 2015. Environmental sustainability of the clementine production systems in Italy and Spain. An approach based on Life Cycle Assessment. In *Ecosystems and sustainable development X*, ed. I. Miralles, J. L. Garcia, and C. A. Brebbia, 173–84. Southampton, UK: Wit Press. ISBN: 978-1-84564-900-5. doi:10.2495/Eco150161.

Norris, G. A. 2001. Integrating life cycle cost analysis and LCA. *International Journal of Life Cycle Assessment* 6(2):118–20. doi:10.1007/BF02977849.

Notarnicola, B., E. Settanni, and G. Tassielli. 2009. Approcci all′integrazione dei costi in LCA: Life Cycle Costing, analisi Input-Output. Paper presented at the Convegno Scientifico della Rete Italiana LCA, accesed June 11-12, Palermo, Italy.

Pergola, M., M. D′Amico, G. Celano, A. M. Palese, A. Scuderi, G. Di Vita, G. Pappalardo, and P. Inglese. 2013. Sustainability evaluation of Sicily′s lemon and orange production: An energy, economic and environmental analysis. *Journal of Environmental Management* 128:674–82. doi:10.1016/j.jenvman.2013.06.007.

Peris Moll, E. M., and J. F. Juliá Igual. 2006. Production costs of the organic Clementine crop in the region of Valencia (Spain). *Spanish Journal of Agricultural Research* 4(1):17–25. doi:10.5424/sjar/2006041-174.

Petrillo, A., F. De Felice, E. Jannelli, C. Autorino, M. Minutillo, and A. L. Lavadera. 2016. Life cycle assessment (LCA) and life cycle cost (LCC) analysis model for a stand-alone hybrid renewable energy system. *Renewable Energy* 95:337–55. doi:10.1016/j.renene.2016.04.027.

Product Ecology Consultants (PRè). 2010. *SimaPro database manual - methods library*. Netherlands.

Rebitzer, G., and D. Hunkeler. 2003. Life Cycle Costing in LCM: Ambitions, Opportunities and Limitations. *International Journal of Life Cycle Assessment* 8(5):253–56. doi:10.1007/BF02978913.

Ren, J., A. Manzardo, A. Mazzi, F. Zuliani, and A. Scipioni. 2015. Prioritization of bioethanol production pathways in China based on life cycle sustainability assessment and multicriteria decision-making. *International Journal of Life Cycle Assessment* 20(6):842–53. doi:10.1007/s11367-015-0877-8.

Ribal, J., C. Ramírez-Sanz, V. Estruch, G. Clemente, and N. Sanjuán. 2016. Organic versus conventional citrus. Impact assessment and variability analysis in the Comunitat Valenciana (Spain). *International Journal of Life Cycle Assessment* 1–16. doi:10.1007/ s11367-016-1048-2.

Russo, M., A. Arigò, M. L. Calabrò, S. Farnetti, L. Mondello, and P. Dugo. 2016. Bergamot (Citrus bergamia Risso) as a source of nutraceuticals: Limonoids and flavonoids. *Journal of Functional Foods* 20:10–19. doi:10.1016/j.jff.2015.10.005.

Russo, M., D. Serra, F. Suraci, and S. Postorino. 2012. Effectiveness of electronic nose systems to detect bergamot (Citrus bergamia Risso et Poiteau) essential oil quality and genuineness. *Journal of Essential Oil Research* 24(2):137–51. doi:10.1080/10412905.2012.659530.

Sanjuan, N., L. Ubeda, G. Clemente, A. Mulet, and F. Girona. 2005. LCA of integrated orange production in the Comunidad Valenciana (Spain). *International Journal of Agricultural Resources, Governance and Ecology* 4(2):163. doi:10.1504/IJARGE.2005.007198.

Sawamura, M., Y. Onishi, J. Ikemoto, N. T. M. Tu, and N. T. L. Phi. 2006. Characteristic odour components of bergamot (Citrus bergamia Risso) essential oil. *Flavour and Fragrance Journal* 21(4):609–15. doi:10.1002/ffj.1604.

Schmidt, W. P. 2003. Life Cycle costing as part of design for environment environmental business cases. The International Journal of Life Cycle Assessment 8(3):167–74. doi:10.1065/lca2003.04.110.

Settanni, E. 2008. The need for a computational structure of LCC. International Journal of Life Cycle Assessment 13(7):526–31. doi:10.1007/s11367-008-0036-6.

Sgroi, F., M. Candela, A. M. Di Trapani, M. Foderà, R. Squatrito, R. Testa, and S. Tudisca. 2015. Economic and financial comparison between organic and conventional farming in Sicilian lemon orchards. Sustainability 7(1):947–61. doi:10.3390/su7010947.

Smith, J., G. Andersson, R. Gourlay, S. Karner, B. E. Mikkelsen, R. Sonnino, and D. Barling. 2016. Balancing competing policy demands: The case of sustainable public sector food procurement. Journal of Cleaner Production 112:249–56. doi:10.1016/j. jclepro.2015.07.065.

Stillitano, T., A. I. De Luca, G. Falcone, E. Spada, G. Gulisano, and A. Strano. 2016. Economic profitability assessment of Mediterranean olive growing systems. Bulgarian Journal of Agricultural Science 22(4):517–26.

Strano, A., A. I. De Luca, G. Falcone, N. Iofrida, T. Stillitano, and G. Gulisano. 2013. Economic and environmental sustainability assessment of wine grape production scenarios in Southern Italy. Agricultural Sciences 4(5B):12–20. doi:10.4236/as.2013.45B003.

Tamburini, E., P. Pedrini, M. G. Marchetti, E. A. Fano, and G. Castaldelli. 2015. Life cycle based evaluation of environmental and economic impacts of agricultural productions in the Mediterranean area. Sustainability 7(3):2915–35. doi:10.3390/su7032915.

Testa, R., M. Foderà, A. Maria, D. Trapani, S. Tudisca, and F. Sgroi. 2015. Choice between alternative investments in agriculture: The role of organic farming to avoid the abandonment of rural areas. Ecological Engineering 83:227–32. doi:10.1016/j.ecoleng.2015.06.021.

WMO. 2011. Scientific assessment of ozone depletion: 2010. Global Ozone Research and Monitoring Project-Report No.52, 516. Geneva, Switzerland: World Meteorological Organization.

Yan, M., K. Cheng, Q. Yue, Y. Yan, R. M. Rees, and G. Pan. 2016. Farm and product carbon footprints of China's fruit production-life cycle inventory of representative orchards of five major fruits. Environmental Science and Pollution Research 23(5):4681–91. doi:10.1007/s11356015-5670-5.

Yang, D., L. Fan, F. Shi, Q. Liu, and Y. Wang. 2016. Comparative study of cement manufacturing with different strength grades using the coupled LCA and partial LCC methods – A case study in China. Resources, Conservation and Recycling. Available online July 4, 2016. doi:10.1016/j.resconrec.2016.06.017.

Appendix

Description of the 18 midpoint impact categories

Midpoint impact category	Definition	Characterization factor	Unit-equivalent	Key references
Climate change (CC)	Represents the potential change in the state of the climate due to human activities and it is related to emissions of greenhouse gases.	Global Warming Potential (GWP)	kg CO_2 eq to air	IPCC (2013; Goedkoop et al. (2013))
Ozone depletion (OD)	Refers to destruction of ozone in the stratosphere due to anthropogenic substances, such as chlorofluorocarbons (CFCs)	Ozone Depletion Potential (ODP)	kg CFC-11 eq to air	WMO (2011; Goedkoop et al. (2013))
Human toxicity (HT)	Refers to the accumulation in the human food chain (exposure), and toxicity (effect) of chemical emissions into urban air.	Human Toxicity Potential (HTP)	kg 1,4-DB eq to urban air	Goedkoop et al. (2013)
Photochemical oxidant formation (POF)	It is related to the formation of ozone in the troposphere by photochemical reactions of NOx and Non Methane Volatile Organic Compounds (NMVOCs). Ozone concentration lead to respiratory problems and toxic effects on plants.	Photochemical Oxidant Formation Potential (POFP)	kg NMVOC to air	Goedkoop et al. (2013)
Particulate matter formation (PMF)	Refers to the formation of complex mixture of organic and inorganic substances that cause human health damage.	Particulate Matter Formation Potential (PMFP)	kg PM_{10} eq to air	Goedkoop et al. (2013)
Ionizing radiation (IR)	Regards the human health effects related to the routine releases of radioactive material in the environment.	Ionizing Radiation Potential (IRP)	kBq U^{235} eq to air	Frischknecht et al. (2000)
Terrestrial acidification (TA)	Acidification is caused by the atmospheric deposition of inorganic substances (NO_x, NH_3, and SO_2) that contribute to the change in the soil acidity.	Terrestrial Acidification Potential (TAP)	kg SO_2 eq to air	Goedkoop et al. (2013)
Freshwater eutrophication (FE)	It is the process of increasing biomass growth and changing species abundance and diversity in surface water due to phosphor enrichment of freshwater.	Freshwater Eutrophication Potential (FEP)	kg P eq to freshwater	Goedkoop et al. (2013); Helmes et al. (2012)
Marine eutrophication (ME)	It is the process of increasing biomass growth and changing species abundance and diversity in surface water due to nitrogen enrichment of seawater.	Marine Eutrophication Potential (MEP)	kg N eq to freshwater	Goedkoop et al. (2013); Helmes et al. (2012)
Terrestrial ecotoxicity (TET)	Refers to impacts of chemical emissions on terrestrial ecosystems.	Terrestrial Ecotoxicity Potential (TETP)	kg 1,4-DB eq to industrial soil	Guinée 2002

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Midpointimpact category	Definition	Characterizationfactor	Unit-equivalent	Keyreferences
Freshwaterecotoxicity (FET)	Referstoimpactsofchemicalemissionsonfreshwater aquaticecosystems.	FreshwaterEcotoxicityPotential (FETP)	kg1,4-DBeqto freshwater	Guinée 2002
Marineecotoxicity (MET)	Referstoimpactsofchemicalemissionsonmarineaquatic ecosystems.	MarineEcotoxicityPotential(METP)	kg1,4-DBeqto marinewater	(Guinée 2002
Agriculturalland occupation(ALO)	Referstoimpactscausedbytheamountofagriculturalarea occupiedforacertaintime.	AgriculturalLandOccupation Potential(ALOP)	m^2*yr(agricultural land)	Goedkoopetal.(2013)
Urbanlandoccupation (ULO)	Referstoimpactscausedbytheamountofurbanarea occupiedforacertaintime.	UrbanLandOccupationPotential (ULOP)	m^2*yr(urbanland)	Goedkoopetal.(2013)
Naturalland transformation(NLT)	Referstoimpactscausedbytheamountoftransformedarea foracertaintime.	NaturalLandTransformation Potential(NLTP)	m^2 naturalland)	Goedkoopetal. 2013)
Waterdepletion(WD)	Isdefinedasthenetreductionintheavailabilityof freshwaterforagiventimeperiod.	WaterDepletionPotential(WDP)	m^3 water (	Bayartetal.(2010)
Mineralsdepletion(MD)	Regardstheamountofmineralextractionfromadeposit overtime.	Mineraldepletionpotential(MDP)	kgFeeq	Goedkoopetal.(2013)
Fossildepletion(FD)	Referstotheamountoffossilfuelextracted,basedonthe lowerheatingvalue.	Fossildepletionpotential(FDP)	kgoileq	Goedkoopetal.(2013)