A life cycle assessment of non-renewable energy use and greenhouse gas emissions associated with blueberry and raspberry production in northern Italy

Published version:

DOI:10.1016/j.scitotenv.2013.04.060

Science of the Total Environment 458–460 (2013) 414–418

Contents lists available at SciVerse ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

A life cycle assessment of non-renewable energy use and greenhouse gas emissions associated with blueberry and raspberry production in northern Italy

Vincenzo Girgenti [a,*], Cristiana Peano [a], Michele Bounous [a], Claudio Baudino [b]

[a] Dipartimento di Scienze Agrarie, Forestali e Alimentari, Università degli Studi di Torino, Via Leonardo da Vinci 44, 10095 Grugliasco, TO, Italy
[b] AgrifruttaSoc. Coop. Agr., Via Beinette 6, 12016 Peveragno, CN, Italy

HIGHLIGHTS

• LCA is a system for evaluating the environmental sustainability of products and processes.
• The disposal of the packaging material is taken into account.
• The LCA methodology has been applied to quantify the emissions of berry fruits.
• Species index: blueberry and raspberry

ARTICLE INFO

Article history:
Received 4 February 2013
Received in revised form 18 April 2013
Accepted 21 April 2013
Available online 15 May 2013

Editor: Simon Pollard

Keywords:
LCA
Sustainability
Strategic planning
Blueberry production
Raspberry production

ABSTRACT

This study examined the emissions produced during the *pre-farm*, *farm* and *post-farm* phases of the production cycle of raspberries and giant American whortleberries (blueberries) cultivated in one of the best-adapted areas in northern Italy.

The *pre-farm* phase included the greenhouse gas emissions from the production of plants in the nursery and the transportation of the plants to the production farms. The *farm phase* involved the emissions of greenhouse gases from chemical products, the water used for irrigation, the generation of waste, and the consumption of electricity and other energy. The *post-farm* phase comprised the transportation of the products to the distribution centre (DC) and their storage in the DC. The use phase is not included in the system, nor is transportation from the supermarket to the home of the final consumer, but the disposal of the packaging is nevertheless taken into account. Indeed, the use of traditional plastic materials during both the field phase (nursery and cultivation) and the post-harvesting phase (*packaging*) produced the greatest estimated impact.

1. Introduction

In Italy, the cultivation of raspberries (*Rubus idaeus* L.) and blueberries (*Vaccinium corymbosum*) has become a dynamic industry in recent years, as demonstrated by its consistent growth between the 1980s and the present day (Bounous et al., 2009). Because of the increased interest in these small fruits, it has been possible to develop their marketing beyond the stereotype of a niche product. In the Alpine valleys of northern Italy in particular, raspberry and blueberry production systems (beginning in the 1970s) have grown into consolidated industries. Italy currently ranks as Europe's 7th largest producer of blueberries, with 1500 tons of production (FAO, 2010), after the main northern European states (Germany, Poland, the Netherlands, Sweden, Romania, and Lithuania). With regard to raspberries, Italy now produces approximately 2000 tons on a land surface of approximately 350 ha (FAO, 2010).

A portion of these products reaching the Italian market comes from eastern European states (Serbia and Montenegro), from countries that are able to supply fruit for industrial processing at prices that are not feasible for Italian companies. In addition, the need to extend the buying season has clearly influenced the decision of certain commercial agencies to begin importing from countries outside of Europe (50%), such as Chile and Argentina. However, the fact that the early years of the last decade saw a significant increase in the export of these small fruits to the affluent markets of the U.K. and Germany should also be noted (Bounous et al., 2009). The import–export system relies mainly on production in the Piedmont and Trentino–Alto Adige regions, which are equipped with proper structures for managing production, organisation, and distribution; while in other areas the sales process is generally handled directly by the farms that cultivate the plants. In Italy, interest in these small fruits is still limited compared to the other main fruit types, and consumption per capita remains low (FAO, 2010). The price element is certainly a limiting factor for the consumer, who regards raspberries and blueberries as a treat for special occasions and not as an everyday foodstuff. These fruits are, however, associated with a wholesome, healthy image, both because

* Corresponding author. Tel.: +39 0116708939; fax: +39 0116708658.
E-mail address: vincenzo.girgenti@unito.it (V. Girgenti).

0048-9697/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.scitotenv.2013.04.060

of their intrinsic properties and because of their strong compatibility with integrated and organic systems. It is therefore possible to say that even in the market for raspberries and blueberries, the demand of the consumer (and, thus, of mass retailers) for a "clean", "healthy" product puts pressure on the whole sector, which is now increasingly focusing on processes and production methods that take these concerns into consideration (Bounous et al., 2009).

The theme of sustainable production and distribution processes within agri-food chains has, in fact, taken on an increasingly central role in the design of promotion and sales strategies for fruit and vegetable products in Italy and elsewhere. The imposition of restrictions to reduce greenhouse gases (the Kyoto Protocol, Directive 2009/29/EC or the *20–20–20 Package*) and the emergence of a consumer category that is increasingly concerned about the environmental sustainability of products are shifting the focus of competition amongst businesses towards eco-innovation and energy efficiency. These strategies are being applied both to the production side and to transportation, which is responsible for a quarter of all CO_2 emissions (Grant et al., 2009). The main methodology employed to evaluate environmental impacts has been the analysis of "eco-balance", based on a collection of indicators of sustainability and environmental impacts using solid theoretical reasoning (Herva and Roca, 2013). This technique has proved effective in guiding decision-making processes and for establishing a practical evaluation framework for monitoring (Cerutti et al., 2010). Sustainability indicators constitute one of the key issues attracting interest in terms of both scientific research and political activity. There are many such indicators, and they are constantly evolving. However, the instrument that is most generally used to assess environmental impacts in terms of CO_2 emissions, greenhouse gases and the consumption of resources is *Life Cycle Assessment* (LCA) (Notarnicola et al., 2012).

LCA is a system for evaluating the environmental sustainability of products and processes. It is a standardised procedure that allows the recording, quantification and evaluation of the environmental damage associated with a product, a process or a service within a certain well-defined context, which has to be established beforehand. The analytical approach underlying this methodology, known as "Life Cycle Thinking", involves studying every phase of the life cycle of a product or process "from cradle to grave" to obtain a complete picture of the flow of the energy and material produced (Greadel and Allenby, 2003a,b).

Many studies have concentrated on the reduction of greenhouse gas emissions and other effects on the environment associated with the production of fresh produce. Mila i Canals et al. (2006) conducted a life cycle analysis (LCA) of apple production in two different regions of New Zealand, as did Mouron et al. (2006) in Switzerland. In Sweden, Carlsson-Kanyama (1998) studied the greenhouse gas emissions involved in the production life cycle of a variety of products (e.g., carrots, tomatoes, potatoes, pork, rice, and dried peas).

Other LCA studies have examined the impact of different means of transport to determine the most environmentally friendly distribution method. Roy et al. (2009) studied the relative greenhouse gas emissions related to transporting tomatoes by road or sea, while Hospido et al. (2009) examined the impact on global warming of either supplying local lettuces or imported lettuces to retail outlets in Britain. The study and assessment of the environmental sustainability of agricultural systems are closely connected to the definition of sustainable agriculture. Indeed, some writers maintain that it is only in agricultural systems that are sustainable over the long term that the *output* of all of the components in the system is capable of balancing the *input* (Lal, 2008). This view of sustainable agriculture, although accepted by the majority of researchers and technicians working in the field, is vague with regard to the actual methods for achieving sustainability (Lichtfouse et al., 2009; Herva and Roca, 2013). In the context of fruit production, there are various sets of guidelines ranging from those that attempt to optimise profitability (conventional production) to those that respect certain norms relative to sustainability (organic production) or that lead to intermediate systems, such as integrated production. Various studies have evaluated these three types of guidelines from an environmental perspective (Sanjuán et al., 2003; Kaltsas et al., 2007; La Rosa et al., 2008; De Barros et al., 2009). The conclusions do not always identify one system of production as best, as they depend, for example, on the assessment methods and environmental indicators employed. However, organic production is generally considered the most ecologically sustainable favourable option (Granatstein and Kupferman, 2006), and integrated production is viewed as resulting in the most efficient use of resources per unit of product (Reganold et al., 2001). In general, fruit production is regarded as a sector with a low environmental impact compared to herbaceous cultivation (Granatstein and Kupferman, 2006) and other agri-food sectors (Carlsson-Kanyama et al., 2003; Garnett, 2006; Cuadra and Bjorklund, 2007; Frey and Barrett, 2007). The environmental costs of fruit growing have been studied in terms of the consumption of resources (e.g., water, soil, air, energy) or in terms of various impacts (e.g., pollution, risks to human health and to the eco-system, reduction of bio-diversity) (Reganold et al., 2001). Some recent studies have attempted to assess the total environmental cost of various fruit species throughout their entire life cycle by applying the LCA criteria (Mila i Canals and Clemente Polo, 2003; Mouron et al., 2006), analysis of the associated ecological footprint (Cerutti et al., 2010), or other methods of evaluation.

The purpose of this study was to assess the emissions of greenhouse gas (global warming potential, GWP) over the life cycle of raspberries and blueberries cultivated in the Piedmont region of northern Italy using integrated production systems. The task was divided into two stages: a) evaluation of the impact of raspberries and blueberries on global warming using the LCA method; and b) identification of possible strategies for mitigating greenhouse gas production.

2. Methodology

The LCA methodology is guided at the international level by the norms of the International Organization for Standardization (ISO), series 14040:2006 (ISO, 2006). According to these guidelines, a life cycle evaluation study should involve four phases: Goal and Scope Definition, Life Cycle Inventory (LCI), Impact Assessment (or Life Cycle Impact Assessment, LCIA), and interpretation of the results, combining the findings to draw conclusions and produce recommendations in reference to the aims of the study. The origins of the LCA method can be traced to the late 1960s and to the context of industrial America (Hunt and Franklin, 1996), and many studies have been conducted to help adapt this system to the agricultural sector (Audsley et al., 1997). The LCA method is currently considered a very useful instrument for comparing products, processes and services and serving as the basis for formulating an environmental product declaration (Schau and Fet, 2008). The results of an LCA analysis are usually presented in a range of different impact categories, such as global warming, acidification, nitrification, ozone reduction, and toxicity (Pennington et al., 2004; Gunady et al., 2012). In the case of the present study, the data refer to production during 2011. The hypothetical end of life scenario envisages that 20% of the plastic materials will be destined for incineration, and 80% will be disposed of in a refuse tip.

2.1. Goal and scope

A "cradle-to-grave" approach is employed in this study. Thus, the production chain is examined from the nursery to the sales point, taking into account all of the processes required for cultivation and post-harvest management as well as the related auxiliary processes, such as the transportation associated with the materials used and the waste produced at each stage. The use phase is not included in the system, nor is transportation from the supermarket to the home of the final consumer. However, the disposal of the packaging material is taken into account.

The purpose of the examined systems is the production of fruit for fresh consumption. The functional unit for reference purposes is the actual sales pack: a 125-gramme flow pack (9.5 × 14.5 × 2.5 cm). With regard to the field, all references are related to a hypothetical 1-hectare plot.

A standard shipping distance is estimated for each material input, including both raw materials and finished products (e.g., for plastic film, this shipping would include PE granules and the film itself), having considered the distance from the producer to consumer. It is assumed that all journeys involve a full load.

The length of the nursery phase of the life cycle is one year for raspberries and two years for blueberries.

The period of cultivation is 10 years for raspberries and 15 years for blueberries. The impacts from all field operations (e.g., fertilisation, planting and plant removal) occurring over the 10- or 15-year plantation life span are summed and then divided by the number of respective years of operation. The same procedure is employed for all of the outputs: productivity is evaluated as an average (in tons) between the period of the plants entering into production and the stage of full production. The productivity rates considered are 12 t ha^{-1} for raspberries and 10 t ha^{-1} for blueberries. The impacts arising from the production of the wooden boxes used for harvesting and the plastic crates (the CPR *system*) used to distribute the product are excluded from the LCA system boundary, as these containers are reused many times.

2.2. Life cycle inventory

After defining the goal and scope of the study, the next stage was to undertake a life cycle inventory of the production chains. Data were acquired through questionnaires administered to 15 raspberry producers and 15 blueberry producers. The required information pertained to the various inputs required for raspberry and blueberry production.

With regard to those aspects related to the nursery stage, the data were acquired from the nurseries that supplied the genetic material to the farms in the study. Information pertaining to the post-harvesting phase was provided by technical personnel at the fruit and vegetable warehouse.

Table 1 displays the main model inputs, detailing the material or machinery employed for each input as well as the unit of measurement used.

2.3. Impact assessment

To analyse the data collected during the inventory phase, the SimaPro 7.3 software, produced by PRé Consultants (2010), was used. This is one of the most commonly utilised types of software for such studies, being employed by large companies, consultancy firms and universities to evaluate the environmental performance of various products, processes and services. It allows the monitoring and analysis of even complex lifecycles in a systematic and transparent way, following the recommendations of the ISO 14040 (2006) series of standards. The databases employed for the inventory were Ecoinvent 2.2 and LCA Food DK.

For each production chain, the data were standardised using mass balance methods in relation to the initial assumptions and were subsequently organised according to 2 categories of impact:

- GWP (global warming potential) IPCC 100a (kg CO_2eq);
- Non-renewable energy (MJ primary).

The choice of these two categories of impact was related (in the first instance) to the need to provide an evaluation of the impact of the examined production in relation to climate change that can be readily communicated to and understood by the consumer. The non-renewable energy source category was selected to provide a view of the impacts in relation not only to emissions but also to consumption, which is considered one of the most critical issues in the primary sector.

Table 1
Principal inputs involved in analysis of the "Delizie di Bosco del Piemonte" production chain for raspberries and giant American blueberries.

Phase	Operation or input	Material or machine
Nursery	Rooting	Substratum (l ha^{-1})
	Mulching	Black PE (kg ha^{-1})
	Covering	White PE (kg ha^{-1})
	Covering	Metal supports (kg ha^{-1})
	Fertigation system	PVC piping (kg ha^{-1})
	Fertigation system	PVC tubing (kg ha^{-1})
	Fertigation	Compost mix (kg ha^{-1})
	Fertigation	Water (m^3 ha^{-1})
	Nozzles	PVC (kg ha^{-1})
	Cold storage	Electrical energy (kWh m^{-3})
Field	Soil preparation	Plough or cultivator (h ha^{-1})
	Soil preparation	Harrow (h ha^{-1})
	Mulching	Bed-former (h ha^{-1})
	Total processes	Diesel consumption (l h^{-1})
	Mulching	PE sheeting (kg ha^{-1})
	Irrigation system	PVC piping (kg ha^{-1})
	Irrigation system	PVC tubing (kg ha^{-1})
	Irrigation	Water (m^3 ha^{-1})
	Irrigation	Electrical energy for the well (kWh ha^{-1})
	Base fertilisation	Manure (t ha^{-1})
	Total fertilisation	Compost (t ha^{-1})
	Covering	White PE (kg ha^{-1})
	Covering	Metal supports (kg ha^{-1})
	Plant protection treatments	p.a. (kg ha^{-1})
Post-harvesting	Refrigeration	Electrical energy (kWh kg^{-1})
	Flow packaging	Electrical energy (kWh kg^{-1})
	Flow packaging	PE tray (g kg^{-1})
	Flow packaging	PE wrapping (g kg^{-1})

For this representation, a cut-off was applied at the 2% mark, and all of the data registering below this percentage were grouped together in the "other" category.

3. Results and discussion

3.1. Pre-farm

When we examine the impacts during the nursery phase (Table 2), we can deduce that the production of a raspberry plant is associated with a GWP of 0.011 kg of CO_2eq and a requirement for non-renewable energy (NRE) equivalent to 1.095 MJ. The effect of the substratum, consisting mainly of peat and perlite, amounts to 79% of the NRE impact and 12% of GHG emissions. The tubing for the irrigation system represents 10% of the NRE impact and 24% of GHG emissions (Fig. 1).

In examining the impacts of the nursery phase for the blueberry (Table 2), we can conclude that the production of a single plant is associated with a GWP of 0.023 kg of CO_2eq and a requirement for non-renewable energy equivalent to 11.952 MJ. The effect of the substratum (mainly peat) amounts to 97% of the NRE impact and 30% of the GWP. The only significant NRE impact relates to the substratum, while the GWP impacts of the nozzles and tubing for the irrigation system are 22% and 16%, respectively.

3.2. Farm

If we add the impacts of nursery production (standardised to the functional unit) to those associated with cultivation, we can infer that 125 g of raspberries entering the warehouse displays a carbon footprint of 0.027 kg of CO_2eq and requires 0.529 MJ of energy from non-renewable sources (Table 3). Analysis of the impacts shows that the nitrogen fertiliser and the tubing for the drip system represent 26% and 11% of the GWP and 7% and 20% of the NRE impacts, respectively. The other significant impacts are shown in Table 3.

Table 2
Impacts in relation to functional units for 1 raspberry plant and 1 giant American blueberry plant at the farm, ready for transplantation.

Input	Category of impact			
	Non-renewable energy MJ UF^{-1}		IPCC GWP 100a kg CO_2eq UF^{-1}	
	Raspberry	Blueberry	Raspberry	Blueberry
Tubing	0.111	0.130	0.003	0.004
Substratum	0.869	11.56	0.002	0.007
Irrigation	0.013	0.019	0.001	0.001
Covering	0.000	0.037	0.000	0.001
Supports	0.000	0.014	0.000	0.001
Fertiliser (N)	0.000	0.013	0.000	0.002
Nozzles	0.000	0.173	0.000	0.005
End of life	0.002	0.001	0.005	0.002
Other	0.000	0.000	0.000	0.000

It can also be noted that important impacts with regard to climate change are associated with the irrigation systems (11%), supports (10%) and covering (9%), while the non-renewable energy source impacts are related, in particular, to the covering (17%), nursery (14%) and irrigation system (10%).

Consider the whole raspberry production chain, the GWP is 0.053 kg of CO_2eq. Over the raspberry life cycle, approximately 1.119 MJ of non-renewable energy is consumed.

If we add the impacts of nursery production to those resulting from the agricultural phase, we can infer that 125 g of blueberries emits 0.023 kg of CO_2eq and requires 0.444 MJ of energy from non-renewable sources. Analysis of the impacts shows that the nitrogen fertiliser and the tubing for the drip system contribute 43% and 11% of the GWP and 21% and 11% of the NRE impact, respectively. It is possible to infer that with regard to climate change, the main impacts come from processing (10%) and irrigation (9%), while the impacts of using energy from non-renewable sources are principally related to diesel (17% data not shown) and to the nursery phase (9%).

3.3. Post-farm

With regard to raspberries, the effects of the field and nursery phases, considered together, are 46% for GWP and 43% for NRE. The types of impact regarded as prevalent in the post-harvesting phase in percentage terms represent the last remaining part of the impact distribution. It can be observed that the PE plastic trays and PE plastic film used in packaging contribute 30% and 9% of the GWP and 35% and 15% of the NRE impact, respectively.

When we examine the whole blueberry production chain, we can highlight that the GWP (IPCC) corresponds to 0.055 kg of CO_2eq, while the chain consumes 1.123 MJ of non-renewable energy.

The effect of the field and nursery phases, considered together, is 38% for GWP and 36% for NRE. The types of impact regarded as prevalent in the post-harvesting phase in percentage terms represent the last remaining part of the impact distribution (Table 3). It can be observed that the PE plastic trays and PE plastic film used in packaging contribute 29% and 9% of the GWP and 35% and 15% of the NRE impacts, respectively.

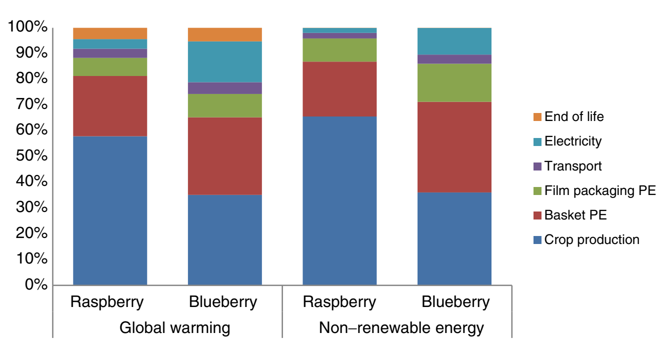

Fig. 1. Representation of the main impacts associated with the production of 250 g of raspberries and 125 g of giant American blueberries (UF) at the distribution platform.

Table 3
Impact in relation to functional units for a130-gramme container of raspberries and a 125-gramme container of giant American blueberries, delivered to the warehouse.

Input	Category of impact			
	Non-renewable energy MJ UF^{-1}		IPCC GWP 100a kg CO_2eq UF^{-1}	
	Raspberry	Blueberry	Raspberry	Blueberry
Compost mix	0.000	0.067	0.000	0.01
Fertiliser (N)	0.037	0.000	0.007	0.000
Tubing	0.106	0.092	0.003	0.003
Covering	0.088	0.000	0.002	0.000
Supports	0.042	0.000	0.003	0.000
Anti-hail netting	0.035	0.028	0.001	0.001
Mulching	0.000	0.025	0.000	0.001
Soil preparation	0.033	0.035	0.002	0.002
Irrigation	0.052	0.038	0.003	0.002
Nursery	0.076	0.041	0.001	0.000
Organic fertiliser	0.000	0.008	0.000	0.001
Diesel	0.000	0.075	0.000	0.001
End of life	0.001	0.001	0.002	0.001
Other	0.039	0.000	0.002	0.000

4. Conclusion and recommendations

The LCA methodology was applied to the production chains of raspberries and blueberries grown in Italy using integrated cultivation methods to quantify the associated emissions. As a result of this study, it is possible to assess the environmental impact of the products in question to identify the weak points in the systems and suggest suitable options to help reduce the environmental impacts of these production systems.

Taking the entire production chain into account, the LCA results show us that the most significant impacts are related to the use of plastic materials derived from fossil fuels during all phases (pre-farm, farm and post-farm).

By examining the individual steps in the chain, it is possible to envisage certain methods for improvement. For example, during the nursery phase, it might be feasible to reduce the quantity of substratum used (mainly peat), whose production and transportation involve the main concentration of energy use. This effect is especially noticeable with regard to extraction and transport in view of the low weight per unit of volume of this particular material.

In the field phase, the main impacts in terms of both energy and GWP are related to the agronomic operations that involve the use of plastics derived from fossil fuels, such as irrigation (tubes), mulching and covering. In these cases, we suggest the adoption of an innovative approach, involving the testing of biodegradable plastics for possible introduction as an alternative material. At present, such materials are associated with significant use limitations due to their lack of durability, making them more suited for short production cycles, such as those of vegetables. In addition, although the lesser impact of biodegradable materials is demonstrated in the literature (Razza et al., 2010), if these materials were to be employed, their entire production chain and the emissions produced during the biodegradation phase would have to be taken into account. The substitution of current materials with biodegradable and/or compostable materials should nevertheless be borne in mind for the future, as in addition to the environmental benefits produced, it could lead to a reduction of costs for farming enterprise through decreasing the labour required for removal work.

The phase in which intervention would produce the greatest environmental benefits is the post-harvesting stage. For raspberries and blueberries to be sold through the major retail chains, it is necessary for packaging to be used for technical reasons. Possible solutions to this issue would mainly involve the substitution of PE with biodegradable materials such as PLA or other low-impact materials, which would allow disposal of the whole package as organic waste (Madival et al., 2009). Williams et al. (2008) reported that there is clear potential here for increasing customer satisfaction while, at the same time, reducing environmental impacts by designing new, eco-friendly packaging systems for foods.

Finally, based not only on this study but also on an analysis of the key literature regarding sustainable fruit production (Granatstein and Kupferman, 2006; Mila i Canals and Clemente Polo, 2003; Mouron et al., 2006), it can be observed that the raspberry and blueberry chains are amongst the production systems showing the greatest interaction with natural systems. Indeed, these types of fruit farms, more than many other agri-food chains, can be seen in terms of a relationship between nature and the technical sphere.

Acknowledgments

This research was supported by the private company Ortofruititalia soc.coop. S.R.L., Saluzzo (CN), Italy.

References

Audsley A, Alber S, Clift R, Cowell S, Crettaz R, Gaillard G, et al. Harmonisation of environmental life cycle assessment for agriculture. Final report, concerted action AIR3-CT94-2028. Brussels, Belgium: European Commission DG VI; 1997.

Bounous G, Beccaro G, Mellano MG. Piccoli frutti: mirtilli, lamponi, more, ribes, uvaspina. Milano: Il Sole 24 Ore/Edagricole978-88-506-5270-9; 20091-393.

Carlsson-Kanyama A. Climate change and dietary choices—how can emissions of greenhouse gases from food consumption be reduced? Food Policy 1998;23:277–93.

Carlsson-Kanyama A, Ekstrom MP, Shanahan H. Food and life cycle energy inputs: consequences of diet and ways to increase efficiency. Ecol Econ 2003;44:293–307.

Cerutti AK, Bruun S, Beccaro GL, Bounous G. A review of studies applying environmental impact assessment methods on fruit production systems. J Environ Manag 2010;92(2011):2277–86.

Cuadra M, Bjorklund J. Assessment of economic and ecological carrying capacity of agricultural crops in Nicaragua. Ecol Indic 2007;7:133–49.

De Barros I, Blazy JM, Stachetti Rodrigues G, Tournebize R, Cinna JP. Energy evaluation and economic performance of banana cropping systems in Guadeloupe (French West Indies). Agric Ecosyst Environ 2009;129:437–49.

FAO. The state of food insecurity in the world; 2010.

Frey S, Barrett J. Our health, our environment: the ecological footprint of what we eat. International Ecological Footprint Conference, Cardiff; 2007. [8–10 May 2007].

Garnett T. Fruit and vegetables and greenhouse gas emissions: exploring the relationship. Working paper produced as part of the work of the Food Climate Research Network. Centre for Environmental Strategy, University of Surrey; 2006.

Granatstein D, Kupferman E. Sustainable horticulture in fruit production. XXVII International Horticultural Congress — IHC2006: International Symposium on Sustainability through Integrated and Organic Horticulture, vol. 767. ISHS ActaHorticulturae; 2006.

Grant J, Carù A, Giordano A, Pallera M. Green marketing — il manifesto. Milano: Francesco Brioschi Editore; 2009.

Greadel T, Allenby B. An introduction to life cycle assessment. Industrial ecology 2nd ed. Upper Saddle River, New Jersey, USA: Pierce Education; 2003a.

Greadel T, Allenby B. The LCA impact and interpretation stages. Industrial ecology 2nd ed. Upper Saddle River, New Jersey, USA: Pierce Education; 2003b.

Gunady MGA, Biswas W, Solah VA, James AP. Evaluating the global warming potential of the fresh produce supply chain for strawberries, romaine/cos lettuces (*Lactuca sativa*), and button mushrooms (*Agaricus bisporus*) in Western Australia using life cycle assessment (LCA). J Clean Prod 2012;28:81–7.

Herva M, Roca E. Review of combined approaches and multi-criteria analysis for corporate environmental evaluation. J Clean Prod 2013;39:355–71. [January 2013].

Hospido A, Mila i Canals L, McLaren S, Truninger M, Edward-Jones G, Clift R. The role of seasonality in lettuce consumption: a case study of environmental and social aspects. Int J Life Cycle Assess 2009;14:381–91.

Hunt RG, Franklin WE. LCA and how it came about and personal reflections on the origin and the development of LCA in the USA. Int J Life Cycle Assess 1996;1:4–7.

ISO (International Standard Organization). ISO 14040:2006 environmental management — life cycle assessment and principles and framework. Geneva, Switzerland: International Organization for Standardization (ISO); 2006.

Kaltsas AM, Mamolos AP, Tsatsarelis CA, Nanos GD, Kalburtji KL. Energy budget in organic and conventional olive groves. Agric Ecosyst Environ 2007;122:243–51.

Lal R. Soils and sustainable agriculture. A review. Agron Sustain Dev 2008;28:57–64.

La Rosa AD, Siracusa G, Cavallaro R. Energy evaluation of Sicilian red orange production. A comparison between organic and conventional farming. J Clean Prod 2008;16: 1907–14.

Lichtfouse E, Navarrete M, Debaeke P, Souchere V, Alberola C, Menassieu J. Agronomy for sustainable agriculture. A review. Agron Sustain Dev 2009;29:1–6.

Madival S, Auras R, Singh SP, Narayan R. Assessment of the environmental profile of PLA, PET and PS clamshell containers using LCA methodology. J Clean Prod 2009;17: 1183–94.

Mila i Canals L, Clemente Polo G. Life cycle assessment of fruit production. In: Mattsson B, Sonesson U, editors. Environmentally friendly food processing. Cambridge and Boca Raton: Woodhead Publishing Limited and CRC Press LLC; 2003. p. 29e53. [Ch. 4].

Mila i Canals L, Burnip GM, Cowell SJ. Evaluation of the environmental impacts of apple production using life cycle assessment (LCA): case study in New Zealand. Agric Ecosyst Environ 2006;114:226–38.

Mouron P, Nemecek T, Scholz RW, Weber O. Management influence on environmental impacts in an apple production system on Swiss fruit farms: combining life cycle assessment with risk assessment. Agric Ecosyst Environ 2006;114:311–22.

Notarnicola B, Hayashi K, Curran MA, Huisingh D. Progress in working towards a more sustainable agri-food industry. J Clean Prod 2012;28:1–8.

Pennington DW, Potting J, Finnveden G, Lindeijer E, Jolliet O, Rydberg T, et al. Life cycle assessment part 2: current impact assessment practice. Environ Int 2004;30:721–39.

Pré Consultants. SimaPro version 7.3; 2010.

Razza F, Farachi F, Tosin M, Degli Innocenti F, Guerrini S. Assessing the environmental performance and eco-toxicity effects of biodegradable mulch films. VII International Conference on Life Cycle Assessment in the Agri-food Sector Bari; 2010. p. 22–4. [September].

Reganold JP, Glover PK, Andrews PK, Hinman HR. Sustainability of three apple production systems. Nature 2001;410:926–9.

Roy P, Nei D, Orikasa T, Xu Q, Okadome H, Nakamura N, et al. A review of life cycle assessment (LCA) on some food products. J Food Eng 2009;90:1-10.

Sanjuán N, Clemente G, Úbeda L. LCA of the integrated production of oranges in the Comunidad Valenciana (Spain). Life cycle assessment in the agri-food sector. Proceedings from the 4th International Conference 2003; 2003. p. 210–3.

Schau EM, Fet AM. LCA studies of food products as background for environmental product declarations. Int J LCA 2008;13(3):255–64.

Williams A, Pell E, Webb J, Moorhouse E, Audsley E. Strawberry and tomato production for the UK compared between the UK and Spain. Proceedings of 6th International Conference on Life Cycle Assessment in the Agri-food Sector towards a Sustainable Management of the Food Chain, November 12–14. Zurich, CH: Thomas Nemecek and Gérard Gaillard; 2008.