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Abstract

In this study, we analysed the environmental profile of the strawberry industry in Northern Italy. The analysis was conducted using two scenarios as reference systems: strawberry crops grown in unheated plastic tunnels using currently existing cultivation techniques, post-harvest management practices and consumption patterns (scenario 1) and the same strawberry cultivation chain in which some of the materials used were replaced with bio-based materials (scenario 2). In numerous studies, biodegradable polymers have been shown to be environmentally friendly, thus potentially reducing environmental impacts. These materials can be recycled into carbon dioxide and water through composting. Many materials, such as Mater-BI® and PLA®, are also derived from renewable resources. The methodology chosen for the environmental analysis was a life cycle assessment (LCA) based on a consequential approach developed to assess a product's overall environmental impact from the production system to its usage and disposal. In the field stage, a traditional mulching film (non-biodegradable) could be replaced with a biodegradable product. This change would result in waste production of 0 kg/ha for the bio-based product compared to 260 kg/ha of waste for polyethylene (PE). In the post-harvest stage, the issue addressed was the use and disposal of packaging materials. The innovative scenario evaluated herein pertains to the use of new packaging materials that increase the shelf life of strawberries, thereby decreasing product losses while increasing waste management efficiency at the level of a distribution platform and/or sales outlet. In the event of product deterioration or non-sale of the product, the packaging and its contents could be collected together as organic waste without any additional processes because the packaging is compostable according to EN13432. Scenario 2 would achieve reductions of 20% in the global warming potential and non-renewable energy impact categories.

Keywords: LCA, strawberry, waste, packaging, mulching

1. Introduction

Over the past 10 years, the issue of sustainable production and distribution has become increasingly important for developing strategies to promote and market fruits and vegetables in Italy and beyond. Constraints related to reductions in greenhouse gas emissions (Kyoto Protocol, Directive 2009/29/EC or "20-20-20") and the emergence of consumer groups that are increasingly sensitive to the environmental sustainability of products have shifted business competitiveness towards eco-innovation and energy efficiency. These approaches have been applied to both production processes and transportation, the latter being responsible for a quarter of total emissions of CO2 (Grant et al., 2009).

To date, the primary methods considered for the assessment of environmental impacts have been so-called eco-balances, based on a set of sustainability and environmental impact indicators with solid theoretical arguments; these arguments are effective in guiding decision-making processes and are capable of returning a concrete monitoring scoreboard (Notarnicola et al. 2012; Milà i Canals et al. 2006). One of the most widely used methodology for the evaluation of environmental impact in terms of emissions of CO2, greenhouse gases and the consumption of resources is the Life Cycle Assessment (LCA) (Greadel and Allenby., 2003 a, b), that has been also applied to the production of fresh produce. Mila i Canals et al. (2006) conducted an LCA of the production of apples in 2 different regions of New Zealand, and a similar study was conducted by Mouron et al. (2006) in Switzerland. Carlsson-Kanyama (1998) studied the greenhouse gas emissions over the life cycle of the production of various products (such as carrots, tomatoes, potatoes, pork, rice and peas) in Sweden. Numerous studies have also been conducted on the environmental impacts of protected crops in greenhouses (Van Woerden, 2001; Williams et al., 2008) and multi-tunnel greenhouses in the Mediterranean (Vallejo, 2004; Romero-Gámez et al., 2009; Torrellas et al., 2012). Roy et al. (2009) researched greenhouse gas emissions associated with the distribution of tomatoes transported by road and sea, while Hospido et al. (2009) compared the effects of global warming on the supply of local and imported varieties of lettuces in retail outlets in England.

Compared to herbaceous crops (Granatstein and Kupferman, 2006) and other agro-food industries (Carlsson-Kanyama et al., 2003 Garnett, 2006; Cuadra and Björklund 2007, Frey and Barrett, 2007), the

production of fruit is generally considered an area of low environmental impact. Traditionally, environmental costs in orchards have been studied in terms of consumption of resources (water, soil, air, energy, etc.) or impacts (pollution, risks to human health and ecosystems, reduced biodiversity, etc.) (Reganold et al., 2001; Mordini et al., 2008). In the case of annual crops, such as strawberries, tomatoes and cantaloupes, the issue of plastics used for cultivation raises some concerns (Romero-Gamez et al. 2009). In Italy, approximately 43,000 t of plastic sheets are used for mulching purposes (ISPRA 2012). Because they are often contaminated with soil, these sheets are classified as non-hazardous special waste, resulting in complicated and costly recovery and disposal processes. In areas of increased consumption of these materials, consortia handle the pick-up and disposal or recovery, while in other areas, individual businesses must address a number of legislative limitations related to disposal. Currently, 14% of these materials are incinerated at the end of their life, 76% go to landfills, and 10% are recycled (Race et al., 2012).

In the fruit and vegetable distribution system for the European fresh market, plastics are widely used for primary, secondary and tertiary packaging (Albrecht et al., 2013). The packaging of food products has been widely assessed, often with contradictory results. Busser and Jungbluth (2009) and Silvenius et al. (2011) found that the shipping of goods and their primary packaging are responsible for only a minor share of the total environmental impact of the system under study. However, for fruits and vegetables, a study conducted by Cellura et al. (2012) showed that the largest proportion of the total environmental impact was associated with packaging and transport.

Although packaging is very important to protect fresh fruits and vegetables for intact delivery to consumers (Albrecht et al., 2013), distributors must also handle large quantities of deteriorating products and packaging to be disposed of daily, especially in the case of highly perishable fresh produce.

In 2010 in the 27-member state EU, approximately 38% of waste was disposed of in landfills (on average, 185 kg per inhabitant per year), approximately 22% was incinerated (109 kg per inhabitant per year), 25% was recycled (121 kg per inhabitant per year) and only 15% (71 kg per inhabitant per year) was composted.

In the last 5 years, the implementation of policies and legislation aimed at reducing waste sent to landfills, particularly biodegradable waste, has produced positive results. In 2009, approximately 76.6 million tonnes of packaging waste were produced, a 6% decrease compared to 2008. The most conspicuous commodity segment in the 27 Member States was cellulose packaging (38.9%), while waste glass packaging, plastic waste and wood waste accounted for approximately 20.9%, 19% and 14%, respectively (ISPRA, 2012).

Directive 94/62/EC and subsequent amendments and additions set recovery and recycling targets. Italy has recycled 65% and recovered 73% of packaging, which was consistent with the recycling target set for 2008 (at least 55% of packaging waste by weight, ISPRA 2012).

In this study, the LCA methodology was applied using a consequential approach to evaluate the energy consumption and environmental burdens associated with the production and deployment of everbearing strawberries in unheated tunnels and the disposal of certain supply chain materials. The study was conducted in an agricultural district in northern Italy, with two scenarios taken into consideration.

The ecoprofile of the traditional system (scenario 1) allowed us to identify the elements of the supply chain with the highest impact in terms of global energy needs, greenhouse gas emissions, eutrophication and waste production. These findings led to the selection and evaluation of 'best practices' and eco-design solutions aimed at reducing the environmental impact of strawberries (replacement plastics and waste recycling introduced in scenario 2).

Strawberries were chosen for this LCA analysis because they are highly perishable, thus requiring more energy for storage and packaging than other fruits and vegetables. The storage processes and materials used in primary packaging have important implications for greenhouse gas emissions in the product's supply chain.

2. Methodology

The LCA methodology is guided by the International Organisation for Standardisation (ISO)'s 14040:2006 standard (ISO, 2006). The LCA methodology has been applied successfully in agricultural and food systems

in recent years. This approach is effective for identifying and quantifying potential environmental impacts throughout the life cycle of a system of production and providing objective support for decision makers. We adopted a consequential approach to LCA developed to assess the product's overall environmental impact from the production system to the product's use and disposal. According to the guidelines, an evaluation study of the life cycle should involve four steps: definition of the goals and objectives, a life cycle inventory (LCI), an impact assessment (or life cycle impact assessment, LCIA) and an interpretation of the results.

The LCA methodology is considered a very useful tool for comparing products, processes and services and formulating environmental product declarations (Schau and Fet, 2008). The results of an LCA analysis are generally presented in a range of different impact categories, such as global warming, acidification, nitrification, ozone depletion and toxicity (Pennington et al.; 2004; Gunady et al., 2012). Scenario 1 assumed that 20% of plastics were incinerated and 80% were disposed of in a landfill. Scenario 2 assumed that 14% of plastics would be incinerated and that 86% would be composted.

2.1. Goal and scope of the application

A "cradle to grave" approach was used in this study. The production chain was examined from the nursery to the sales point. All of the processes needed for the cultivation and post-harvest management were considered, including associated auxiliary processes, such as transportation of the materials used and the waste generated at each stage. The usage phase and transportation from the point of sale to the end consumer's home were not considered. However, the disposal of the packaging material was included in the analysis.

The scope of the systems examined encompassed the production of strawberries for fresh consumption. The functional unit for the purpose of reference was the consumer-unit, a 250-gram flow pack (9.5 x 14.5 x 2.5 cm). The standard shipping distance was estimated for each input of material, including raw materials and finished products (e.g., for the plastic film, the transportation of PE pellets and the film itself was

included), taking into consideration the distance from the producer to the consumer. It was assumed that full loads were carried on all trips.

The duration of the life-cycle nursery phase was set as 1 year. The productivity period was set as 2 years. The impact of all materials (tarpaulins, covers, etc.) used for more than 5 years of life were summed and then divided by the number of years of usage. With regard to the field, production was estimated to be 30 t ha-1 and then reported to the functional unit of 250-gram flow pack.

The impacts associated with the production of wooden boxes used for the collection of the fruit and the plastic crates (CPR® system) used to distribute the product were excluded from the LCA system scope because these containers are reused several times.

In scenario 1, all of the stages (processes and materials) that were evaluated were representative of the integrated production of everbearing strawberries in the area analysed (the Piedmont in Italy). In scenario 2, the mulching and packaging (consumer-unit) processes remained unchanged, although we considered a substitution of materials normally used (PE and PVC) with bio-based materials (Mater-BI® and PLA®).

2.2. Life Cycle Inventory

After defining the goal of the system and scope of the analysis, an inventory of the life cycle of the production chain was conducted. Most of the primary data related to the production and distribution of the crop of strawberries were obtained from measurements taken in the tunnel by a trade representative from the local community. The data were collected through questionnaires administered to 15 producers each for scenarios 1 and 2. The requested information related to the various inputs needed for production was collected.

Data pertaining to the nursery phase were acquired from nurseries that provided the genetic material for the farms under study. The data related to the post-harvest phase were provided by the technical staff at the fruit and vegetable warehouse and by 2 distributors. Secondary data for the environmental analysis

were obtained mainly from the Ecoinvent 2.2 database (Ecoinvent, 2010), including data on the production of greenhouse components, substrates, pesticides, fertilisers, disposal materials and a combination of electrical energy production and transportation. The processes most similar to those of the analysed system were selected to model the production and distribution system.

Table 1 shows the model's main parameters, including the materials and equipment used for each input in scenarios 1 and 2 and the appropriate units of measurement.

2.3. Impact Assessment

The SimaPro 7.3 software, developed by PRé Consultants (2010), was used to analyse the data collected during the inventory phase. This program is the most commonly used software for studies by large corporations, consulting firms and universities to assess the environmental performance of various products, processes and services. SimaPro is used in the monitoring and analysis of life cycles (including complex cycles) in a systematic and transparent manner that follows the recommendations of the ISO 14040 standard (2006).

For each production chain, the data were standardised to the initial hypotheses using mass balance methods and were subsequently organised according to two impact categories: GWP (global warming potential) IPCC 100 (kg CO_2 eq) and consumption of non-renewable energy resources, calculated from the energy contents of the required resources (non-renewable energy primary MJ eq.) (Razza et al 2009) .

The choice of these two impact categories was related primarily to the need to provide an assessment of the impact of production examined in relation to climate change that could be easily communicated and understood by consumers. Energy from non-renewable sources was considered to provide an overview of the impacts related not only to emissions but also to consumption, which is considered one of the most critical points of the primary sector.

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

3. Results and discussion

SCENARIO 1

Taking into account the impact of the nursery phase reported in Table 2, we note that for scenario 1, the production of a strawberry plant had a GWP of 0.000097 kg of CO_2 eq and a need for non-renewable energy (NRE) equal to 0.000721 MJ. It derives from the aggregation of inputs and operations as in Girgenti et al., 2013.

The impact analysis shows that the greatest impact was associated with the plastics mulch derived from fossil fuels for which represented approximately 12% of NRE impacts, similar to the whole nursery phase, where nevertheless the impact is distributed on a bigger number of plants on equal surface. Other significant impacts are shown in Table 2.

Note that the following factors contributed to climate change: waste disposal or end of life (18%), mulching (11%) and coverage (8%). The use of energy from non-renewable sources in addition to mulch primarily affected nursery (11%) and cover (10%).

For the entire strawberry supply chain, the GWP (IPCC) was estimated to be 0.003804 kg of CO_2 eq, and the consumption of non-renewable energy was estimated to be 0.006677 MJ.

The combined effect of the field and nursery stages was estimated to be approximately 60% for both NRE and GWP. The impact categories considered prevalent in the post-harvest stage represented the remaining portion of the impact reported in Table 2.

Waste PE and PE plastic film used for packaging accounted for approximately 30% of the NRE and greater than 32% of the GWP.

SCENARIO 2

The results obtained from the LCA study of the strawberry supply chain as currently implemented (scenario 1) were discussed in numerous meetings with stakeholders, who highlighted the possibility of substituting materials at specific points along the analysed supply chain.

One point of discussion was the field stage, during which plastic materials from non-renewable sources could be replaced by substituting conventional mulching with Mater-Bi®. The other point in the supply chain at which a substitution of materials was suggested was the marketing stage, during which the PE film and the PET basket used for packaging the product could be replaced with Mater-Bi® film and a PLA® basket, respectively (scenario 2, Figure 1). The replacement of mulching covers is immediately feasible because these products are already on the market, whereas the use of Mater-BI® packaging film is in the advanced stage of experimentation (Peano et al., 2013).

A longer shelf life achieved by the replacement of packaging material (Almenar et al, 2009) leads to a reduction in food waste (Peano et al., 2013).

Modified-atmosphere packaging has been mentioned by other authors (Roy et al., 2009) as being advantageous for perishable products, such as tomatoes. Good post-harvest practices affect the maintenance of quality characteristics in food, thereby reducing food losses and consequently reducing the need for greater production to meet demand (Roy et al., 2009).

Based on our analysis, the replacement of materials alone could result in a savings of 0.000229 MJ NRE compared to the current practice, not including avoided food losses (Table 2).

In the innovative scenario (2), the mulching film would not need to be removed and disposed because it is biodegraded in the soil, as shown in Figure 2.

The packaging, however, could be disposed of with organic waste and composted, thus generating less impact than landfilling or incineration.

4. Conclusions and Recommendations

A consequential approach using LCA methodology was applied to the production and distribution of cultivated strawberries using integrated growing methods in unheated tunnels in northern Italy. This analysis approach was shown to be useful for quantifying associated emissions and emphasising the need to consider the ways in which the materials used in cultivation and distribution are disposed of at the end of their useful life. After an assessment of the environmental impacts of strawberry production and the weaknesses in the current system (scenario 1), the same type of evaluation was applied in organisations using alternative materials (scenario 2), which made it possible to quantify the reduction in the environmental impact associated with the substitutions.

Although the reduced environmental impact of biodegradable materials compared to non-biodegradable materials has already been documented in the literature (Breed et al., 2010), the focus of this study was on the environmental impacts of different agricultural production and distribution materials and their treatment at the end of their useful life.

With respect to the replacement of materials used in the field cultivation phase (mulching covers), an evolution of this process in a growing number of businesses will require assessment of the different perspectives of production costs through cost-benefit analysis, particularly in terms of the hours of labour required (Torrellas et al., 2012). Moreover, the possibility of increased yields resulting from the further optimisation of cultivation techniques could lead to further reductions in environmental loads per unit of product (Torrellas et al., 2012).

In the distribution phase, substitution pertains to alternatives to the plastic materials derived from fossil fuels that are widely used today for packaging.

The strategy evaluated in this study (substitution with PLA® baskets and Mater-Bi® film) involved a trial in progress (Peano et al., 2013) that seeks to increase a product's shelf life and to dispose of all packaging as organic waste following deterioration at the point of sale (Madival et al., 2009).

Note that the replacement of packaging materials requires experimentation with the relationship between the fruit and the packaging material in terms of the latter's capacity to create barrier properties for gas (O_2

and CO_2) and water to maintain optimal storage conditions. Additionally, the adaptability of the packaging to any specific treatment required, such as coating, should be considered (Chonhenchob and Singh, 2003; Lopez Camelo 2004). Other aspects also play a role in the decision-making process leading to the replacement of a packaging system, including the flexibility of the design (shape, appearance, printing, labelling); suitability for use with bar codes or RFID tags and other logistics systems; and the weight, handling and stacking features (Albrecht et al., 2013).

The results of this study do not provide a comprehensive assessment of sustainability because only two of the environmental aspect of the system studied was considered. However, the results nonetheless provide important information for territorial policy planners and the agri-food industry.

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References

Albrecht S, Brandstetter S, Beck T, Fullana-i-Palmer P, Grönman K., Baitz M., Deimling S., Sandilands J., Fischer M. An extended life cycle analysis of packaging systems for fruit and vegetable transport in Europe, Packaging Systems Including Recycling. Int J Life Cycle Assess 2013:1-19.

Almenar Eva, Samsudin H, Auras R, Horte J. Consumer acceptance of fresh blueberries in bio-based packages. J Sci Food Agric, 2010; 90:1121-1128

Amton Vallejo MA. Utilización del Análisis del Ciclo de Vida en la Evaluación del Impacto ambiental del cultivo bajo invernadero Mediterráneo. Barcelona, Doctoral thesis, Universitat Politècnica de Catalunya, Doctoral thesis, 2004.

Büsser S, Jungbluth N. The role of flexible packaging in the life cycle of coffee and butter. Int J Life Cycle Assess 2009;14(Suppl 1):80-91.

Carlsson-Kanyama A. Climate change and dietary choices-how can emissions of greenhouse gases from food consumption be reduced? Food Policy 2009;23:277-293.

Carlsson-Kanyama A, Ekström MP, Shanahan H. Food and life cycle energy inputs: consequences of diet and ways to increase efficiency. Ecological Economics 2003;44(2–3):293-307.

Cellura M, Longo S, Mistretta M. Life cycle assessment (LCA) of protected crops: an Italian case study. J Clean Prod 2012;28:56-62

Chonhenchob V, Singh SP. A comparison of corrugated boxes and reusable plastic containers for mango distribution. Packag Technol Sci 2003;16:231-237

Cuadra M, .Björklund J. Assessment of economic and ecological carrying capacity of agricultural crops in Nicaragua. Ecological Indicators 2007; 7(1):133-149.

Ecoinvent. Ecoinvent Database v. 2.2. Swiss Centre for Life Cycle Inventories, Dübendorf, 2010.

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.

Girgenti V, Peano C, Bounous M, Baudino C. A life cycle assessment of non-renewable energy use and greenhouse gas emissions associated with blueberry and raspberry production in northern Italy. Science of the Total Environment, 2013;458-460: 414-418.

Granatstein D, Kupferman E. Sustainable Horticulture in Fruit Production. XXVII International Horticultural Congress - IHC2006: International Symposium on Sustainability through Integrated and Organic Horticulture. In: ISHS ActaHorticulturae, 2006;vol. 767.

Grant J, Carù A, Giordano A, Pallera M. Green marketing — il manifesto. Milan: 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 M.G.A., Biswas W, Solah VA, James AP. Evaluating the global warming potential of the fresh produce supply chain for strawberries, romaine/cos lettuces (Lactucasativa), and button mushrooms (Agaricusbisporus) in Western Australia using life cycle assessment (LCA). Journal of Cleaner Production 2012;28:81-87.

Frey S, Barret, J. Our health, our environment: The Ecological Footprint of what we eat. International Ecological Footprint Conference, 8-10 May 2007,Cardiff.

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;14:381-391.

ISO (International Standard Organization), ISO 14040:2006 Environmental Management e Life Cycle Assessment andPrinciples and Framework. International Organization for Standardization (ISO), Geneva, Switzerland, 2006.

ISPRA, Rapporto Rifiuti Urbani 2012, Roma, ISPRA, 2012

López Camelo AF. Manual for the preparation and sale of fruits and vegetables. From field to market. Rome, Food and agriculture organization of the United Nations; 2004.

Madival S, Auras R, Singh SP,Narayan R. Assessment of the environmental profile of PLA, PET and PS clamshell containers using LCA methodology. Journal of Cleaner Production 2009;17:1183-1194.

Milà 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. Agriculture, Ecosystems & Environment 2009;114 (2–4):226-238.

Mordini M, Nemeceek T, Gaillard G.Carbon & Water Footprint of Oranges and Strawberries: A Literature Review. Sustainable Agriculture Initiative Working Group on Fruit, 2009. Available at: http://www.saiplatform.org/uploads/Library/WG%20Fruit%20-%20ART%20Final%20Report.pdf

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 statistical risk assessment. Agriculture, Ecosystems & Environment. 2006;114(2–4):311-22.

Notarnicola B, Hayashi K, Curran MA, Huisingh D. Progress in working towards a more sustainable agri-food industry. Journal of Cleaner Production 2012; 28 (0):1-8.

Pennington DW, Potting J, Finnveden G, Lindeijer E, Jolliet O, Rydberg T, Rebitzer G. Life cycle assessment Part 2: current impact assessment practice. Environmental International 2004;30;721-739.

Razza F, Farachi F, Tosin M, Degli Innocenti F, Guerrini S. Assessing the environmental performance and eco-toxicity effects of biodegradable mulch films. In: VII International Conference on Life Cycle Assessment in the agri- food sector Bari, 22-24 September, 2010.

Razza F, Fieschi M, Degli Innocenti F, Bastioli C. Compostable cutlery and waste managment: an LCA approach. Waste Management 2009; 4: 1424-1433.

Razza F, Degli Innocenti F, Peano C,Girgenti V, Bounous M. Improving the efficience of agricultural and food systems by supply chain: experience from northern Italy. Proceedings 8th International Conference on Life Cycle Assessment in the Agri-Food sector, INRA-Agrocampus Rennes, 866, 2012.

Reganold JP, Glover PK, Andrews PK, Hinman HR. Sustainability of three apple production systems. Nature 2001;410:926–929.

Romero-Gámez M, Anton A, Soriano T, Suarez-Rey EM, Castilla N. Environmental impact of greenbean cultivation: Comparison of screen greenhouses vs. open field. Journal of Food, Agriculture and Environment. 2009; 7(3-4): 754-760.

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. Journal of Food Engineering. 2009;90(1):1-10.

Schau EM, Fet AM. LCA Studies of food products as background for environmental product declarations.

International Journal of LCA 2008;13(3):255-264.

Silvenius F, Katajajuuri JM, Grönman K, Soukka R, Koivupuro HK, Virtanen Y. Role of Packaging in LCA of Food Products. In: Finkbeiner M (ed) Towards Life Cycle Sustainability Management. Springer, 2011, pp 359-370.

Torrellas M, Antón A, Ruijs M, García Victoria N, Stanghellini C, Montero J. Environmental and economic assessment of protected crops in four European scenarios Journal of Cleaner Production 2012.

Van Woerden S. The application of Life Cycle Analysis in glasshouse horticulture. In: International Conference LCA in Foods, 136–140,Gothenburg, Sweden, 2001.

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.