Moving toward scientific LCA for farmers

Carmen M. Torres[1,*], Assumpció Antón[2], Francesc Castells[1]

[1] Departament d'Enginyeria Química, Universitat Rovira i Virgili, Països Catalans 26, Tarragona 43007, Spain
[2] IRTA, Ctra. de Cabrils, km 2, 08348 Cabrils, Barcelona, Spain
[*] Corresponding author. E-mail: *carmenmaria.torres@urv.cat*

ABSTRACT

Certain complexities in the agricultural production differentiate this sector from the conventional industrial processes. The main feature to take into account is that the resources consumption and production is subjected to high variability in soil, rainfall and latitude. We show here an environmental tool developed in close cooperation with farmers in order to achieve applicability and comprehensibility. The procedure relies on the data retrieved from parcel management monitoring of different crops, mostly allocated in Catalonia and Ebro river watershed region (NE Spain). A set of comprehensive but also simple reports are provided, including material and energy balances, agronomic efficiencies and water and carbon footprints. The calculations also cover impacts due to infrastructure, including the estimation of materials in the use of greenhouses. Besides, a simple algorithm for reporting uncertainty using an approximation method of error propagation was added using the input uncertainties as defined by their data pedigree.

Keywords: decision making, calculation tool, sustainability indicators, growers, uncertainty analysis

1. Introduction

Today's society is more aware than ever of the state of the planet and the necessity of enhance the environment protection to deal with new issues such as global warming, overpopulation, water scarcity, etc. To face these challenges environmental regulations become more restrictive, and the productive sectors are forced to adopt measures, providing reliable information and applying tools for understanding and mitigating environmental damage. Particularly, the global food system, from land use change, through fertilizer manufacture, to food storage and packaging, is responsible for about one-third of all anthropogenic greenhouse gases (GHG) emissions (Vermeulen et al 2012). In this sense, the Global Warming Potential (GWP) is the most widely studied impact category as a result of the evidences of the rising global temperatures that are accompanied by changes in weather and climate thus affecting ecosystem and society. The GWP measures the environmental impact from a life-cycle perspective as the sum of GHG emissions caused by an organization, event or product, expressed in CO_2 equivalents. International standards such as the ISO 14067:2013 (ISO, 2013) provide guidelines for calculating carbon footprints. Furthermore, specific standards such PAS 2050.1 (BSI, 2011) provide specific guides for measuring the Carbon Footprint (CF) of horticultural and agricultural products.

Together with climate change, water scarcity has become one of the biggest environmental problems worldwide. The lack of access to fresh drinking water and sanitation has major impacts on people's well-being, causing massive health impacts. Moreover, the lack of water for productive purpose results in malnutrition, poverty and illnesses for a large portion of the world population. Agriculture represents a serious burden as the largest consumer of water and the main source of nitrate, ammonia and phosphate pollution in ground and surface water. It is of capital importance the implementation of good water management practices in irrigated agriculture, in an attempt to fix this increasing problem while providing food for the fast growing population. The concept of Water Footprint (WF) introduced by Hoekstra et al (2011) provides a framework to analyze the link between human consumption and the appropriation of the freshwater resources that incorporates both direct and indirect water use of a consumer or producer.

Nevertheless, the application of standardized LCA methodology to the evaluation of the agriculture sector has more complexities when compared to conventional industrial processes. The main issue to take into account is that the resources consumption and production is subjected to high variability in soil and weather conditions. Besides, the lower energy consumption of agriculture activities compared to industrial processes increases the relative significance of other parameters like transport or infrastructure. Therefore, in addition to the complexity of LCA tools we need to account for the extreme variability of agriculture. All these complexities and variability in the LCA indicators associated to agriculture make unpopular their application for farmers.

With the aim of involving the farmers in the tasks of accounting sustainability in their decisions and to retrieve from them reliable information, the principle of parsimony "as simple as possible and as complex as necessary" (Pidd 1996) is applied to develop the structure of a combined tool for the sustainable performance evaluation of agriculture processes.

Within the calculation and software tools available in the agricultural field, two calculators stand out: the Fieldprint calculator (www. fieldtomarket.org/fieldprint-calculator/) that assesses the CF and WF associated to crop production, and the Cool Farm Tool calculator (Hillier et al 2011) that is an open source software that considers crop management, livestock and manure management, field energy use and primary processing energy use. Both the mentioned software tools as well as the tool presented hereby are designed for farm-scale usage and for a certain growing season because of the variability above mentioned. Moreover, they are intended to be a decision-support tool for the farmer based on inputs that are well-known by the user.

Within the context of LCA, uncertainty analysis is used to better explain and support LCA conclusions based on the cumulative effects of uncertainty and variability. Reporting the outcome of the model with a quantitative measurement of the data quality means an added value compared with building deterministic models that assign single values to model parameters to obtain results as point estimates. In this sense, ISO 14044:2006 lists under "data quality" several aspects such as reliability, uncertainty/precision, methodological consistency, data sources used and reproducibility. The procedure implemented in the tool for the uncertainty quantification provides additional information about the confidence of the LCA results.

2. Methods

The calculations of the model are based on the primary data provided by the farmer at Farm Management Unit (FMU) level, which is the portion of land for which the data are representative. Two types of indicators are computed for FMU and growing season, carbon footprint (CF) and water footprint (WF), besides other agronomic parameters such as crop yield, gross irrigation requirements, pumping energy use efficiency and water used efficiency that are directly connected with the production costs.

The applicability of the tool is shown with four case studies: corn, nectarine, grape crops and tomato production in low-tunnel greenhouse. The obtained indicators are referred to mass of product (kg or t), although the reference flow for the compilation of the input data in the inventory questionnaire is referred to hectare and campaign. The use of this unit simplifies the work of the farmer when providing the information, because the amount of materials and energy corresponds to the spent for a hectare of land for the whole campaign assessed (a year in annual crops).

To carry out the CF and WF calculation a cradle to gate system boundary was considered. The frame includes the pre-farm processes such as the extraction of raw materials, production and transport of inputs. Within the production system (gate to gate) activities, the tool assesses the transport of the product to the closest cooperative, tillage tasks, energy consumption, irrigation, heating (protected crop), waste management, packaging and auxiliary equipment. Results of CF and WF are presented distributed in the different stages so the user can extract some valuable conclusions about the relative GHG emissions, material, energy and water consumption in the different process steps, for future environmental improvements and savings.

The software is developed in a spreadsheet format for its adaptation as a web tool with the following structure:

- Inventory questionnaire: list of necessary activity data for the compilation of all model inputs that have to be provided by the user.
- Database and default data: secondary data are provided from datasets of Ecoinvent Database (http://www.ecoinvent.org/), likewise default data for intermediate calculations are included (such as life span or material composition).
- Greenhouse module: equations for the accounting of materials involved in the greenhouse infrastructure.
- Calculation module: translates the activity data that characterize every sub-process in the system boundaries to environmental impact indicators considered.
- Uncertainty analysis module: applies an approximation method of error propagation from the activity data and emission factors uncertainties.
- Results: numerical and graphical report of the resulting values.

2.1. Inventory and scope

The system boundary was defined from raw material extraction to farm gate. Pre-farm processes (often referred to as 'cradle') such as the extraction of raw materials, production, and transport of inputs used on the farm are also included in the assessment. The production system (farm-gate) is structured in different stages: fuel, transport, energy, fertilizer, treatments, packaging, infrastructure, etc. Fuel stage includes the fuel consumption from farm tasks, and energy stage involves the pumping consumption for irrigation. The transport stage includes the production transport from farm to wholesale, the transport of materials within the farm and the transport of waste materials to a treatment plant. The fertilizer stage implies both manufacturing and consumption. In addition, four types of greenhouse structures are available: glass, multi-tunnel, "parral" or "Almeria-type" and low-tunnel. The assumptions applied for the average dimensions and the materials involved in each type can be found in Antón et al (2013), as well as the equations that relates the size and other parameters (depending of the type and subtype of greenhouse) with the amount of materials used.

2.2. Carbon footprint

The carbon footprint is a measure of the impact that human activities have on the environment in terms of the amount of GHG emitted over the full life cycle of a process or product measured in units of carbon dioxide equivalents ($CO_{2\text{-eq}}$). The CF is calculated based on the IPCC guidelines (IPCC 2006) that suggest a time horizon of 100 years for the decay rates and can be expressed as follows (Eq.1):

$$CF = EV * AD \qquad \text{Eq. 1}$$

where, *EV* is the emission vector per unit of reference for the specific activity (*e.g.* kg $CO_{2\text{-eq}}$ per kg of pesticide for the activity of pesticide manufacturing); *AD* is the activity data that expresses the intensity of the activity in the units of reference per functional unit (*e.g.* kg of pesticide$\cdot$(ha$\cdot$y)$^{-1}$).

The calculations include the N_2O induced emissions from managed soils, both direct and indirect releases. It comprises the emissions due to nitrification and denitrification processes from soils to which the nitrogen is added, volatilization of NH_3 and NO_x and subsequent redeposition, and leaching and runoff of nitrogen. Default emission factors are used for the evaluation of these three pathways based on the equations proposed in the chapter 11, volume 4 of the IPCC guidelines (IPCC 2006).

2.3. Water footprint

The water footprint indicator distinguishes the quantity of water consumed using a color code (green, blue and grey) depending on the type of water sourced and polluted. WF in a crop can be calculated using equation 2 (Hoekstra et al 2011):

$$WF = WF_{green} + WF_{blue} + WF_{grey} \qquad \text{Eq. 2}$$

where, WF_{green}, is the volume of rainwater consumed (the total rainwater evapotranspiration plus the water incorporated into the harvested crop); WF_{blue}, is the volume consumed of fresh surface or groundwater; WF_{grey}, is the volume of freshwater required to assimilate the load of pollutants based on natural background concentrations and existing ambient water quality, although this concept was left out of the scope in this study.

The mentioned water volumes can be used as translated to midpoint and endpoint impacts in assessment methods when applied to freshwater consumptive use by using the Water Stress Index (WSI) (Pfister et al 2009). The WSI can range from 0.01 to 1 and indicates the portion of consumptive water use that deprives other users of freshwater for a certain watershed, where a value of 1 means a serious water stress in a basin (0.259 for the Ebro basin). Therefore, the water footprint impact assessment for WF_{blue} and WF_{green} can be calculated as follows (Eq. 3 and 4):

$$WFIA_{blue} = WF_{blue} * WSI \qquad \text{Eq. 3}$$

$$WFIA_{green} = dGW * WSI \qquad \text{Eq. 4}$$

where $WFIA_{blue}$ and $WFIA_{green}$, are the water footprint impact assessment for the WF_{blue} and WF_{green}, respectively; *dGW* is the delta green water consumption (Nuñez et al 2012) that can be calculated as the difference between the WF_{green} and the consumed by the reference system (crop evapotranspiration) represented as ET_c.

2.4. Uncertainty analysis module

The procedure included in this module assesses the uncertainty that arise from two types of parameters: activity data and characterization factors. The approach follows the detailed guidance of the ILCD Handbook about data quality concept and approach and the data quality guidelines for Ecoinvent database v.3 (Weidema et al 2012).

Parameter uncertainty is represented by a lognormal probability distribution using the Pedigree Matrix approach that relates quality indicators to uncertainty ranges. Both basic and additional uncertainty, through variances of the underlying normal distribution, can be assigned. On the one hand, the activity data uncertainty is defined by the user/farmer following quality rules depending on the type of data estimation. However, there are available default uncertainty values according to different types of exchanges. On the other hand, basic uncertainty of the characterization factors is quantified for each LCA vector included in the inventory, as well as additional uncertainty according to five independent characteristics: reliability, completeness, temporal correlation, geographical correlation and further technological correlation.

As long as the tool needs a prompt response about the environmental performance of the scenario (i.e., for a given growing season and facility), an analytical propagation method is proposed. Particularly, Taylor series expansion method (Ciroth et al 2004) was formulated in the model to retrieve the uncertainty of the studied scenario computing the geometric standard deviation (GSD) as a function of each parameter GSD and its sensitivity associated (i.e., the influence or contribution of the impact due to a certain parameter over the total inventory impact). Therefore, the impact indicators of the crop (e.g., kg $CO_{2\text{-}eq}$ per kg of product) for a given season and field are depicted with an error bar.

3. Results & discussion

Figure 1 shows the results that the tool provides in terms of the carbon footprint impact for the production during a campaign of corn, grape and nectarine, with yields of 50800, 15300 and 47100 kg·(ha·y)$^{-1}$, respectively. The outputs are detailed for different productive processes considered in the system. Besides, error bars are included to represent the uncertainty associated with each value. From the results of the carbon footprint is possible to conclude that the contribution of fertilizer production and application to the global warming potential is the highest in grape and corn crops, while for nectarine the fuel consumption has the highest impact.

In addition, the uncertainty analysis yields the worst value for the corn production while the lowest uncertainty is obtained for the vineyard farm. These outputs are explained by the influence that the most uncertain activities have in the overall result. It is the case of the impact for transport and the use of fertilizers. In the case of transport, the uncertainty is due to the default uncertainty associated to the activity data. In the case of fertilizers the emissions factors have high uncertainty according to their data pedigree, as well as the high default uncertainty associated with the emissions of N_2O for the nitrogen application. Both activities are determinant in the corn faming because of their high contribution in the total impact.

In Figure 2 the water footprint values obtained for the three mentioned crops are displayed. The results raise higher water footprint impact assessment for corn production due to a higher value of blue water footprint considering the Ebro basin, followed by the grape and finally the nectarine production as the less water consumptive. The same trend for the green water footprint is shown, that is also higher in the case of corn farm.

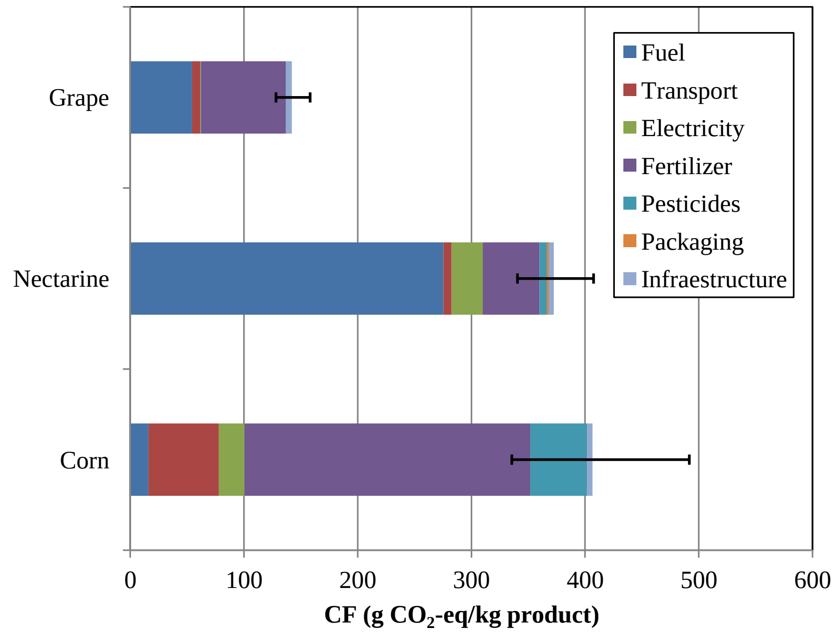

Figure 1. Carbon footprint results for each type of crop and distributed in different activities of productive process.

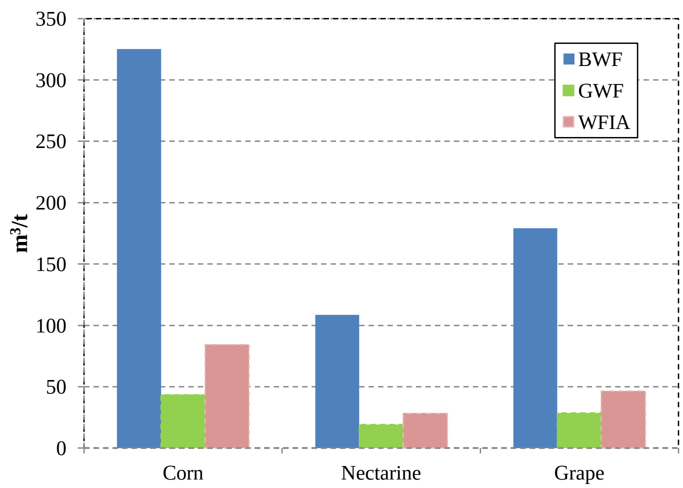

Figure 2. Blue and green water footprint (BWF and GWF) results and the total water footprint impact assessment (WFIA) for each type crop.

The production of 150000 kg·(ha·y)$^{-1}$ of tomatoes in a low-tunnel greenhouse without heating was evaluated obtaining a total carbon footprint of 293 g $CO_{2\text{-eq}}$/kg of tomatoes. The water footprint was not analysed for this time. Figure 3 shows the share of the different activities included in the inventory. The carbon footprint calculation for the tomato production in low tunnel greenhouse highlights the importance of including the infrastructure impact in the protected crops evaluation. Particularly, near a 30% of the global warming potential impact comes from the greenhouse structure followed by the fertilizers contribution. Nevertheless, the contribution of the structure would to the total impact would be reduced the 10% if the crop requires climate control systems since their impact usually become the most important.

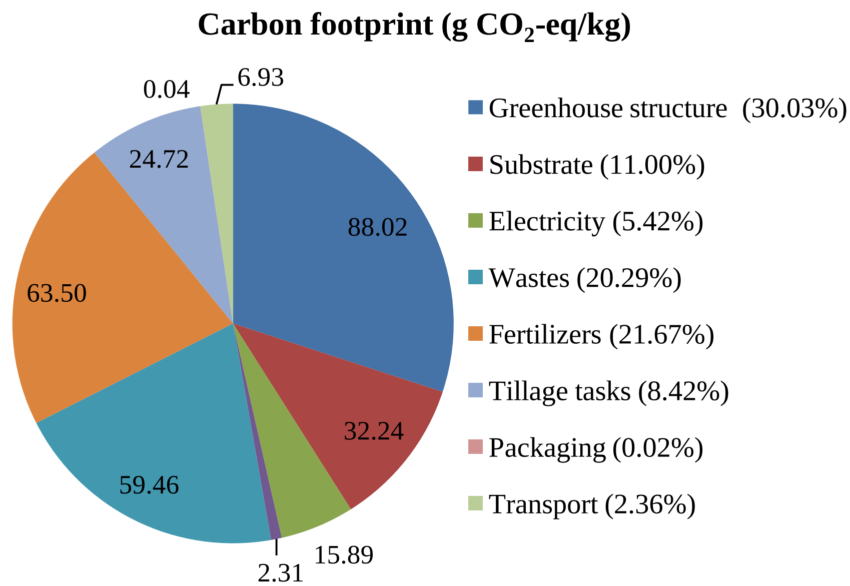

Figure 3. Carbon footprint impact for the tomato production in low tunnel.

Table 1 shows the values reported for the uncertainty analysis in the case of the corn production. The GSD of the whole inventory allows us defined 95% confidence interval for the calculated environmental indicator; particularly, the values correspond to the carbon footprint calculation. The Monte Carlo simulation was applied for the internal validation of the analytical propagation method proposed. More precisely, 5000 iterations were simulated using this method obtaining the corresponding confidence interval and the relative error indicated in the fourth column. A relative standard deviation of 24% was obtained from the uncertainty propagation procedure over the CF value obtained for corn production. The selected approximation method yields similar results to the Monte Carlo simulation with a difference lower than 5%, although the stochastic procedure tends to overestimate the impact. Nevertheless, the uncertainty outputs can be qualitatively characterized by comparing the resulting uncertainty with the intrinsic variability of the process, which is due to several factors varying with growing season and farm characteristics (e.g., crop production, weather conditions, soil conditions, etc.). Therefore, a quality rating can be derived depending on where the scenario's uncertainty is located with respect to the intrinsic variability of the system. This can be accomplished taking advantage of the potential spreading of the use of this tool, allowing us the access to primary data from different estates, crops and weather conditions.

Table 1. Results reported by the uncertainty analysis module for the carbon footprint of corn production.

	Taylor series expansion approximation	**Monte Carlo simulation**	**Error %**
Geometric mean	0.407	0.419	3.568
Geometric standard deviation	1.100	1.108	0.708
95% lower bound	0.334	0.342	2.187
95% upper bound	0.490	0.516	4.930

Some innovative aspects of the presented tool can be highlighted: the adaptation of the required data for the LCA to the reality of farms after conducting a sensitivity analysis for the identification of key inputs; the linking between the tool and quality standards for processes that are implemented at farm level, such as Nature 's Choice, GLOBALGAP or Integrated Production; and the best available technology for the data acquisition in surveillance systems to measure and calculate the actual values of the parameters needed for the evaluation and that can be also used to compute the effects of mitigation measures.

4. Conclusions

The developed tool provides a thorough inventory to assess the carbon and water footprint at farm level that is at the same time accessible and handy for the farmers to make available the reliable primary data needed. The tool is designed to support decision making, adapting the requirements of data to the reality of the farms.

The application of life cycle assessment indicators (carbon and water indices) enabled to take advantage of their benefits for suggesting environmental improvement in crop production. Through the carbon and water indices is possible to identify hotspots within the studied life cycle stages such as tillage task, energy consumption, treatment, fertilization, transport, etc. Moreover, the feedback from the users and stakeholders helps to incorporate new features and to continuously improve the tool.

The findings of this work reveal that the use of fertilizers has an important contribution in the global warming potential and hence it can be a priority in the reduction of the greenhouse gas emissions. Besides, the use of fertilizers is a source of uncertainty; therefore it is vital to have an accurate estimation of the fertilizer's contribution by means of the collection of high quality primary data about the chemical amount and composition, and the use of recognized emissions factors for the fertilizer manufacturing. The module for the calculation of the materials of the greenhouse structure is a value add-in given the widespread use of protected crops and the high impact in terms of carbon footprint of which greenhouses structures are responsible.

Additionally, the procedure for the uncertainty quantification module provides additional information about the confidence that the LCA inventory results can have. The method is intended to improve the agricultural activities management. The impact indicators accompanied by the confidence interval derived provide an important perspective when interpreting the results and when defining benchmarks for product comparison.

To achieve the indispensable participation of the farmers in the compilation of the inventory data, their cooperation is rewarded by raising awareness of the benefits that the results of the resulting reports can offer: adjusting the resources consumption (water, fertilizers, energy requirements, etc.); application of simple metrics for the diagnosis, comparison and impact evaluation of the management decisions; useful information in accordance with other quality requirements (e.g., Global GAP); and the availability of technical arguments for the product distinction in the market. Moreover, farmers use the tool based on data from their usual field notebook, in this way they can directly relate the resulting indicators, such as water or carbon footprint, to their common practice. Thus, a reduction in diesel consumption in irrigation and machinery can be evaluated simultaneously as economical and environmental savings.

Furthermore, the benefits are extended to the supply chain and stakeholders since the results allow them to evaluate different suppliers based on the mentioned metrics by product origin, thus helping in a better communication with the final consumer.

5. References

Antón A, Torrellas M, Raya A, Montero JI (2014) Modelling the amount of materials to improve inventory datasets of greenhouses infrastructures. Int J Life Cycle Ass 19:29-41

Ciroth A, Fleisher G, Steinbach J (2004) Uncertainty calculation in life cycle assessments—a combined model of simulation and approximation. Int J LCA 9:216-226

BSI British Standards, Carbon Trust and Department for Environment Food and Rural Affairs (2008) Guide to PAS 2050 How to assess the carbon footprint of goods and services. BSI, London

BSI British Standards, Carbon Trust and Department for Environment Food and Rural Affairs (2011) Specification for the assessment of the life cycle greenhouse gas emissions of goods and services. BSI, London

Hillier J, Walter C, Malin D, García-Suarez T, Mila-i-Canals L, Smith P (2011) A farm-focused calculator for emissions from crop and livestock production. Environ Modell Softw 26:1070-1078

Hoekstra, AY, Chapagain, AK, Aldaya, MM, Mekonnen, MM (2011) The water footprint assessment manual: setting the global standars. Water Footprint Network. Enschede

IPCC Intergovernmental Panel on Climate Change (2006). IPCC Guidelines for National Greenhouse Gas Inventories. Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K. Prepared by the National Greenhouse Gas Inventories Programme. IGES, Japan

ISO International Organization for Standardization (2006). ISO 14044:2006. Environmental Management – Life Cycle Assessment – Requirements and Guidelines. International Organization for Standardization: Geneva, Switzerland

ISO International Organization for Standardization (2013). ISO 14067:2013. Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification and communication. International Organization for Standardization: Geneva, Switzerland

Nuñez M, Pfister S, Antón A, Muñoz P, Hellweg S, Koehler A, Rieradevall J (2012) Assessing the environmental impact of water consumption by energy crops grown in Spain. J Ind Ecol 17:90-102

Pfister S, Koehler A, Hellweg S (2009) Assessing the environmental impacts of freshwater consumption in LCA. Environ Sci Technol 43:4098-4104

Pidd, M (1996) Five simple principles of modelling. The 1996 Winter Simulation Conference, California

Torrellas M, Antón A, Montero JI (2013). An environmental impact calculator for greenhouse production systems. J Environ Manage 118:186-195

Vermeulen SJ, Campbell BM, Ingram JS (2012) Climate Change and Food Systems. Annu Rev Environ Resour 37:195-222

Weidema BP, Bauer C, Hischier R, Mutel C, Nemecek T, Reinhard J, Vadenbo CO, Wernet G (2012) Data quality guideline for the Ecoinvent database version 3. The Ecoinvent Center, St. Gallen

Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector

LCA Food 2014

8-10 October 2014 - San Francisco

Rita Schenck and Douglas Huizenga, Editors
American Center for Life Cycle Assessment

The full proceedings document can be found here:
http://lcacenter.org/lcafood2014/proceedings/LCA_Food_2014_Proceedings.pdf

It should be cited as:

Schenck, R., Huizenga, D. (Eds.), 2014. Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014), 8-10 October 2014, San Francisco, USA. ACLCA, Vashon, WA, USA.

Questions and comments can be addressed to: staff@lcacenter.org

ISBN: 978-0-9882145-7-6