POSTER SESSION C
Primary sector and energy crops

Life cycle assessments of biodiesels: *Jatropha* versus palm oil

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ABSTRACT

Biofuels are globally under considerable pressure, caused by sky high expectations, and serious concerns on environmental and social impact. Studies are needed to assess impacts on global warming, acidification, eutrophication and land quality. Life cycle assessment (LCA) is an appropriate tool to make such assessments. In this paper we compare the LCAs of two booming tropical biofuels: (*i*) *Jatropha* biodiesel and (*ii*) an palm oil system. The environmental impacts of both *Jatropha* and palm oil biodiesels are calculated against the fossil diesel reference system. The results show that both systems reduce fossil energy use (FEU) and global warming potential (GWP) compared to their reference system. *Jatropha* shows higher reduction in FEU but lower reduction in GWP (82% and 55%) compared to its reference system than palm oil (45% and 77% respectively). However, *Jatropha*'s impact on acidification, eutrophication and ecosystem quality is higher than the impact of palm oil.

Keywords: Biofuel, LCA, land use impact, environmental impact, *Elaeis guineensis*

1. Introduction

There is a strong interest in biofuels in the public, political and scientific domain, driven mainly by the aims of reducing impact on global warming and by geopolitical issues, such as reducing dependency on (foreign) fossil fuel (Verrastro & Ladislaw, 2007). However, along with this growing interest, biofuels are increasingly criticized as well. Several reports describe economic (e.g. subsidies, protectionism), social (e.g. food security, labor conditions) and environmental risks (e.g. loss of biodiversity and natural carbon stock) (UN-Energy, 2007; FAO, 2008; Fargione et al., 2008; Michell, 2009). Concerning environmental sustainability, biofuels essentially need to meet two minimum requirements: (i) They need to be produced from renewable feedstock, and (ii) their environmental impact should be lower than their fossil fuel alternative. Evaluating biofuels against these requirements implies in-depth investigation of (i) impact on ecosystem structural and functional quality and (ii) impacts on global warming, acidification and eutrophication. The holistic approach of life cycle assessment (LCA) makes it an appropriate method to evaluate whole production processes.

In this study we compare the LCAs of two tropical biofuels: biodiesel produced from (i) oil palm (*Elaeis guineensis*) and (ii) *Jatropha curcas* L. (further referred as *Jatropha*). Oil palm is a perennial crop of the humid tropics often competing with natural valuable grounds or lands suitable for intensive food production. In this case it replaces a mixture of traditional

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agricultural land uses. The trees offer a high oil yield which is useful both as kitchen oil and for biodiesel production. Consequently, palm oil is a significant subject in the deforestation (Fargione *et al.*, 2008) and food-versus-fuel debate (Kam *et al.*, 2009). *Jatropha* is a drought tolerant shrub (Maes *et al.*, 2009) producing seeds bearing a toxic oil. As *Jatropha* is hyped for its ability to produce this toxic oil in marginal, degraded areas that are not suitable for food production or natural carbon storage, its use is mainly aimed at simultaneous wasteland reclamation and biodiesel production (Francis *et al.*, 2005) and consequently is assumed to affect neither food security nor nature conservation.

2. Material and Methods

2.1. Goal, scope and system boundary definition

The overall goal of the *Jatropha* and palm oil LCAs is to quantify the environmental impacts of the production processes of both biodiesels in order to (i) evaluate their environmental sustainability, (ii) gain insight into possible system improvement and (iii) compare the environmental performance of the two alternative biofuel sources.

The environmental impacts will be assessed per 100 km driven fueled by biodiesel, which is the Functional Unit (FU) for five impact categories: (i) Fossil energy use (MJ), (ii) Global warming potential (kg CO_2eq), (iii) Eutrophication potential (kg O_2eq), (iv) Acidification potential (kg SO_2eq), (v) Land use impact on ecosystem quality (relative [%] to the local potential natural vegetation, according Achten et al. (2009)).

The system boundaries are shown in Figure 1. Note that the palm oil system under research produces both kitchen oil (olein) and biodiesel. These system boundaries were choosen in order to avoid allocation of environmental burdens to by-products by using system boundary expansion (Jensen et al., 1997; ISO 14044, 2006)) in which the by-products are substituted by products in the reference system.

As such the reference systems produce the same functions (100 km driven on fossil diesel) and products (e.g. synthetic glycerine as a substitute of the glycerol produced during transesterification of crude oil) as the biodiesel systems under research. The system expansion is different for the *Jatropha* reference and palm oil reference. The *Jatropha* reference substitutes for glycerine only, while the palm oil reference substitutes for the kitchen oil (olein), palm kernel meal and palm kernel oil. These by-products are completely or partly substituted by production of crude palm oil. These substitution reflect the local reality. These references allow us to quantify reductions or increases of environmental impacts by changing from the fossil based system to the bio-based system.

2.2. Inventory

In the inventory analysis all inputs and outputs of the production system under study have been quantified. The data necessary for the inventory was obtained through: (i) First hand factory and plantation data (*Jatropha* cultivation on wasteland in Allahabad, India; palm oil cultivation on former agricultural land at 3 locations in Cameroon); (ii) Interviews with farmers and plantation and factory experts; (iii) Literature data (including models).

2.3. Impact assessment

For the impact assessment of fossil energy use (MJ), Global warming potential (kg CO_2eq), Eutrophication potential (kg O_2eq) and Acidification potential (kg SO_2eq) the methodologies as described in the ISO standards (Jensen *et al.*, 1997; ISO 14044, 2006)) were followed. The land use impact was based on the methodology described by Achten *et al.* (2009).

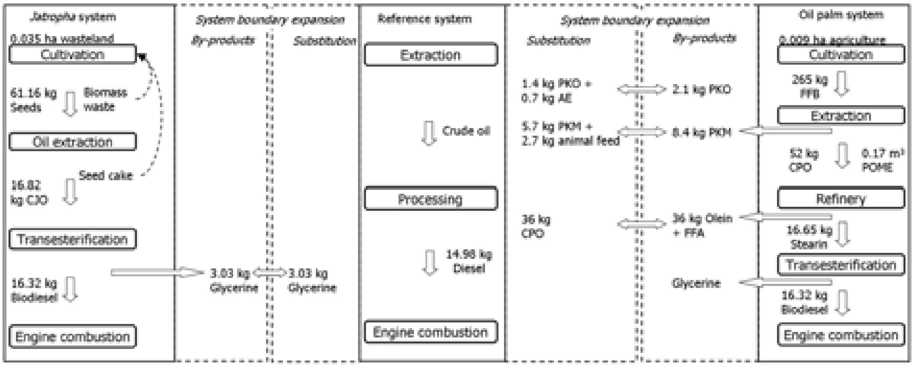

Figure 1: System boundaries and system boundary expansion of the *Jatropha* and palm oil biodiesel system. Intermediate products, by-products and end products are quantified per functional unit. (CJO: crude *Jatropha* oil; PKO: palm kernel oil; AE: alcohol ethoxylates; PKM: palm kernel meal; CPO: crude palm oil; FFA: free fatty acids; FFB: fresh fruit bunches; POME: palm oil mill effluent)

3. Results & Discussion

3.1. Fossil energy use

For one functional unit, *Jatropha* requires on average 141.63 (±6.73) MJ fossil energy; in the palm oil system this requirement is 601.0 (±30.6) MJ. Compared to the reference system this is a reduction of respectively 82% and 45% (Figure 2a). In the *Jatropha* system the transesterification (48.9%) and the oil extraction (39.1%) steps are the biggest contributors to the energy requirement, while the biggest contributor in the palm oil system is the cultivation (44.3%).

These results show that *Jatropha* triggers a higher reduction in energy use than palm oil. Besides the absence of the refinery step in the *Jatropha* system, this can be explained by the nature of the *Jatropha* system present in Allahabad, India. This is a low-input, small-scale system, using inorganic fertilizer only during plantation establishment. This is also apparent in the small contribution of the cultivation phase to the fossil energy use impact (Figure 2a). The palm oil cultivation in Cameroon is more intensive than the *Jatropha* cultivation in Allahabad.

3.2. Global warming potential

The *Jatropha* biodiesel case showed an emission of 78.9 (± 22.8) kg CO_2-eq FU^{-1}, which is a 55% reduction in GWP compared to the reference system. The palm oil system emitted 37.9 (± 6.0) kg CO_2-eq FU^{-1}, representing a 77% reduction compared to the reference system (Figure 2b). In both systems the cultivation step, particularly the N_2O field emissions, is the biggest source of emissions in the production and use of the biodiesels (*Jatropha*: 86%, palm oil: 66%).

Palm oil clearly has a higher global warming reduction potential than *Jatropha* and the difference lies in the cultivation phase (Figure 2b). This is due to the higher productivity per ha of oil palm and the better agronomic knowledge of its cultivation. In the palm oil system nitrogen application is optimized by monitoring the nitrogen content in the leaves. This is a much more efficient way of applying nitrogen then bringing back the available seed cake to the *Jatropha* fields, both in terms of nitrogen availability as in terms of field emissions. This would indicate a strong potential to improve the *Jatropha* system performance by optimizing the fertilizer application, and, by extension, by increasing the agronomic knowledge of *Jatropha*.

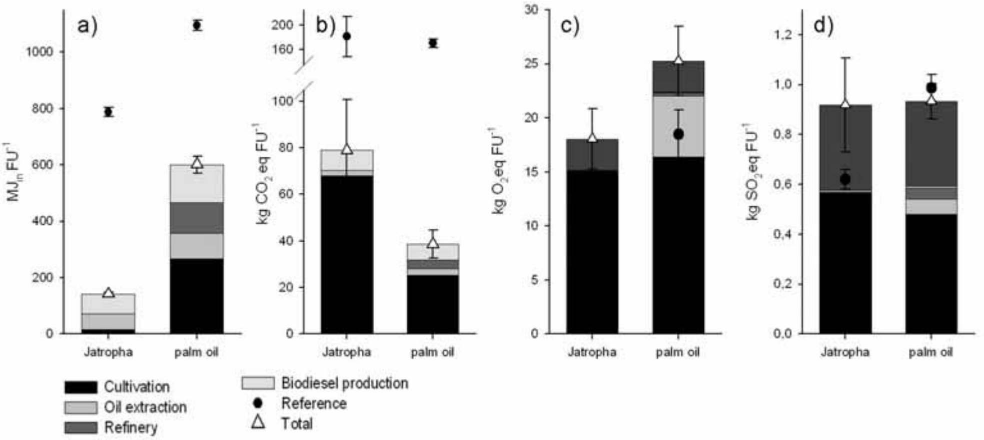

Figure 2: Impacts on a) fossil energy use, b) global warming potential, c) eutrophication potential and d) acidification potential. Stacks indicate the contribution of the different production phases, error bars show standard deviation.

3.3. Eutrophication potential

The eutrophication potential of the *Jatropha* system is 430% higher than the eutrophication potential of the reference system (Figure 2c). 84% of the total eutrophication potential of the *Jatropha* biodiesel systems is caused during the cultivation phase. Within this phase, nitrogen leaching is the most important contributor to the eutrophication potential (75%). The palm oil system shows a 39% increase in eutrophication potential, 65% of which occurs during the cultivation phase. Nitrogen leaching represents 74% of that contribution.

In absolute figures the palm oil system has a higher impact than the *Jatropha* system; however, relative to the reference system, the palm oil scores much better. The main reason for the palm oil scoring worse in absolute terms than *Jatropha* is related to waste management. At the Cameroon sites, mill effluent is dumped directly into a river. If the waste water were treated, the absolute impact would be similar to that of *Jatropha* (Figure 2c). The main reason for the palm oil scoring much better in relative terms is because the reference system in the palm oil case study has a high impact compared to the reference of the *Jatropha* system. The palm oil reference is high because it also contains palm oil cultivation to substitute for the kitchen oil (olein) (system boundary expansion: Figure 1).

3.4. Acidification potential

The *Jatropha* system showed an increase in acidification potential of 49% compared to the reference system (Figure 2d). Palm oil system does not have significantly greater impact than the reference system; rather, the results show an average reduction of 5.4% compared to the reference. In both systems, the cultivation step creates the most impact (*Jatropha*: 91%; palm oil: 51%).

Although the absolute impact of the palm oil system is similar to that of the *Jatropha* system, it again scores better relative to its reference than *Jatropha*. This can be explained by the system boundary expansion method which causes a higher acidification impact of the reference system of the palm oil case study than of the *Jatropha* case reference.

3.5. Land use impact on ecosystem quality

Changing wasteland to *Jatropha* triggers an improvement of the Ecosystem Structural Quality (ESQ) (impact of -14.6 ± 9.3%) but a reduction in Ecosystem Functional Quality (EFQ) (impact of 24.0 ± 8.9%) (Figure 3a). This means that the *Jatropha* plantation has a higher storage capacity in terms of biomass, structure and biodiversity than the wasteland, but that it has less control over water, material and nutrient fluxes (see Dewulf *et al.* (2008) and Achten et al. (2009)). The land occupation impact of *Jatropha* block plantations shows an ESQ reduction of 55.4 ± 9.4% and an EFQ reduction of 66.1 ± 11.4% compared to the potential natural vegetation. These land use impacts apply to 350 m^2 y^{-1} FU^{-1}.

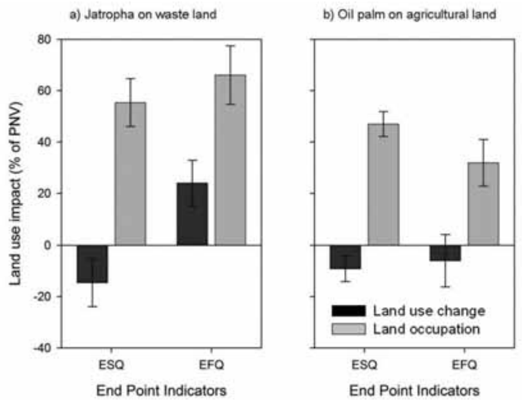

Figure 3: End point indicator scores on Ecosystem Structural Quality (ESQ) and Ecosystem Functional Quality (EFQ) for land use change and land use occupation of a) *Jatropha* cultivation in former waste land and b) oil palm cultivation in former agricultural land. Error bars show standard deviation.

The land use change impact from the mix of traditional agricultural land use to oil palm triggers an improvement of both the ESQ and the EFQ (impact scores: ESQ = -9.2±5.0% and EFQ = -6.0±10.2% relative to the local potential natural vegetation (PNV) (Figure 3b). Land occupation by oil palm plantations results in a reduction of 47.0±4.8% of the potential ESQ while the potential EFQ is reduced by 31.9±9.0%. These reductions apply to 92m^2 y^{-1} FU^{-1}.

The better performance, both for land use change and land occupation impact on ESQ and EFQ, of oil palm is mainly linked to the biomass production. Oil palm produces more biomass in trunk, leaves and fruit than *Jatropha*. In the difference between land use change impacts there is an additional effect of the reference land use. In case of *Jatropha* this is wasteland, hosting almost no human intervention, while for oil palm this is agricultural land, another human dominated land use type. Compared to this agricultural land, the oil palm is an overall improvement, but for *Jatropha* only the ESQ is improved by converting the wasteland. The EFQ is lowered, mainly due to reduced infiltration rate compared to the wasteland.

4. Conclusions

At current practice these results show that palm oil biodiesel has a better environmental performance than *Jatropha* biodiesel. However, attention should be paid to socio-economic performance as well. In the cases discussed here, *Jatropha* is planted in wasteland, while oil palm is planted in agricultural land, which causes direct land conflicts with food production. Further it should be noted that the full potential of *Jatropha* is yet to be explored. Therefore *Jatropha* still hosts potential progression in terms of environmental performance.

The comparison between *Jatropha* and palm oil can be made based on these LCA results since they are site-independent. However, it must be made clear that *Jatropha* and oil palm have distinct land and climate requirements. Therefore this exercise is a comparison of the environmental performance of two similar systems each implementable within their geographic and climatic niche.

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LCA evaluation of 3 organic crop rotations

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ABSTRACT

Agricultural production systems may have a wide range of environmental impacts that can be evaluated using the life cycle assessment (LCA) methodology (Consoli *et al.,* 1993). The aim of this work was to evaluate the environmental impacts of 3 crop rotations (2005-2008) differing only for the presence/absence of cover crops.. Crops included in the LCA calculation were: the cover crops, oat–vetch–pea, rye–vetch and forage sorghum; the crops, soybean, maize and einkorn. As expected, the crop rotations lacking of cover crops presented a reduction in the consumption of fossil fuels dued to a decrease in the number of tillages. Despite the decrease of greenhouse gases emission of the two cover crops was higher than the rotation including bare soil. These results were partially in contrast with what reported by different authors on the positive effects of organic farming.

Keywords: organic matter, cover crops, organic farming, crop rotations, LCA.

1. Introduction

The life cycle assessment (LCA) method was the first developed to assess the environmental impacts of industrial processes. In term of impact on the environment, agricultural and industrial processes differ in some important aspect: (1) agriculture is very intensive in term of land use; (2) agricultural production relies heavily on natural resources; (3) agricultural production is dependent on soil type, water availability, presence or absence of weeds, insect pests and pathogens; (4) there is a strong seasonality of agricultural production, which depends on temperature and water availability (Nemecek and Kägi, 2007). On the other hand, when dealing with cropping systems evaluations, frequently the focus is given on individual effects such as nitrate leaching or ammonia volatilization (Bach and Becker, 1995) although agricultural production systems may have a wide range of environmental impacts (e.g. climate change, acidification, eutrophication etc.). The analysis of individual effects does not permit an overall evaluation while. LCA appears to be suitable to define all environmental impacts connected to the entire agricultural system (Consoli *et al.*, 1993); in the case of cropping systems this may include not only on-field activities but also all impacts related to the production of farm inputs, such as emissions and resource consumption due to the production and transport of fertilizers, pesticides, seeds and so on.

The transformation of a farming system from conventional conduction to organic generally determines a decrease of agricultural inputs (Haas *et al.*, 2001) but very often includes the introduction of cover crops. In the last two decades, many authors have recognized cover crops environmental importance, as potential scavenger of the soil mineral nitrogen left by the preceding crops or released from the ongoing decay of soil organic matter (Martinez and Guiraud, 1990; Thorup-Kristensen, 1994). Cover crops can also reduce the loss of nitrogen from autumn-applied manure and in general the nitrogen loss determined by weather conditions (Fielder and Peel, 1992), but these crops have to be cultivated increasing thus the impact on different compartments.

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The aim of this work is to investigate the environmental impacts of different cover crops inserted in different crop rotations. We utilized LCA for analyzing the different cover crops as it appeared to be a suitable tool for comparing similar products and to allow the identification of possible improvements of products and processes during their whole life cycle.

2. Methods

According to ISO 14040 (ISO, 1997) LCA was divided into four steps: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation.

The environmental analysis was made using the software program SimaPro 7.2 (Pré Consultant).

2.1. Goal and scope definition

Our goal was to compare the environmental impacts of different organic rotation systems.

In this study the results from a field trial held in the Experimental Farm of Padova University (Project financed by: Progetto FISR - SIMBIO-VEG) were used. Three croppins systems were compared from November 2005 through October 2008. Crops included in the LCA calculation were:

- Cover crops: oat-vetch-pea (OVP), rye–vetch (RV) and forage sorghum (FS), in comparison with bare soil (BS);
- Crops: soybean (SO), maize (MA) and einkorn wheat (EK).

The three crop rotations under control differed only for presence/absence of cover crops not for the crop sequence, allowing thus to focus on the effect of cover crops (in A and B) compared to bare soil (C) within the same rotation (Table1).

Table 1: Crop rotations under investigation in the organic field trial.

A = EK – FS – OVP – SO – OVP – MA
B = EK – FS – RV – SO – RV – MA
C = EK – BS – SO – BS – MA

The crop rotations were replicated three times.

2.2. System boundary and allocation

The temporal system boundaries of a plant product were fixed as follow: for maize, soybeans, einkorn wheat, the inventory started after the harvest of a preceding crop and ended with the harvest of the crop itself; for cover crops there was no harvest so the end was set to the day of mowing and chopping the crop.

The system boundary includeed all activities on the field during the whole crop rotation period; in addition the production of all agricultural inputs were taken into account: use of machines, including their production, transport, maintenance and the buildings required for shelter; fuels (diesel); production and transport of organic fertilizers (poultry manure); production of seeds; application of poultry manure in the field, and so on.

The production and storage of manure (use in this field experiment) was allocated to animal production and so not included in this inventory. Fertilisers and emissions (during fallow periods) were fully allocated to the crop to which they were applied. The einkorn wheat, soybean and maize residues were left on the field and incorporated into the soil.

2.3. Functional units

The functional unit (ISO, 1997) chosen for this work was one hectare during the whole period of the crop rotation (3 years).

2.4. Life cycle inventory (LCI) analysis

The inventory analysis compiled all resources that were needed for and all emissions that were released by the specific system under investigation and related them to the defined functional unit (ISO, 1997).

The calculation of soil atmospheric CO_2 storage was carried out by estimating carbon content in the residues of maize, soybeans and einkorn wheat, and in the total biomass for cover crops. The CO_2 fixation and sequestration was calculated only for cover crops and added as “carbon dioxide” in “emission to the air” category with negative value. The value was determined as proposed by Yang *et al*. (2004).

Land transformation during fallow periods were not allocated to a single crop, but included in the LCA for the whole crop rotation (Nemecek *et al*., 2007).

2.5. Life cycle impact assessment (LCIA)

The data represents the values accumulated since the start of field trial (September 2005) until autumn of 2008. As we worked on 3-year crop rotations we summed the values obtained from each rotation.

The results referred to the impact categories proposed by SETAC (Consoli *et al.*, 1993) and calculated with Eco-indicator 99 H/A.

3. Results and discussion

The fossil fuel consumption tends to increase with the augment of the amount of green manure (cover crops) incorporated into the soil (Figure 1); this does not led to a relevant increase in the climate change molecules emissions because we introduced in the calculation the amount of organic matter not degraded in the soils. In figure 1 it is possible to observe only a tendency in the increase in Climate Change impact; in fact two opposite effects act at the same time: from one side, the incorporation of higher amounts of organic matter induces an increase of CO_2 stored into the soils, from the other, each crop requires a certain number of tillage which are responsible of an increase in GHG emissions. The increase in green manure is associated with the presence of cover crops (rotations A and B).

The increase of the amount of green manure incorporated into the soil leads to an increase in the Land Use impact (figure 2). This result is in a contrast with what reported in the literature. In fact, the point laying on the negative part of the figure 2 corresponds to the rotation C in which there was no cover crops. This is consistent with the fact that the cover crops occupy the soil for a long period but it is in contrast with the increase in biodiversity in the organic farming systems reported by Mader *et al*. (2002).

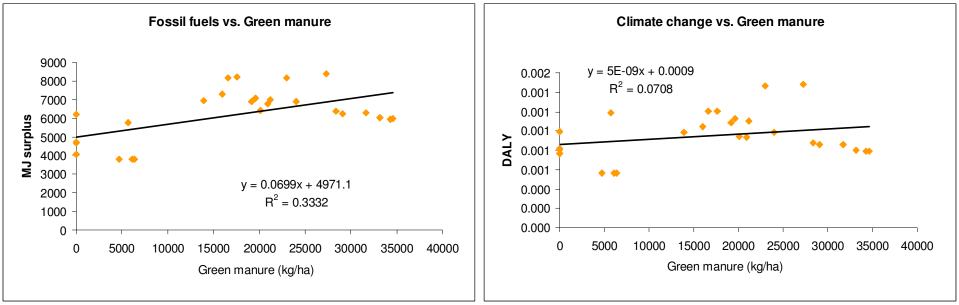

Figure 1: Fossil fuel consumption and climate change impact as a function of the quantity of green manure incorporated in the soils in the three years crop rotations.

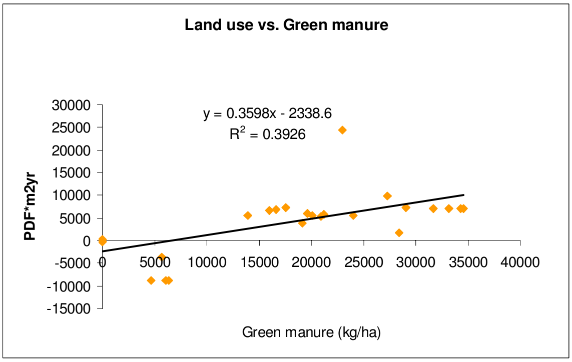

Figure 2: Land use impact as a function of the quantity of green manure incorporated in the soils in the three years crop rotations.

As previously observed the crop rotation including the cover crops (A and B) show a higher impact (figure 3) in the consumption of fossil fuels and, as a consequence, in the emission of Climate Change substances. This increase is only partially mitigated by the accumulation of organic matter incorporated into the soil and only partially degraded.

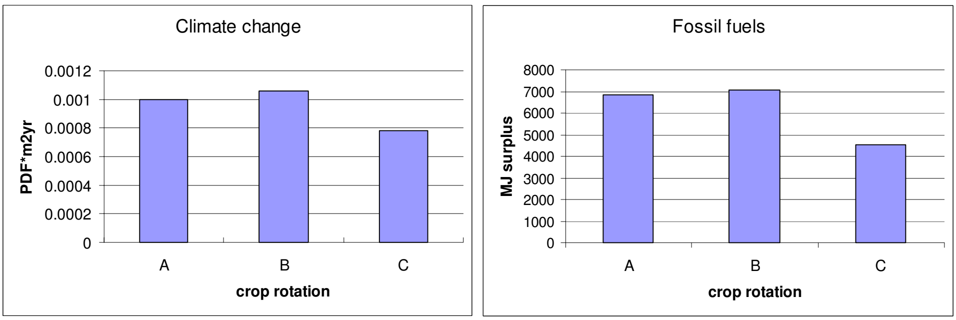

Figure 3: Fossil fuel consumption and climate change impact as a function of crop rotation (sum of the three years crop rotations).

There were very little differences in the results of Land Use impact category (figure 4) between the crop rotations including cover crops (A and B), but the rotations including fallow resulted negative. This result is not consistent with the consideration made by Mader *et al*. (2002). At present in the algorithms for the calculation of the impacts (Eco-indicator 99

H/A) there no possibility for estimating the percentage of the organic matter not degraded into the soil if some conservative agricultural techniques are used.

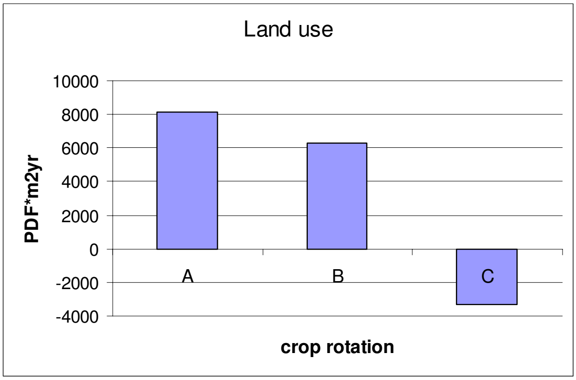

Figure 4: Land use impact as a function of the quantity of crop rotation (sum of the three years crop rotations).

Even tough land use keeps into account the modification in biodiversity the calculation used does not take into account the positive effects of cover crops on the micro and macro organisms which leads to an increase in biodiversity (Mader *et al.*, 2002).

Crop rotations including bare soils seem to be less impacting if compared with rotation including cover crops. There are large evidences for organic farming role on the environment and this is widely supported by a great number of researches (Mader *et al.*, 2002). The Intergovernmental Panel on Climate Change (IPCC) has suggested a range of measures for mitigating greenhouse gas emissions from agricultural ecosystems (Smith *et al.*, 2007) among which organic farming is one of the most promising tool.

4. Conclusions

LCA applications on the agricultural sectors are recent and so evaluations could lead to some inaccuracies. Furthermore not many studies have been made on LCIA for the agricultural sector and some adaptation or revision on the procedures should be implemented.

Some inaccuracies appear to be in the land use evaluation. The effect on soil organic matter conservation and accumulation as a function of soil tillage is widely known but this is actually not included in LCA. Furthermore when large amounts of crop residues are incorporated into the soil there is an increase in soil organic matter. These two aspects should be taken into account when dealing with crop evaluation. An approach utilizable for this purpose could be what proposed by Bona *et al.* (2009). The authors estimate the soil organic matter variations as a function of the cumulative soil tillage depth (the large the value the greater the degradation) and the amount of crop resides incorporated into the soils. This could be easily integrated in the LCIA.

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Life Cycle Assessment of the tomato production

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ABSTRACT

The LCA methodology had been used to identify the environmental burdens associated to the production and processing of tomato purée, the end of life were excluded from the analysis. The functional unit was represented by 100 kg of harvested tomato. Primary and secondary data were be considered; energy and material consumptions referring to the processes were be collected, also the emission in air soil and water were be quantified. The PE and Ecoinvent databases were used for the data referring to the production of energy and materials. The CML 2001 impact assessment method was used to analyse the environmental impact of the input and output measured during the inventory phase. The results of LCA allowed to identify the "hot-spots" of the chain of tomato products. The analysis of the input and output materials and energy flows has enabled us to propose a hypothesis for reducing the impact of this products on the environment.

Keywords: Life cycle assessment, Simplified LCA, Tomato products, Environmental effects, Agro-food.

1. Materials and methods

1.1 Goal and scope definition

LCA methodology was applied to the life cycle of tomato purée as regulated by ISO 14040:2006 and ISO 14044:2006 standards (ISO, 2006a; ISO, 2006b). Both the agricultural phase and the industrial phase were studied, the latter only consisting of processing of the raw material, because the packaging and the end life were excluded from the system boundaries. Figure 1 shows the input and output flows of energy and materials, with the functional unit represented by 100 kg of harvested tomato grown in open field. Figure 1 shows the layout and system boundaries.

1.2 Life cycle inventory (LCI)

<u>Agricultural phase</u> The production phase of the raw material includes all the agronomic practices connected to managing and irrigating tomato crops, with the exception of the data referred to the plants and some pesticides. The missing of these data was determined by the difficulty in order to founding valid information (e. g. data about the effect into the environment of the molecules of an active ingredient of a pesticide). The agronomic practises considered were been distinguished in soil cultivation, irrigation, application of fertilizers and plant protection products (from now on indicated as "PPP"). The crop is presumed to be in the southern Italy, and so the characteristics of the soil, the climatic conditions and the choice of fertilizers and PPP all refer to this area (www.inea.it; www.sian.it; Antòn *et al.,* 2004; Brentrup *et al.*, 2000; Crutzen *et al.,* 2008). The transport to the industry was also considered.

<u>Industrial phase</u> As for the industrial phase, all the steps necessary to process the fresh matter in order to obtain tomato purée were analysed. After the reception, the fresh product is washed and selected, a phase of grinding and hot break follows the calibration. After the

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tomato past is filtered and evaporated. The concentration phase allow to obtain the tomato purée that must be sterilised and packaged in tins.

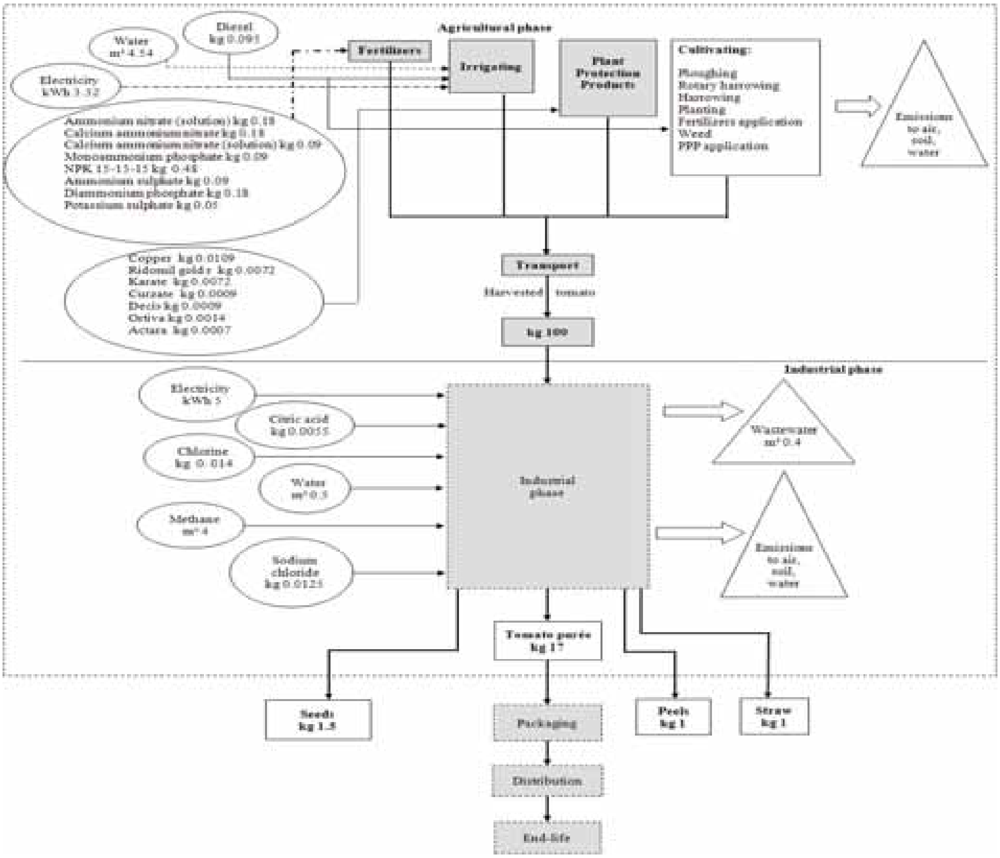


Figure 1: Layout referred to 100 kg of harvested tomato

1.3 Data quality

The inventory data was collected from various sources. The information relating to the agricultural phase was received directly from people working in the sector. It was thus possible to estimate the consumption of fuel (for the agronomic practices) and electricity. As far as electricity production is concerned, the Italian mix was the type considered (www.aeeg.it). Emissions to water, air and soil deriving from the agricultural phase were calculated using the models available in the literature; emissions linked to the use of fertilisers were estimated, for the N-fertilisers, the percentage of NH_3, NO, N_2O in air and Norg, NH_4+, NO_3- leaching in the water derives from specific study about N-uptake and leaching in tomato crops cultivated in the geographical context (Rinaldi *et al.,* 2005); the N_2O emissions from the agricultural soil were also considered. As for the PPP, the MacKay model (Mackay *et al.,* 1997) and the Hauschild dispersion model (Hauschild, 2000) were used to assess the environmental distribution of the molecules of the active ingredients referred to the pesticides. Ecoinvent databases were also used, as a means of assessing the impact of fertilizer and pesticide-production (Frischknecht *et al*., 2004), but not all the PPP was considered, because of the missing of valid data, specially as for the neonicotinoids.

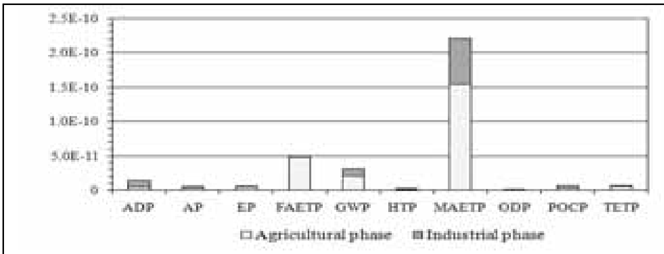
The data concerning the technological processing was collected among processing companies; from these firms it was possible to detect the right quantities of all the inputs considered in the system as defined in the figure 1 and relatives emissions in air, soil and water. As for the quality of data considered in the system boundaries, over 40% of the data derive from literature, the data calculated are almost 20%, estimated data are little over 10%, measured data are almost 5%, for the remainder there are no statement. All collected data was processed using GaBi4 software (IKP and PE, 2002).

2. Results and discussion

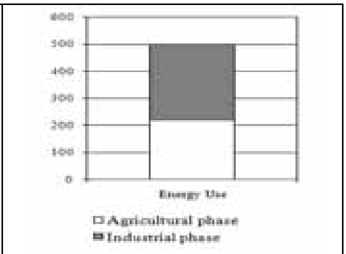
2.1 LCIA (Life Cycle Impact Assessment)

The CML 2001 impact assessment method update on December 2007 was used to analyse the environmental impact of the input and output measured during the inventory phase. Figure 2 shows the normalized results distinguishing between the agricultural and industrial phase, also the energy consumption was analysed (category "energy use"). As shown in figure 2, the agricultural phase is more pollutant than the processing phase and among the various category the most important are these referred to the toxicity and the global warming. As for the GWP (figure 3), the ploughing, the electricity (needed to irrigating and spraying pesticides) and PPP and fertilizers emissions are the most important "hot spots" of the agricultural phase, carbon dioxide and nitrous oxides are the principal substances emitted in air during this phase. As far as the industrial phase, the sub-phase that mainly contribute to the GWP is the electricity supply followed by the methane supply. The total quantity of CO_2-equiv. referred to the functional unit is almost 14.5 kg (10 kg affected by the agricultural phase and 4.5 kg deriving from the processing phase) (Assumpcio *et al.,* 2005). By analyzing the toxicity categories (figure 4 and 5), as for the agricultural phase the FAETP is mainly affected by the use of fertilizers, but also the emissions of PPP and electricity needed to the irrigation contribute to the total impact. MAETP instead results more affected by the use of PPP and then by the contribution of the electricity, while the fertilizers impact is lower. The impact of MAETP derive from the hydrogen fluoride emitted in air and the great quantity of copper released in agricultural soil. By analyzing the industrial phase, figure 4 and 5 show that the sub-phases that mainly involve impacts are evermore the supply of electricity and methane, but also the supply of tap water increase the total contribution.

Finally, figure 6 and 7 show, distinguishing for the sub-phases of the agricultural and industrial process, the MJ of energy referred to the functional unit. Over of the 50% of the total energy consumption is linked to the industrial phase, and in particular for the electricity and methane supply. The energy use (EU) referred to the agricultural phase in mainly affected by the PPP, irrigation and fertilizers. (Chapagain *et al.,* 2009)

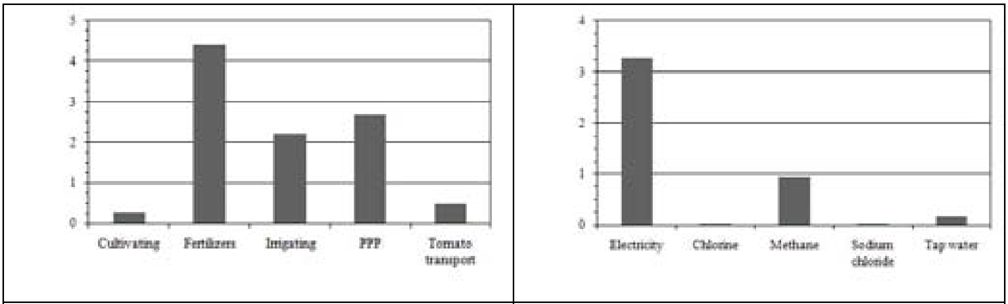


Results normalized



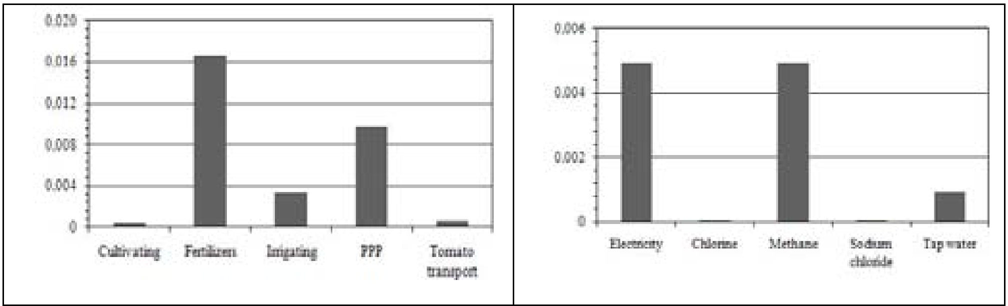
MJ/100 kg of harvested tomato

Figure 2: Impacts of the tomato purée distinguished between agricultural and industrial phase



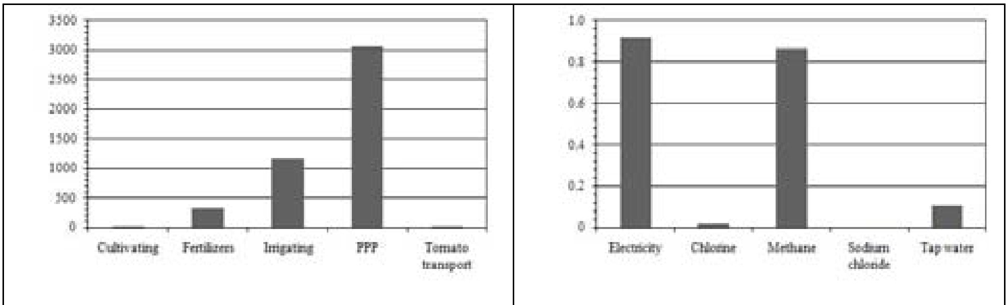
Agricultural phase	Industrial phase

Figure 3: Global Warming Potential (GWP) (kg CO_2-Equiv.)



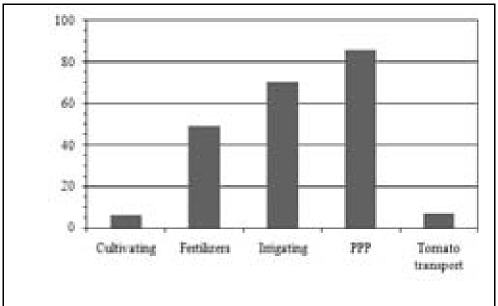
Agricultural phase	Industrial phase

Figure 4: Freshwater Aquatic Eco-Toxicity Potential (FAETP) (kg DCB-Equiv.)



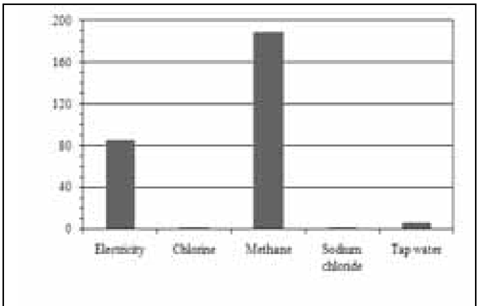
Agricultural phase	Industrial phase

Figure 5: Marine Aquatic Eco-Toxicity Potential (MAETP) (kg DCB-Equiv.)



Agricultural phase

Figure 6: Energy Use (EU) (MJ)



Industrial phase

Figure 7: Energy Use (EU) (MJ)

2.2 Life cycle interpretation

The system analysed, includes some data with a percentage of uncertainty, specially as regards data referred to the agronomic aspects (e. g. quantity and dispersion of fertilizers and PPP). By the GaBi 4 software a Monte Carlo analysis was carried out, hypothesizing a standard deviation of ±10% of the uncertain data, in order to calculate the variability of the results for the most important impact categories: GWP, FAETP and MAETP. Figure 8 shows the Gaussian distribution of the clusters deriving from the simulation. As far as the toxicity, a new model called “USEtox” was performed in order to assess the Human Toxicity and Freshwater Ecotoxicity (Ralph K. Rosenbaum *et al.,* 2008). A comparison between this model and that performed by CML 2001 (updated at December 2007), could be useful in a methodological point of view, in order to highlight the differences and understand if some improvements could be applied in this food LCA.

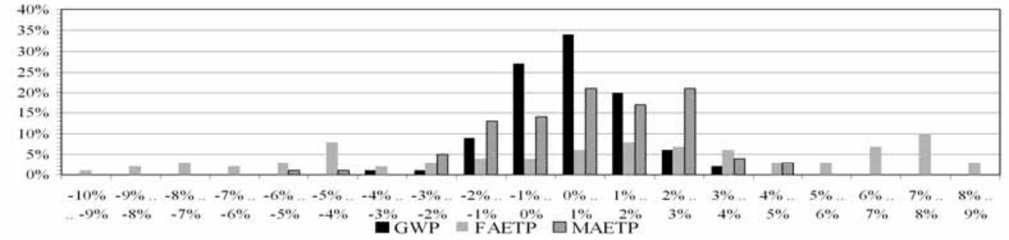


Figure 8: Monte Carlo Analysis

3. Conclusions

The analysis presented has highlighted the “hot spots” of the life cycle of tomato processed as tomato purée. Although some of the data considered in the Inventory analysis (LCI) may have a degree of uncertainty, this study has painted a picture of the environmental performance that stems from the production of tomatoes and the processing system of tomato purée. Results show that the most important environmental problem derive from the agricultural phase, and in particular from the great use of fertilizers (organic and mineral) and pesticides, also the great volume of water used for irrigating and spraying PPP contribute to increase the total environmental impact due to the electricity needed to pump water from the artesian well to accumulation tank and after from this former to the field. The electricity supply is also resulted, with the methane supply, the most serious problem arising from the industrial phase. Some solutions could be proposed for improving the agricultural and industrial phases, in order to optimize the use of material and energy resources and reducing the waste and the emissions. As far as the agricultural phase, it needs to consider that the tomato is a crop cultivated in a short period of time (about three months) so the efforts to reduce the environmental impact affected by the use of fertilizers and pesticides should be concentrate on the improving of the soil quality with a correct plan of crop rotation in order to exploiting the agronomic advantages of the previous crop, optimizing the agricultural practices and educing fertilizers and pesticides use. As for the water use, in the geographic context in which the LCA was carried out, the quantity per hectare of water employed is about 600 – 800 mm, so the optimization of the use of electricity for irrigating, should be a fundamental objective, especially in this areas characterized by long periods of drought. Here, almost all farmers, who cultivate tomatoes, use efficient irrigation techniques, such as localized system with micro-droppers, so the only environmental improvement should concern the minimizing of the impacts deriving from energy production. This objective could be achieved by, e.g., installing renewable energy sources at the farm in order to use the electricity directly for these uses. The same solution could be adopted in order to improve the environmental performance of industrial phase. The processing factories could use also process waste and wastewater to produce biogas (by anaerobic digestion) and so reducing the costs of wastewater treatment and methane supply. In most cases, the adoption of these solutions, made with regard to achieving the objectives of eco-compatibility, leads to advantages, which are not only environmental, but also economic (i.e. lower costs).

Contribution of authors: *This paper has been thought, discussed and written by the three authors and it is the result of their common commitment in particular C. Russo contributed to data collection and classification, and bibliographical research, G.M. Cappelletti contributed to elaboration and comment on data, G.M. Nicoletti contributed to planning and final review of research.*

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Product Categories Rules for flowers production

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ABSTRACT

Floriculture is one of the productive activities that can get more benefit by using techniques that respects the ecological equilibrium. It is necessary to establish Product Categories Rules (PCR) in order to provide the information for the creation of an Environmental Product Declaration (EPD) on flower production. The PCR specifies requirements for LCA study, system boundaries, data quality requirements, the format and content of EPD itself, in order to guarantee the correct comparison of the EPDs of products belonging to the same category. Product Category Rules for "cut flowers" and "flower in vase" have been developed by studying flower producers of the Distretto of Terlizzi (Bari). The obtained results give a tool to reduce environmental impact of flower production and generally of all greenhouse cultivation, through an integrated approach during all the phases of the life cycle of flowers: production, distribution, use and treatment at the end of life.

Keywords: Flowers production, EPD, Product category rules, LCA

1. Introduction

Floriculture in Italy has a complex productive structure: this sector is represented by different productive segments, each one with a consisting economic relevance.

There are more than 22.000 flower farms in Italy, on a surface of approximately 13.000 ha. More than 60% of the farms have tunnels, greenhouses tunnels and greenhouses, covered with plastic films and glass, equipped with irrigation systems, fertirrigation and microclimate conditioning systems.

In greenhouse cultivations (both cultivation of cut flowers and flower in vase), the irrigation is essential. The amount of water distributed to the cultivations is often more than the effective necessities of the plants and this surplus causes waste of water and pollution of the ground and of the ground water by pesticides and fertilizers, transported by drainage waters (Lomoro et al, 2006).

Benefits due to the use of techniques that respects ecological equilibrium are many: fewer costs, more attractive products for market, possible use of public financings and support, less use of chemicals and reduction of environmental impacts. But, in order to permit the accomplishment of these results, the use of green production criteria in a flower production company has to be certified and guaranteed through a specific label.

In the ambit of the IPP the Environmental Product Declaration (EPD), according to ISO 14025 standard, is an innovative voluntary tool, able to realistically communicate the impact of a product/service, favouring its social acceptance.

Main EPD elements are:

- Objective, due to the requirement to use internationally-accepted methods for life cycle assessment (LCA) in order to identify environmental performance;
- Comparable, through establishing product-specific requirements (PCR= Product Category Rules) that define the environmental performance to be communicated in

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order to allow the comparison between several products belonging to the same category;
- Credible, thanks to the inspection, review and follow-up by an independent verifier.

The release procedure of the EPD according to ISO 14025 requires at the beginning the definition and approval of the Product Category (PCRs), which define the specific rules, requirements and guide lines in order to develop the EPD of one or more product categories.

Product Category Rules for "cut flowers" and "flower in vase" have been developed. PCRs of flowers has been drafted according to ISO 14025 standards, by studying flower producers of the Distretto of Terlizzi (Bari) during a Life/Env Project, through the life cycle analysis of the flower and the Environmental Review of the productive sites (LIFE04 ENV/IT/000480).

2. LCA study of flower farms

Flower production in the district of Terlizzi has fairly widely differing methods of organisation of production, even among farms producing the same kind of flowers. The survey analysed both glasshouse production on agricultural soil and using hydroponics. None of these farms uses closed cycle production (with complete recycling of the drained nutrient solution) but a semi-closed system is adopted.

Collected data have been gathered in the inventory and than into software, specific for environmental evaluation, to make the LCA calculations.

The study was used to create a database of LCA inventories for flower production to be used with simplified software for lifecycle analyses, allowing to identify environmentally-friendly production strategies.

The functional unit to which we refer the main flows of materials and energy was established as 100 cut stems for rose cultivation and 6 pots for cyclamens, with their relative packaging.

The boundaries adopted in the study include:
- The building of the production structures including the covering materials and the systems used in the growing and preserving phases (Audsley et al., 1997); The creation of the materials that make up the structures (concrete, steel, plastics) and their transport have been included in the system boundaries;
- The production of young plants in the farm and their packing and transport;
- The flower cultivation phase including the production and transport of substrate, fertilisers and pesticides.

The analyses show a trend of results that are similar for farms with the same productive system. This confirms the applicability and the compliance of the analyses carried out.

Consumption of fossil fuels for heating is the main cause of pollution in the production of cut flowers (Figure 1).

The variability of the data gathered shows that the producers are not careful in their management of the energy resources. As well as paying greater attention to the management of the microclimate in the glasshouses, other possible ways of saving energy and causing less impact on the environment are: the use in the glasshouses of layers of covering and / or heat shields; the use of renewable energy such as solar panels and wind generators, the use of residual heat from industrial production, the use of biomass for cogeneration, the use of methane in place of traditional fossil fuels.

The structures and systems have a significant effect on environmental impact generated by flower production with respect to other inputs. In particular the structures of the farms with glass covering have a greater impact than those covered in plastic film. The presence of discarded plastic sheeting suggests the need for a good solution for their final disposal. The common practice of using rainwater, given the scarcity of water supplies in the south of Italy, should be further encouraged (Attanasio et al, 2007).

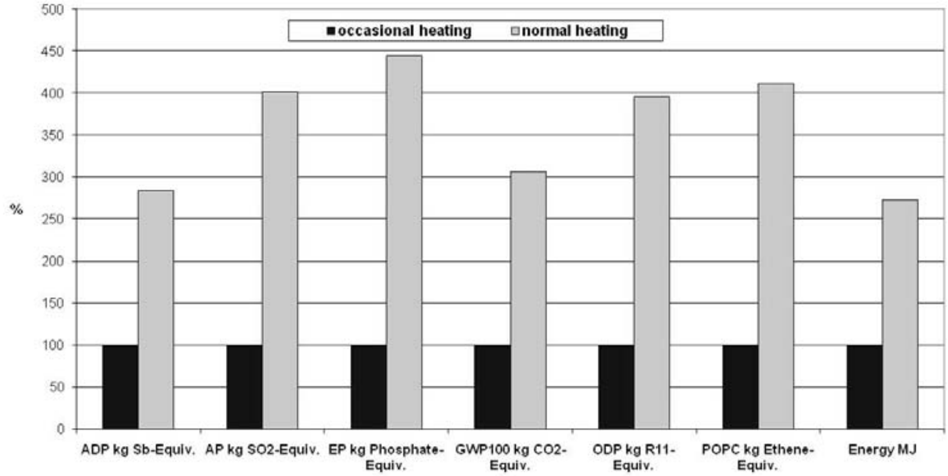

Figure 1: Comparison between farms producing with normal heating and with occasional heating

On the base of LCA study, two categories of product have been identified to write up the PCR: flowers in vase and cut flowers.

3. Definition of the Product Category (PCRs) of flowers,

The PCR specifies the requirements for the LCA study, system boundaries, data quality requirements, the format and content of EPD itself, in order to guarantee the correct comparison of the EPDs of products belonging to the same category.

The ISO 14025 standard indicates the following steps for the drafting of the document: 1) identification of the product category; 2) LCA of the product; 3) PCR's drafting.

The result of the LCA study on floricultural farm, have been analyzed in detail in order to carry out the right choice with regard to system boundaries, cut-off rules, allocation rules and identification of the parameters to be declared in the EPD.

According to LCA results, the system boundaries include the Construction of infrastructure and machinery, because the share on impacts deriving from their realization is significant.

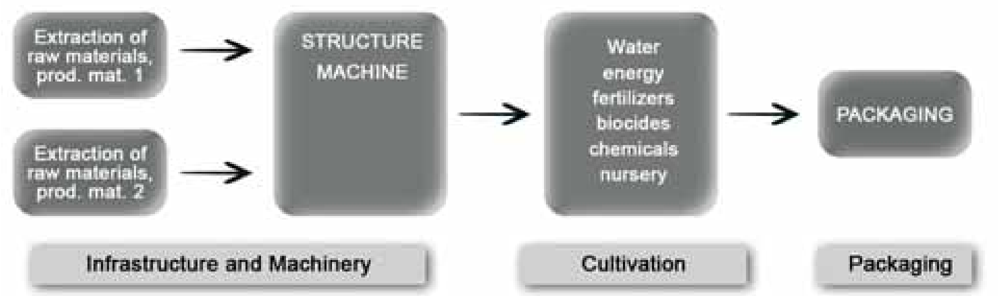

Figure 2: System boundaries

For every phase of the life-cycle has been settled down the information to include in a LCA study to the drafting of a EPD.

For example in the phase of building of infrastructure and machinery the construction of electric plants and refrigerators can be excluded, therefore system boundaries include greenhouses structures and covering materials, heating and cooling plants, fertirrigation systems, cultivation systems (soilless or in soil), other materials (floor covering, cables and poles, lanes, etc.).

In order to draft cut off rules and allocation rules, it has been verified the possibility of excluding from the inventory analysis processes/materials/components that altogether contribute in measure smaller of 1% to system total mass.

The proposal of PCRs (both for cut flowers and for flowers in vase) has been submitted to public consultation. The consultation has been activated by requesting opinions of selected interested parts (who represent as the public as private purchasers) and by open discussion of the PCR proposal in a web-forum.

Altogether, 250 stakeholders (private and public) have been invited to the public consultation: flower producers, flowers markets in Italy and Europe, national and international business associations (agriculture, commerce and tourism), Institutions (Ministero dell'Ambiente, Assessorato all'agricoltura e ambiente of Apulia), Chambers of Commerce, certification bodies, research institutes. The consultation lasted 30 days.

At the end of the process, the final version of the PCR's for "cut flowers" and "flowers in vase" has been issued. The contents of the document are: General information (scope and validity period), Product and company description, List of materials and chemical substances, Functional unit, System boundaries, Cut-off rules, Allocation rules, Calculation rules and data quality requirements, Parameters to be declared in the EPD, Other environmental information.

Even remaining in the scope of the reference standards, accordingly with target companies (SMEs) it has been attempted to introduce simplifications in EPD's contents and procedures where possible.

Both PCR for cut flowers and flower in vase show the list of materials and chemical substances that can affect human health and environment to be declared in the EPD: fertilizers, active substances used in biocides and their risk classes, other chemicals and risk phrases, refrigerants.

The functional unit for the LCA study consists of 100 stems for cut flowers and of 1 plateau containing 6 vases for flowers in vase.

PCRs show the information to be included in the EPD for every phase included in system boundaries (Table 1).

Table 1: Information to be included in the EPD for every phase included in system boundaries

Phase	Information to be included
Infrastructure and machinery	- Greenhouses (structures, covering materials) - Heating and refrigerating plants and fertirrigation systems - Cultivation systems (soilless or in soil), other materials (floor covering, cables and poles, lanes, etc.)
Cultivation	- Fertilizers, biocides e other chemicals - Nursery plants - Water, electricity and fuels
Packaging	- Product packaging

Parameters to be declared in the EPD refer to three categories of data (Table 2).

Table 2: Parameters to be declared in the EPD

Data category	Parameter
Data from life cycle inventory analysis (LCI)	Renewable energy consumption (MJ) Non Renewable energy consumption (MJ) Fresh water consumption (m^3)
Life cycle impact assessment (LCIA) results	Climate change (kg CO_2 eq.) Acidification (kg SO^2 eq.) Eutrophication (kg PO_4^{3-} eq.)
Waste	Hazardous waste (kg) Non hazardous waste (kg)

Both PCR for cut flowers and flower in vase provides that additional information may be included, e.g. the adoption of systems for optimising water resources or recovering the nourishing solution in soilless cultivation.

4. Conclusions

The PCRs have been elaborated in compliance with the document "ECOFLOWER program, general requirement for type III ecological label of product attribution". This document describes: the general instructions of the Ecoflower Program for EPD label release, the methodological framework, the content of the LCA study and the information to be included in the EPD declaration of flowers. The document has been verified by an accredited certification organ and evaluated as in compliance with reference standards.

The LCA, from the first phase of planting in greenhouses, to the collection and sell of cut flowers and plants in vase, allowed to evidence flows of materials, resource and energy, to quantify the environmental impact of typical flower production, looking particularly at the criticalities; it also allowed to evidence best practice, through the comparison between various productive modalities.

Floricultural production criteria based on environmentally-friendly processes and on the use of production techniques with a reduced environmental impact, provide for less use of resources, fertilizers and pesticides.

The obtained results give a tool to reduce environmental impact of flower production and generally of all greenhouse cultivation, through an integrated approach during all the phases of the life cycle of flowers: production, distribution, use and treatment at the end of life.

The environmental improvement of flower production reduces risk for environment by means of a larger control of the production cycle, by making easier the use of sustainable resources and energy, by reducing the use of noxious substances and waste generation.

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Integrated assessment of the nutritional and environmental performance of horticulture in Mediterranean area with compost or mineral fertilizers

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ABSTRACT

Even though the primary function of food is to satisfy nutrition, in most environmental assessments the functional unit is based on mass. In this study apart from yield reference, two extra functional units that include nutritional value are considered. The system studied is the Mediterranean horticultural production of cauliflower, comparing compost (C) or mineral fertilizers (M) use. We assess the potential environmental impacts of the whole agricultural cycle using Life cycle assessment (LCA) methodology. Although yield was highest in M option, nutritional values were better for C. The differences in the magnitude of individual environmental impacts between cultivation options, and also the order, were highly dependant on the functional unit considered. When functional unit associated with production and total phenols content were considered, the C option had the highest impact in 4 out of 7 categories, whereas for the functional unit involving sinapic acid content, this cultivation option had the least impact in 6 out of 7 categories.

Keywords: compost, nutritional value, cauliflower, Mediterranean horticulture, functional unit

1. Introduction

The increasing consumers demand for environmental-friendly food products, requires scientifically defensible information to present alternatives to the current intensive production methods. The LCA is a suitable methodology for their environmental evaluation.

More attention is also being paid to the role of diet in human health (Podsedek, 2007, Lairon, 2010). Therefore, secondary metabolites content must be considered as a valuable factor during the assessment of agriculture systems due to their potential health benefits (Sun and Tanumihardjo, 2007; Pyo *et al.*, 2004; Podsedek, 2007). A wide range of factors can influence the mix of secondary metabolites that a plant manufactures, as they play direct roles in plant responses to stress (Benbrook *et al.*, 2008; Lairon, 2010).

Despite the potential importance of this topic for human well-being, only a limited number of studies have been carried out around the effects of organic and conventional fertilizing

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on secondary metabolites content. These studies indicate a tendency towards nutritional superiority but lower yields of organic products (Benbrook *et al.*, 2008; Lairon, 2010).

Cauliflower was chosen for the study because its high content in secondary metabolites and because it is widely consumed throughout the world (Gratacós-Cubarsí *et al.*, 2010).

The functional unit is the basis for comparisons between different systems in LCA (ISO, 2006). Even though the primary function of food is nutrition, in most of the articles on the environmental assessment of food production, the functional unit is based on mass or volume. Other potential functional units are mass or volume parameters, economic value, quality of the product, consumer's reaction to the product, land use, etc. (Schau and Fet, 2008).

In the present study, the potential effects in the content of two antioxidants compounds for cauliflower cultivation with compost or mineral fertilizers were quantified, and then the environmental assessment of the whole system from a productivity and nutritional standpoint was performed.

2. Methodology

This section has been split into four parts: the agricultural experimental methodology; the laboratory methods for bioactive compounds; and, finally, the LCA methodology.

2.1. Agricultural methodology

The experimental plot was in Santa Susanna (Barcelona, NE Spain) with Mediterranean climate. The cauliflowers (Brassica oleracea L. var. botrytis) were transplanted on September 2007 and cultivated for 110 days. Cultivation followed the best available techniques for integrated crop management. The experiment had a block design with three replicates for each cultivation option.

Table 1: Organic and mineral nitrogen doses applied for each cultivation option

Cultivation option	**Nitrogen dose (gN/m^2)**		
	Organic N [1]	**Mineral N [2]**	**Total N**
C	15.23	9.93	25.16
M	0.00	20.10	20.10

[1] Nitrogen added by compost. Nitrogen available the first year after the spreading of compost.
[2] Nitrogen added by mineral fertilizers, irrigation water and rainfall.

The cultivation options, characterized by the type of fertilization, were compost (C) and mineral fertilizers (M). The high nitrogen content of the irrigation water (192 g/m^3 of NO_3^-), a result of the excessive use of fertilizers in the region, was a relevant mineral source of nitrogen for both cultivation options. The doses of fertilizers were decided by taking into account the soil nutrient content and the agricultural necessities with the aim to compare cultivation options with similar available nutrient rates (Table 1).

2.2. Bioactive compounds analysis

Cauliflower samples were vacuum packed, frozen at -80 ºC and analyzed within 2 months. Frozen cauliflower florets were minced in a blender mixer. Samples were extracted and analyzed as previously described by Gratacós-Cubarsí *et al.* (2010).

According to Gratacós-Cubarsí *et al.* (2010), quantification of sinapic acid derivatives was made with an Acquity UPLC-MS/MS system (Waters, Millford, US) equipped with a Diode Array Detector (DAD) and a Triple Quadrupole Mass Spectrometer (TQD) operated in negative electron-spray ionization mode (ESI-). Sinapic acid derivatives were quantified as sinapic acid equivalents (SAE), taking into account their molecular weight.

Total phenols were evaluated following the methods of Singleton and Rossi (1965), with minor adjustments and using a Shimadzu UV-Visible Spectrophotometer UV-240 Graphicord (Shimadzu Europe GmbH, Duisburg- Germany). Total phenols content was expressed as caffeic acid equivalents (CAE) with a caffeic acid calibration curve.

2.3. LCA methodology

LCA was used for evaluating the potential environmental impacts of the crop considering their entire life cycle and following the ISO 14040 (ISO, 2006). The stages considered in the system (Figure 1) were the same as described by Martínez-Blanco *et al.* (2010b). The whole system, from obtaining raw materials to the management of generated waste, was considered for each stage. The cultivation option with compost (C) considered the three stages (Figure 1) while the M option did not consider the compost production and transport. Most of the considerations were according to the inventory descriptions of Martinez-Blanco *et al.* (2010b) for tomato crop but considering agricultural data for cauliflower cultivation.

The broad system of study required a detailed data-collection process. Most of this data were obtained experimentally by the authors or from previous research of the group (Martínez-Blanco *et al.*, 2010a; Martínez-Blanco *et al.*, 2010b). When local information was not available, bibliographical sources and the ecoinvent database v2.0 (Swiss Centre for Life Cycle Inventories) were used.

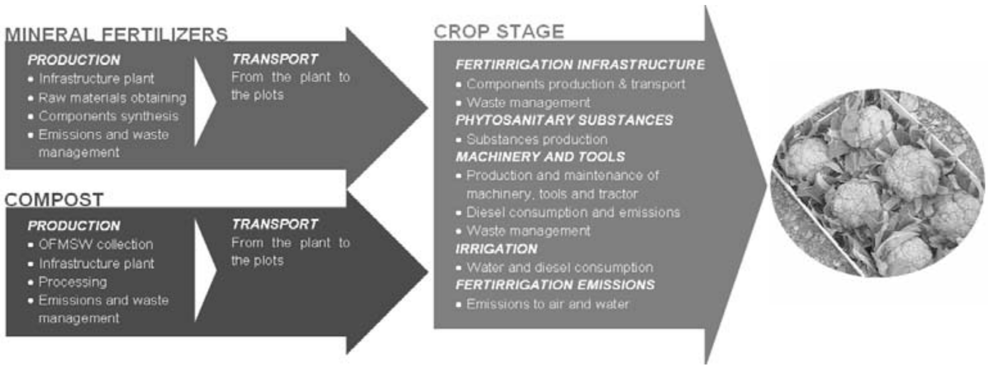

Figure 1: Cauliflower production system description

To consider different bases of comparison between the cultivation options, two functional units were considered apart from the yield. The two additional bases dealt with the nutritional content, considering the content of total sinapic acid derivatives and the total phenols.

Six impact categories defined by the CML 2001 (Guinée, 2001) and an energy flow indicator were considered. The SimaPro v. 7.1.8 program (PRé Consultants) was used for impact analysis, with the obligatory classification and characterization phases defined by the ISO 14040 regulation (ISO, 2006).

According to the "cut-off" method each system is assigned the waste burdens for which it is directly responsible. On the other hand, composting, as well as providing fertilization, is an option for organic waste management, which is not the case in the production of mineral fertilizers. To take this into account, the burdens of dumping organic waste were subtracted from those options that include composting (2010b).

The highly polluted irrigation water was given a virtual concentration of 50 g/m^3 of NO_3^- and the extra 142 g/m^3 of NO_3^- were accounted as added mineral fertilizer (HNO_3), considering its production, transport and application. The carbon sequestration, which is the carbon still bound to soil after 100 years, is 8% of the carbon introduced with compost (Favoino and Hogg, 2008).

3. Results and discussion

3.1. Agricultural results: yields and antioxidant parameters

The commercial yield and the antioxidant compounds content are shown in Table 2. Significant statistical differences were observed between cultivation options for the three parameters assessed. Cultivation option with compost had nearly a third lower yield than option M, while the former had 77% and 24% higher content of total sinapic acids and total phenols, respectively.

Table 2: Cauliflower harvest production and antioxidant compounds content

Cultivation option	**Commercial yield**	**Antioxidant compounds**	
		Total sinapic acid derivatives	**Total phenols**
	t/ha	SAEmg/kg	CAE mg/kg
C	12.2^a	40.9^a	275.5^a
M	17.0^b	23.3^b	222.0^b
C/M (%)	- 28%	+ 76%	+ 24%

SAE = Sinapic acid equivalents; CAE = caffeic acid equivalents
Data were analyzed with the ''Enterprise Guide'' software package (SAS institute Inc.). Analysis of variance was conducted using the General Linear Models procedure and the least significant difference test (LSD, $p < 0.05$). Different letters indicate significant effect at $p = 0.05$.

3.2. Environmental results

Three different functional units were considered for the inventory assessment. The results are presented in Figure 2. For each impact category, the results are showed as a percentage of the environmental impact of M, which was considered as 100% for the three functional units.

For the eutrophication potential (EP), the global warming potential (GWP) and the ozone layer depletion potential (OLDP) categories, C had the minimum environmental impacts for all functional units due to the avoided burdens by composting and not dumping municipal organic waste. Moreover, the environmental impacts of C for EP and GWP were negative and between 22 and 47 times less impacting than M for EP and between 6 and 13 times, for GWP, depending on the functional unit. Regarding OLDP, C option had between 13-59% less impact than the other option.

For photochemical oxidation potential (POP), the impact order was reversed regardless of the functional unit The higher impacts in option with compost were due to the emissions of volatile organic compounds during organic waste decomposition in the composting facility (Martínez-Blanco *et al.* 2010). The impacts for C were between 22 and 48 times greater than for M, depending on the functional unit.

Regarding the other three impact categories, abiotic depletion potential (ADP), acidification potential (AP) and cumulative energy demand (CED), the impact order between C and M depended on the functional unit. When commercial yield was considered, C had higher environmental impacts than M, between 55-102% higher, for ADP, AP and CED, due to the upper yield for the latter. The content of total sinapic acid derivatives in C was twice that of

M, so that, in all categories apart from POP, C had the lowest impacts. For this functional unit, C had between 4-26% lower impact, for ADP, AP and CED. In contrast, smaller differences were measured for total phenols content, so that the order of the cultivation options with this functional unit was the same as for commercial production but with lower differences. For ADP, AP and CED, and considering total phenols content as functional unit, C had between 26-63% higher impacts.

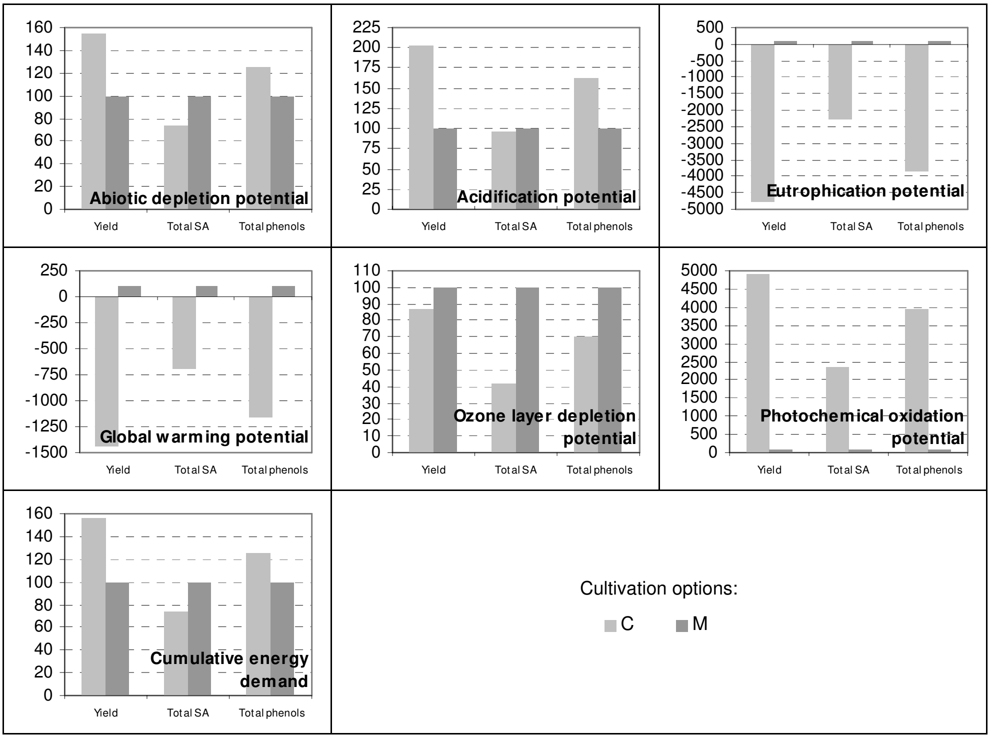

Figure 2: Environmental impacts (percentage) for the two cultivation options considering the three functional units (yield, total sinapic acid derivatives content and total phenols content)

4. Conclusions and perspectives

While higher commercial yield were found for the M cultivation option than for option with compost, the content of bioactive compounds for the latter was higher than for the former, particularly for total sinapic acid derivatives content.

For EP, GWP and OLDP categories, C cultivation option had less impacts than M regardless of the functional unit, and for POP, the impact order was reversed. The environmental results obtained for the other three impact categories (ADP, AP and CED) greatly depended on the functional unit considered. When total sinapic acid derivatives content were considered as functional unit, M was more impacting for these categories.

More research is necessary on the effects of different cultivation techniques, apart from the increase or decrease in yield. In addition, from the results and trends reported in this study, the importance of comparing environmental impacts with several functional units is clear, especially for food products assessment.

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The environmental implications of agriculture: from food miles to Life Cycle Assessment

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ABSTRACT

Agricultural ecosystems have become incredibly efficient at producing food, but these increased yields have environmental costs that cannot be ignored. Therefore, various tools have been used to assess these costs, relying on the idea that particular characteristics of specific resources can be monitored and recorded, so that any information obtained may serve as an aid for decision making by governments, farmers and food manufacturers. Analyzing the portfolio of evidence produced to date by scholars, policy makers and professionals, the current research discusses and investigates the legitimacy of two product-based methodologies as credible measures of agricultural environmental costs: food miles and Life Cycle Assessment (LCA).

Keywords: Food miles, Life Cycle Assessment (LCA), sustainable agriculture.

1. Introduction

Most economic activities affect the environment, either through the use of natural resources as an input or by using the clean environment as a sink for pollution. Hence with growing public concern over environmental degradation and climate change, indicators of human responsibility have begun to proliferate. In particular, agriculture's paradigm of maximizing profit and maximizing production has begun to change direction; the concern is no longer focused solely on quantity, but rather quality (Holloway *et al.*, 2007). In this context, food represents a unique opportunity for consumers to lower their personal environmental load due to its high impact and high degree of personal choice (Weber and Matthews, 2008). Therefore sustainability of agriculture is without doubt a prominent topic in today's environmental debate and it is widely acknowledged that the current system of economic calculations grossly underestimates the present and future value of natural capital.

Nevertheless, several attempts to put a cost on some of the pollution arising from agriculture in the USA and Europe, have proven to be extremely complex. However, through the assessment of existing food systems, opportunities for improvement towards the goal of greater sustainability of agriculture may become easier. Consequently, a large number of sustainability indicators have been proposed by agri-food scholars. Researchers and environmentalists in developed countries have investigated the concept of food miles for years, but its popularity has increased considerably in recent times (Wynen and Vanzetti, 2008). This popularity reflects the globalization of the food sector and the growing demand for out-of-season foods, rising fuel and food prices, greater awareness of the link between transport and carbon emissions and the desire to limit environmental damage. However, there is still vast skepticism on the validity of food miles as a credible measure of environmental costs (DEFRA, 2005; Saunders *et al.,* 2006; Williams, 2006). Indeed, while producers in importing countries have embraced the food miles movement (also as a mean of protecting themselves from foreign competition), exporting nations have rejected the concept, arguing that the

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question of sustainability in food production is far broader than emissions of fossil fuels used in transportation. A prominent alternative model to food miles is life cycle assessment (LCA), in which all relevant emissions and resources used through the life cycle of a product are aggregated and expressed per unit of the considered product. Nowadays, several LCA studies on agricultural products can be found in the literature (e.g. Carlsson-Kanyama, 1998; Berlin, 2002; Mattsson and Wallén, 2003; Berlin *et al.*, 2007). The objectives of the current paper are twofold: to review the academic literature that has analyzed the environmental sustainability of agriculture and contribute to the general debate with the discussion of the legitimacy and accuracy of the most popular indicators of agricultural environmental costs, food miles and LCA. This approach will hopefully stimulate public authorities and opinion leaders to assess the effectiveness of specific policies with more comprehensive measurement systems.

The paper is structured as follows. First the theoretical framework of environmental sustainable agriculture is presented. The selected indicators are then briefly described and analyzed. Finally, the advantages and shortcomings of the two methods are depicted and discussed, together with further research avenues.

2. Environmentally sustainable agriculture

Despite the broad consensus on its importance, a high degree of variability can be observed both in how sustainability in agriculture is defined (Hansen, 1996; Lewandowski *et al.*, 1999; Sands and Podmore, 2000; Heller and Keoleian, 2003) and how it is pursued in practice in the policy-making process. Moreover, the general public in developed countries tends to associate sustainable agriculture with a large set of values underpinned by conservation of the environment, safe food, animal welfare and economic support for small and family farmers (VanLoon *et al.*, 2005). The sustainable agriculture movement evolved from several reform movements in the USA and Western Europe that developed in response to concerns about impacts of agriculture such as depletion of non-renewable resources, soil degradation, environmental effects of agricultural chemicals, food quality, farm worker safety, decline in self-sufficiency, and decreasing number and increasing size of farms. The Food and Agricultural Organization (FAO) of the United Nations (1995) defines sustainable agriculture not "just [as] a means to obtain more food and income, in socially acceptable ways which do not degrade the environment…[but rather as] an opportunity to improve the quality of the environment…and social, economic, and institutional components." Consequently, agriculture today must balance a wide and continually evolving array of demands and environmental challenges (see Figure 1). The initial focus on conserving the natural resource base upon which agriculture depends has broadened to include other priority areas such as the impact of pesticides and fertilizers, the potential entry of pathogens into water, the release of particulate matter, odors and greenhouse gases, wildlife habitat availability and the conservation of species at risk. Therefore achieving the goal of long-term environmental sustainability in the agriculture and agri-food sector has become a more pressing and increasingly complex challenge.

While there is general agreement that growth in sustainable agriculture must happen through added-value products and the more efficient use of input rather than mere output increases, no broad consensus can be found on the use of sustainability indicators. Indeed, alongside indicator development programs being undertaken by national governments as well as international organizations, there is still a rapidly developing literature on the topic, which provides a variety of definitions of what an indicator is and different understandings of the primary roles of indicators. As effectively described by Coley and colleagues (2009), a wide range of tools have sought to analyze the problems of sustainable agriculture, and the method chosen often depended primarily on the way sustainability was viewed and/or the background of the particular investigator. Besides, a number of studies have highlighted several shortcomings on sustainability assessment in agriculture, such as the lack of specific evaluation of multi-functionality in sustainability assessments (Rossing *et al.*, 2007) and the full consideration of interactions between indicators (Morse *et al.*, 2001).

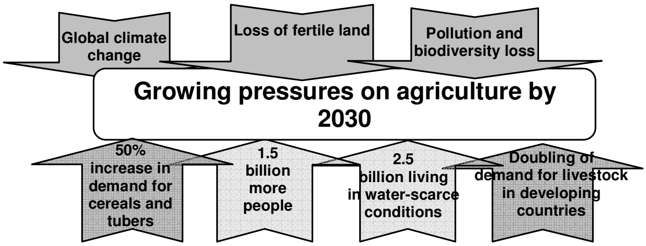

Figure 1- Growing pressures on agriculture by 2030. Source: Our elaboration on IISD, 2009

In a world of globalized agriculture, environmental sustainability should be measurable across regions, countries and commodities. For a fair comparison of different farm types and regions around the world, all strengths and potentials, as well as deficiencies and bottlenecks, must be considered. Hence, nowadays it is crucial to use well-defined environmental indicators and valid data to describe resource use and emissions, in order to correctly identify (and where possible modify) the most polluting sources of agricultural production. In this paper we argue that some of the current debates regarding the meaning, nature and purpose of environmentally sustainable agriculture indicators are misleading and not relevant in practice, and their value springs from their actual potential to improve decision making.

3. Food miles

In the mid-nineteenth century, the wheat produced in a given location could be moved up to 66 miles without the cost of transport exceeding the cost of production, for potatoes the maximum distance was ten miles, for sugar beet four (Benedict *et al.*, 1935). In today's globalized food commerce these limitations are pointless. Although the increasing distance between agri-food products and consumers has long been acknowledged both by economists and sociologists, the food miles movement has gained much momentum in the last two decades (Desrochers and Shimizu, 2008). Even if the phrase food miles was first coined by British Professor Tim Lang in the mid-1990s the concept started to become more widely used from the beginning of the new millennium to raise general concerns about the environmental impacts of food production and consumption. The main environmental rationale for reducing food miles, the distance food travels between being produced and being consumed, is to cut the energy and pollution associated with transporting food from source to destination. Therefore the concept of food miles is spontaneously attractive: the further food has to travel, the worse it is for the environment, since more transport requires more energy use and consequently more emissions. However, the average distance food travels from farms to consumption markets has increased dramatically in recent decades globally, mainly due to the exclusion of environmental and social externalities from fuel pricing (Jones, 2001). The issue of sustainability in food production is obviously far greater than that of emissions from fossil fuel use, including questions of water pollution, rural economics, landscape amenity and a host of others (Pretty *et al.*, 2005).

A number of scholars have demonstrated that the concept of food miles, as typically used, is of little value *per se* and that other types of emissions per unit of produce (e.g. carbon) over the transport chain actually matter (Lal *et al.*, 2004; Coley *et al.*, 2009). Moreover, different modes of transportation require differing amounts of energy per unit of produce (thus not necessarily the item that has traveled the fewest miles has consumed the least energy). According to several studies on the environmental costs of food transport, the contribution of such costs to total food chain energy costs vary from around 4 percent (Desrochers and Shimizu, 2008) to about 11 percent (Pirog *et al.,* 2001). In addition, a further problematic aspect of the food miles perspective is that it ignores productivity differentials between agricultural and food processing practices and dissimilarities among geographical locations. This difficulty has been demonstrated by several findings showing that, in some circumstances, buying locally produced food can be more damaging to the environment than importing similar products from distant sources (DEFRA, 2005; Saunders *et al.*, 2006). As a result, environmentally-minded consumers are being misled if they are told that food miles will help them make fully informed purchasing choices.

4. Life Cycle Assessment

Life cycle assessment (LCA) is an analytical method used to evaluate the environmental impact associated with a product, process or activity during its life cycle by identifying and quantitatively or qualitatively describing its requirements for energy and material, as well as the emissions and waste released to the environment. The entire life cycle is included in the assessment, which means that the product under study is followed from the initial extracting and processing of raw materials through manufacturing, distribution, and use, up to final disposal, including all transportation involved. Besides identifying the environmental impact of the product or activity, LCA also identifies which activities in the product life cycle contribute most to this impact. The environmental impact categories assessed in LCA can be divided into three main groups: resource depletion, human health impacts and ecosystem consequences. The LCA methodology, as described in ISO 14040 series, comprises four phases: goal and scope definition; inventory analysis; impact assessment; and interpretation. Acquisition of raw material through production, use and disposal, for which the environmental impact is assessed in classical LCA, does not properly describe the agricultural production process (Haas *et al*., 2000) since for most agricultural products the primary production is an important determinant of the total resource use and environmental impact. Therefore, applying LCA to agricultural systems without due consideration to the specific characteristics of agriculture may raise problems. As previously highlighted by several scholars (Audsley *et al*., 1997; Weidema and Meeusen, 2000), the main problems are *a)* the establishment of consistent descriptions of the production system; *b)* the definition of the functional unit[1]; *c)* allocation of environmental effects to the different functions of a multi-function system; *d)* characterization of specific impacts such as acidification and eutrophication and impact on soil quality and biodiversity.

Comparing the environmental performance of different production systems and management options as well as setting benchmark indicators, LCA studies support modern agriculture and food production in defining possible options for environmental improvement[2]. Al-

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[1] An important characteristic of agricultural LCA is the use of multiple functional units. Commonly used functional units include mass of final products (kg), energy or protein content in food products (kJ), area (ha), unit of livestock (Roy *et al.*, 2009).

[2] Nowadays there are examples of large food companies, such as Arla Foods, Unilever and Cerelia, performing LCA on specific projects.

though LCA techniques have improved, further international standardization would enable direct comparison of different case studies. Moreover, the LCA method is still under development and the methodology to assess some potential environmental impacts has not yet been conclusively determined (e.g. biotic depletion, impacts of land use, biodiversity loss). In addition, as LCA is not site-specific, the severity of impacts from different locations cannot be distinguished.

Table 1 – Life cycle energy inputs for selected agri-food products (MJ/kg)

Product	Energy use	Reference
Central Europe raspberries	7.5	Carlsson-Kanyama *et al.* (2003)
Central Europe white cabbage	5.1	Carlsson-Kanyama *et al.* (2003)
Danish prawn	6.6	Thrane (2006)
French organic pig	22.2	Basset-Mens and van der Werf (2003)
German bread	15.8	Brashkay *et al.* (2003)
Italian white milled rice	15.72	Blengini and Busto (2009)
Norwegian chicken	55.0	Ellingsen and Aanondsen (2006)
Southern Europe herbal spice (commercially dried)	36	Carlsson-Kanyama *et al.* (2003)
Southern Europe oranges	6.8	Carlsson-Kanyama *et al.* (2003)
Southern Europe tomatoes	5.4	Carlsson-Kanyama *et al.* (2003)
Swedish beef	40.0	Cederberg and Darelius (2002)
Thai shrimp	45.6	Mungkung (2005)

5. Discussion and research developments

Global climate change and the continuous growth of human population (and consumption) are placing new pressures on arable land, water, energy and biological resources, leading to serious doubts regarding the long-term environmental viability of current agricultural production systems. However, these concerns are not always matched by corresponding policy actions. The key challenge occurs because the environmental effects (externalities) of agriculture are not always reflected in market prices, and thus the market alone does not lead to an economically and environmentally efficient allocation of resources. Consequently, governments of developed countries are seeking effective methods and schemes that can assist farmers and food producers achieve environmental friendly practices. Therefore, information tools in the form of ecological sustainability assessment systems are being widely developed. Increasingly utilized at farm, corporate and public policy levels, these efforts promise to make agricultural production more environmentally sustainable. The great development of scientific knowledge, together with improvements in data quality and availability, have promoted integrative, non-aggregate and holistic assessments of the agricultural system and the construction of more sophisticated indicators that effectively estimate environmental implications of agriculture. The existence of specific data on the costs and benefits of each single action will help improve public discussion about the diverse options. Sometimes the public debate is based on a series of hypothetical statements about costs and benefits over which the proponents of various viewpoints do not agree. If there are useful numbers to attach to the discussion, then it could focus more on issues and less on which hypothetical statement is most accurate. The challenge should be shifted from developing new indicators and assessment tools to understanding how existing tools and methods work in practice, how these tools and methods can co-exist and how they can enter mainstream use. While much of the alternative agri-food literature rests on the assumption that localizing food systems will bring environmental benefits, very little research has provided valid empirical proof. In particular, the appeal of the food miles perspective, with its promise to reconnect people with food, neighboring producers and seasonality while delivering environmental, economic and social benefits, has been proved simplistic: localized food systems do not necessarily always equate to greater environmental sustainability. In contrast, recent advances in agricultural science has proven the usefulness of LCA to compare different products, processes or services, evaluate alternative life cycles for specific products or operations and identify parts of the life cycle where the greatest improvements can be made. Nevertheless, trade-offs between complexity and manageability have still to be successfully addressed.

In our review we highlight the need for simple, visually clear, robust and transparent assessment systems that all users can easily understand and handle. This necessity is also strengthened by reports from several developed countries that emphasize consumers' increasing awareness of the potential environmental impacts of their food purchasing and consumption decisions (Weatherell *et al.*, 2003; Seyfang, 2006; Brown *et al.*, 2009), and their growing interest in purchasing more environmental friendly food. Therefore science must be more connected with the policy development process to generate reliable quantitative information about environmental effects of agriculture and support analytical tools that allow this information to be integrated into the consumer decision-making process. Moreover, strong expectations rely on the participation of stakeholders in the development of these measurement tools with the benefit of better balancing standardization and comparability with specific and local needs. In addition, since attempts to analyze the sustainability of food chains are usually limited to a rather narrow focus, they should try to consider all the dimensions of sustainability and develop assessment and documentation methods that embrace the environmental, social and economic pillars of sustainability. This is an ambitious goal for the near future.

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Life Cycle Assessment analysis of greenhouse tomato production in Turkey

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ABSTRACT

Tomato production in greenhouses has been rapidly increasing for the last decade in Turkey. The volume of tomato production in Turkey, which is the fourth biggest tomato producer country in the world, is approximately 10 million tones. Fresh vegetables consumption is essential for balanced and healthy daily diet. Tomato is one of the most important vegetables for human health because it contains lycopene and on the other hand tomato has special flavor especially for Mediterranean cuisine. Although it has a high value for human nutrition, some chemical inputs, which are hazardous, are emitted to soil, water, air etc during the production process. The objective of this study relies on applying LCA methodology to agriculture and, focusing on environmental burdens of tomato production in greenhouses in Turkey. The data for this study is collected from tomato producers who produce tomato conventionally in greenhouses in Antalya Region. The survey is made by talking to producers and their advisers; they filled out the questionnaire about input material usage during the production process. The expected contribution of this study is the use of LCA methodology and tools, to create a discussion on sustainable production and production methods.

Keywords: LCA for agriculture, tomato production, questionnaire, Turkey.

1. General information

Greenhouse tomato production has been rapidly increasing for the last decade in Turkey. The volume of tomato production in Turkey, which is the fourth biggest tomato producer country in the world (FAOSTAT, 2009), is approximately 10 million tones. Besides many advantages of greenhouse production system, this system creates landscape changes, ecosystem flux variations and rising on the energy inputs and residue generation occurs (Parrado and Bojaca, 2009). Also this production system is often perceived as an artificial process, characterized by low nutritional quality of the final product and the heavy usage of chemical inputs (Muñoz et al., 2008). Today, production techniques are more advanced and sometimes new technologies brings pollution by heating boiler in greenhouses (especially coal usage), emissions from fossil-fuel combustion by transport and trucks etc. While getting fresh vegetables for daily diet, production techniques may give harm to environmental components (mostly to soil, water, product, air, human etc.)

The scope of Life Cycle Assessment (LCA) studies and its components are highly diverse. LCA methodology application on agriculture sector is essential to explore environmental side effects of production. Despite many restrictions to find accurate agricultural data, it is also hopeful to use some databases (e.g Eco Indicator 99 (H) LCA Food V2.02 etc.) to make LCA analysis.

Searching environmental burdens in tomato production is aimed in this study. There are environmental costs to the new generation on earth, and techniques to be used for decreasing environmental friendly methods. The objective of this empirical study, is determining the

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main factors of environment pollution, caused by the tomato production in greenhouses, by using LCA methodology.

2. Material and method

This study has arisen from the regional environmental assessment need for agricultural products. The main source of this study consists of the original data collected from tomato producers in Antalya province in Turkey. Tomato is the most prefered vegetable because of its marketing facitilites and high profit margin. Tomato needs more fertilizers and pesticides than the other vegetables in this region. Antalya is the biggest tomato producer region in Turkey (1.712.000 tones and 18% of total tomato production in Turkey). Therefore, while the quantity of production rises, the amount of input rises as well.

The method of this study was based on LCA, to explore environmental affects from the production stages. Life cycle inventory analysis is the first part of this study. Then, collected data was analyzed according to the impact categories. According to Nemecek and Erzinger (2005), due to the large number of influencing factors (climate, soil, farm size and type etc.) the production situations and emissions are highly variable. Finding proper data for evaluating the environmental impacts of the products is relatively difficult outside of Europe, U.S. and Japan. Available databases are not suitable for LCA analysis of agricultural products in Turkey. Because, the structure, production type, product variety, inputs, environmental conditions, climatic characteristics etc. vary. Since agricultural production doesn't have an homogeneous structure, there is an high diversification between the regions. Therefore, making LCA studies for agriculture is not easy (Weidema and Meuesuen, 2000). Most of the literature sources related to LCA, refers that the survey methods needs more time, labor and budget. This fact is also valid for Turkey. Turkish producers have a small scale structure and this makes the data collection more difficult. To handle this problem, sampling method is used in this study and the survey is conductued for tomato producers. Therefore, a 'face to face' interviews have been done with producers. At first, preliminary questionannaire was applied to check whether the question works or not. The biggest and most serious problem was, collecting fertilizer and pesticide data from producers because most of the producer don't keep records. Sampling area is 65550 m2 and producers grow tomato either in plastic greenhouses or glass greenhouses. Producers produce tomato two season cycles in a year. They generally plant nurseries (small plants) in the soil by the the mid August and they start to harvest after 70-100 days following and it continues till January. After that, producers make preparations and plant the nurseries (not seeds) by February and start harvesting by March until June.

The functional unit is determined as 'kg' according to the LCA litterature for tomato cultivation. Nemecek and Erzinger (2005) is defined the system boundry as the 'production process'. System boundry excludes wastes by the production. Also, carbon fixation by plant in agriculture, is not considered as a negative emission (Anonymous, 2009). In this study, SimaPro 7.1 is used and the study discusses the results of tomato production variables entered into this LCA Software. Eco Indicator 99 (H) LCA Food V2.02 database results is used for emission for this study.

Greenhouses are defined as means of overcoming climatic adversity, using a free energy source, the sun (Hanan, 1997). However, only some parts of the world, heating may not be required. Mediterranean countries are one the place that solar energy is very convenient for providing energy. Anton et al., (2003) and Anton et al. (2005) indicated that almost all producers don't use heating materials because of the production period in traditional greenhouses especially in Mediterranean countries. Therefore, environmental burdens have arisen from heating, are highly limited. Producers in the research area also declared that there is no need for heating. But it isn't the same everywhere in Antalya region. They apply solarization during summer before planting the plants, so, plants are stronger against the diseases and it indirectly reduces the heat needed. Plastic cover (nylon) for soil is used for solarization to eliminate the pathogens. However, plastic materials pollute the environment (indicated in the next section of the study) as much as the other products. After the solarization process, plants are ready to plant out.

Many substances are considered as an "inventory" part of LCA. However, some of them are not included in the impact assessment side. Some inputs and materials do not have important effects. For example, the pesticides, the fungicides and the other chemical substances used for pathogens and viruses in plants, could not be included to LCA. The emissions in database don't exist to analyze the impact assessment. Electricity is not included in inventory analysis due to traditional greenhouses that doesn't need much electricity for machine usage and water pumping. Also, it is assumed that, the water quality is the same in every field. The quantity of water is estimated roughly according to the characteristics of the region.

3. Results and discussion

The basis of any LCA is creating a model which contains the amounts of all inputs and outputs of processes that occur during the life cycle of a product (Anonymous, 2009). Impact assessment has been applied with the variable entries in the inventory database. The categories were depicted in Figure 1 as percentages of damage assessment and listed in Table 1 as values with equivalent units.

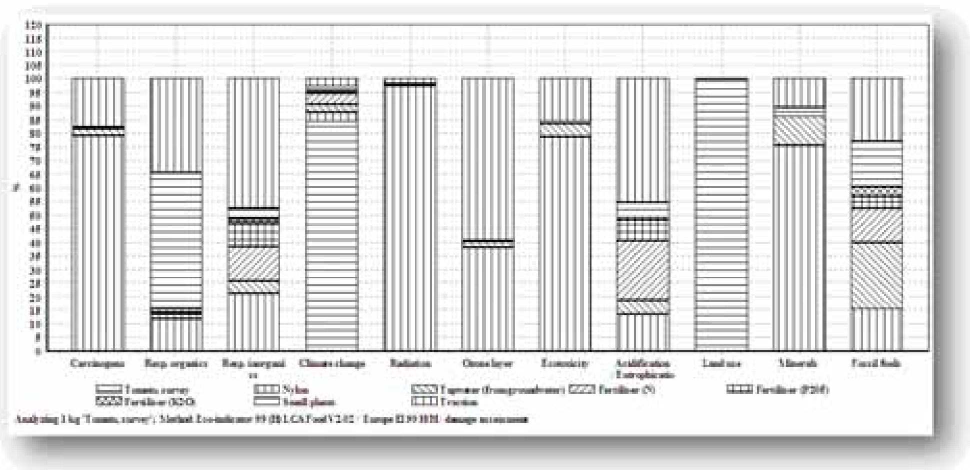

Figure 1: Percentage of damage assessment of material used for tomato production (SimaPro 7.1)

It is mentioned in a Final Report of Concerted Action, as a general rule, "the emissions associated with Nitrogen (N), Phosphorous (P2O5) and Potassium (K2O) should be allocated according to recommended quantity for each crop" (EU Commission, 2003). Hence, the fertilizers were allocated to active ingredients which are based on N, P and K. Acidification/ Eutrophication (CML) is occurred by 22% Fertilizer (N), 15% Nylon, 45% Traction and the others. Therefore, if we exclude the traction, Fertilizer (N) and Fertilizer (P2O5) will have the highest percentage for causing to CML respectively. Ozone layer depletion is 60% nylon (plastic), 37%fossil fuel used in traction process and 3%. Respitory organics has occurred because of small plants were plant out by traction process. About climate change, fertilizers (N) percentage (5%) was found relatively lower than the expected in this study. Nylon usage has the highest ratio (75%) to cause Carcinogens and Radiation (97%) Fossil fuels depletion is caused by the different sources as tapwater (25%), traction (23%), small plants (21%), nylon (15%) and fertilizers (K2O and P2O5) respectively. Ecotoxicity is also caused by the nylon usage. It can be mentioned that nylon has the highest environmental burdens. If another material is found (except nylon or plactic) for solarization of soil, this impact will be reduced (Figure 1). Damage categorization is explained with values in Table 1 which has the same results in Figure 1.

Table 1. Analyzing 1 kg 'Tomato, survey' with Impact Categories (SimaPro 7.1)

Impact category	Unit	Nylon	Tapwater	Fertiliser (N)	Fertiliser (P205)	Fertiliser (K2O)	Traction
Fossil fuels	MJ surplus	0,0056068	0,009041594	0,00447548	0,00166347	0,00120012	0,0084331
Minerals	MJ surplus	3,45E-05	4,79E-06	0	0	0	4,82E-06
Land use	PDF*m2yr	0,0001557	6,81E-06	0	0	0	1,67E-05
Acidification/ Eutrophication	PDF*m2yr	8,85E-05	3,74E-05	0,00014446	4,98E-05	6,72E-06	0,0003035
Ecotoxicity	PDF*m2yr	0,000102	6,33E-06	1,84E-10	1,54E-10	6,60E-11	2,02E-05
Ozone layer	DALY	4,31E-12	2,08E-13	0	0	0	6,70E-12
Radiation	DALY	1,21E-10	7,12E-13	0	0	0	2,46E-12
Climate change	DALY	1,16E-09	9,77E-10	1,42E-09	1,99E-10	1,36E-10	1,00E-09
Resp. inorganics	DALY	3,19E-09	6,79E-10	1,92E-09	1,29E-09	2,11E-10	7,22E-09
Resp. organics	DALY	8,03E-12	1,25E-12	5,83E-13	6,00E-13	1,90E-13	2,35E-11
Carcinogens	DALY	2,79E-10	8,57E-12	1,84E-13	8,01E-14	5,77E-14	6,29E-11

4. Conclusions

In this study, tomato production is assessed according to the life cycle assessment approach in this study. Although, there are numerous studies about N-use investigations (Bentrup et al., 2004), there are no studies or reports about LCA applications in the scope of agriculture yet in Turkey. This study is prepared to attract attention to the environmental pollution caused by agriculture and to obtain portable data. This study was conducted for only traditional tomato cultivation in greenhouses. The results show that the first impact category called “acidification” is occurred mostly from traction (%45) and fertilizer usage (%25) respectively. “Carcinogens and radiation” and “ozone layer depletion” impact categories are consists of nylon (plastic) material mostly. Therefore, beside fertilizers the other substances also should be evaluated if data are available to make analysis.

In this study, raw materials and the energy resources (environmental input) is included to LCA analysis. The lack of the study is, pesticide contribution to environmental damage and waste management analysis. Also other substances like fertilizers and building materials would be added to inventory analysis. The production process of the tomato does not generate co-products so allocation rule was not applied. As Anton et al., (2003) indicated in her study, there is a need to develop more knowledge on transfer factors taken into account local conditions and type of application for each pesticide. It is also essential that soilless culture in modern greenhouses should be examined and compared (by LCA) in two different systems. Because, inputs as technology, labor, natural resource usage differs from traditional and modern greenhouses. LCA studies need local databases , and local areas need more LCA studies to reduce the environmental damages in many production or service sectors. For further studies, more databases should be created for Turkey by different projects.

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Life Cycle Assessment of tomato and potato farming in the Autonomous Community of the Basque Country

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ABSTRACT

Farming of food raw materials is an essential step when life cycle assessment is performed to ecodesign food products. Under a project financed by the Basque Government, several comparative environmental analysis among the main agricultural raw materials farmed in the Autonomous Community of the Basque Country were carried out in order to gain more knowledge about the environmental impact and resource use along the agricultural production chain. An exhaustive quantitative inventory was carried out for both potato and tomato farmed traditionally as well as in an organic way, being afterwards their Life Cycles compared in detail. The major finding was that the production and application of fertilizers and pesticides accounted for the most polluting phase, except for the production of organic tomato. Finally, regional eco-balances resulted to be very useful to ecodesign Basque food products that contain vegetal raw materials, in a cheaper and easier way.

Keywords: agricultural production Systems, LCA, environmental impacts

1. Introduction

In recent years there has been an upward trend in developing more efficient foods with lower costs and environmental impact, and safer in order to make the food industry more sustainable.

This is expected to be achieved by means of a product design strategy that considers the efficiency along all the steps involved in the life cycle of the product: obtaining of natural resources, processing, packaging, preservation, retailing, commercialisation, consumption and final disposal (Zufía, *et al,* 2008).

As a result of previous research (EIPRO 2006; Foster et al, 2006), raw materials coming from agriculture, fishing and livestock farming have a great influence in the global impact within the food chain.

Therefore, it is important to find out the main origin and causes of these impacts and develop new measures and technologies to reduce them.

Detailed comparative eco-balances and impact assessments for agricultural raw materials (potato and tomato farmed traditionally and in organic way) in the Basque Country were carried out, and the most important environmental impacts were established by AZTI.

2. Method/Approach

2.1. Functional unit

The functional unit for both crops was 1 kg at storehouse ready to be delivered. In both crops distinction was made between organic and conventional cultivation.

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2.2. Data sources

Neiker-Tecnalia, the Basque Institute for Agricultural Research and Development provided specific data on production and resources consumptions for farming these vegetal raw materials in the Basque Country. The software used for developing the full comparative LCA has been SIMAPRO 7.1.toghether with ECOINVENT (2007) data base.

Some considerations about the data are:

- Data provided are the average values of real experiences.
- Fuel consumptions data are average values calculated on the basis of the quantity of time used by the tractor in each labour and the average fuel consumption of the tractors used.
- Emissions to air and to water are obtained from Ecoinvent equations (Nemecek et al, 2007)
- Data are based on figures obtained from farms located in the region of Alava in the Autonomous Community of the Basque Country.

2.3. Considerations to scope and Life Cycle inventory

The phases integrating the LCA of the crops under study are observed in Figure 1

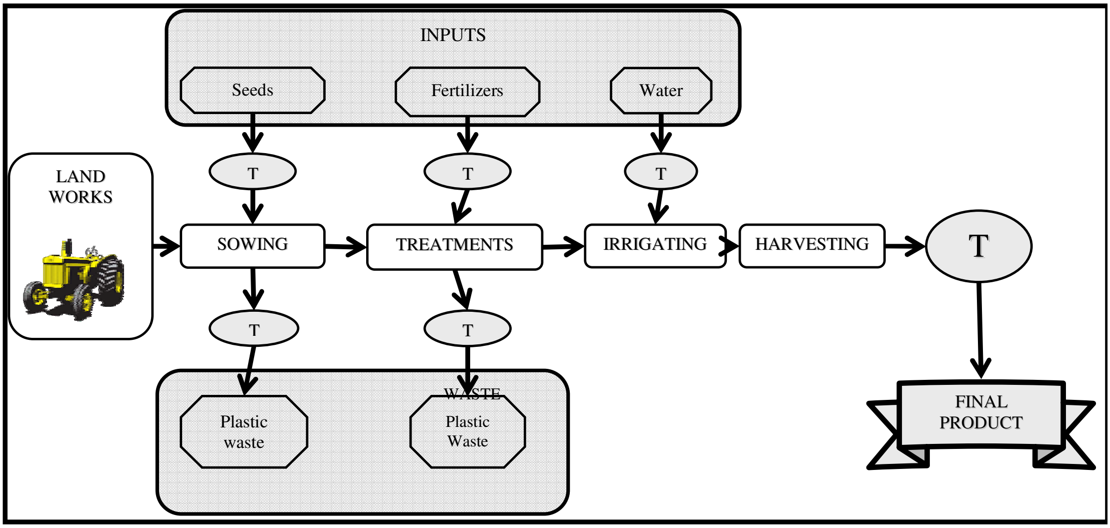

Figure 1: Life Cycle Assessment phases studied for the potato and tomato crops in the organic and conventional agricultural production systems

However, there are some singularities to be considered in the study of the following phases:

<u>Making the land arable</u> (sidehill plow, disc harrows, ridging the soil, etc.): Traditionally farmed tomato is considered in the hydroponic way, so it is the most representative farming way nowadays in the Basque Country. When it is compared to the organic one, soil exploitation is lower.

<u>Fertilizers and Pesticides</u>: In traditionally farmed potato the dose and type of fertilizers used are very variable depending on the soil characteristics, the climate in the area, the expected efficiency, the price of the different fertilizers and the farmer habits. Due to these reasons, the average input of the most applied fertilizer in the Basque Country was calculated.

The impact of pests and diseases is also very variable from one year to another, and so are the treatments. Moreover, these treatments can very much from farm to farm, even between farms belonging to the same farmer.

Some common applications with commercial products were considered: data collected by NEIKER, consultations to local farmers and a study about phytosanitary products exploitation carried out by Nekazal Ikerketa eta Teknologia, S.A. (IKT, S.A.), Agricultural Research and Technology Center.

Regarding to organic potato cultivation neither fertilizers nor phytosanitary products can be used. Compost was assumed to be the organic fertilizer.

In the traditionally farmed tomato, phytosanitary treatments vary much depending on the variability of the impact of plagues and diseases in each of the greenhouses. Nevertheless, the synthetic phytosanitary products consumption has a downward trend in its use for biological fight.

In spite of this variability, averages of real data from the Basque Country have been used, and non-biological treatments have been considered for calculations.

In the organic tomato manure was used as common organic fertilizer.

Land works: Organic tomato is farmed on a raised bed between furrows, so no agricultural machinery is used for this labour. Heating the greenhouses is the only requirement.

The machinery used for organic agriculture has lower power than those used in conventional agriculture.

Irrigating: Traditionally farmed potato is mainly cropped in the region of Alava in the Basque Country, and irrigation water comes from a main rain reservoir that is distributed by sprinkler irrigation and by means of gravity to the plots to be irrigated. Most of the farmers do not use any fuel, but there is low fuel consumption where an intermediate reservoir is needed. Therefore this fuel consumption was considered. Nevertheless, the irrigation water needs mainly depend on annual climate conditions, plot's location, and the farmers' habits.

For the organic tomato trickle irrigation is used.

Raw materials transport: Table 1 shows the distances in km considered for seeds, fertilizers and pesticides transportation to the farm and also the distance from the cultivated crops to the storage point to be later delivered.

Table 1. Distances (km) considered for vegetal raw materials, phytosanitary products, and delivery to the storage point of the crops.

CROP	Seed (km)	Fertilizers and/or pesticides (km)	Storage point (km)
Traditionally farmed potato	10-20	10-20	10-20
Organic potato	10-20	10-20	5-10
Traditionally farmed tomato	40	20	10
Organic tomato	20	20	10

Waste output: Plastic waste outputs come from the packaging of fertilizers, pesticides, and substrate (tomato). Recycling quantity was considered 20% of the plastic produced in the Basque Country (IHOBE, 2008).

3. Life Cycle impact assessment

The purpose of the third phase of the LCA is to analyse the inventory results to better understand their environmental significance by classifying the inputs and outputs of the inventory phase in specific categories and modelling the inputs and outputs of each category into an aggregate indicator (ISO, 2000)

The following impact categories were chosen among CML 2 Baseline 2000 V2.04.:

Abiotic resources depletion (kg SB eq.)
Acidificación (kg SO_2 eq)
Eutrophication (kg PO_4^{--} eq)
Global warming (100 years) (kg CO_2 eq)
Ozone layer depletion (kg CFC-11 eq)
Human toxicity (kg 1,4-DB eq)
Fresh water aquatic ecotoxicity (kg 1,4-DB eq)
Marine ecotoxicity (kg 1,4-DB eq)
Terrestrial ecotoxicity (kg 1,4-DB eq)
Photochemical oxidation (kg C_2H_4)

Life cycle assessment graphs for traditionally and organic farmed potato and tomato are respectively shown in the Figures 2 and 3 for all the categories previously mentioned

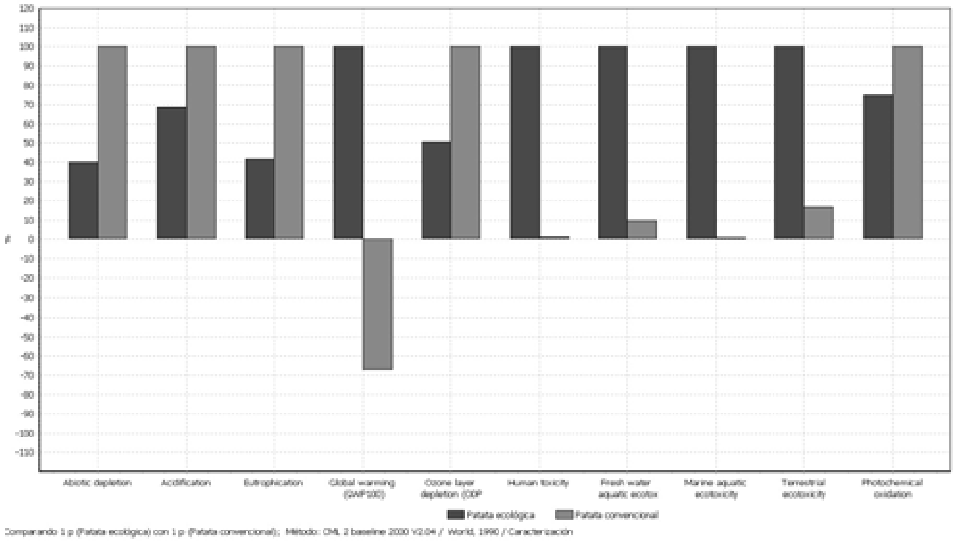

Figure 2: Comparative impact assessment between traditionally and organic farmed potato

4. Results and discussion

Once the most significant impact categories were identified, a contribution analysis enabled us to identify the subsystems with the highest environmental loads.

- Production and exploitation of fertilizers and pesticides is the phase with highest inputs and outputs for three of the four crops analysed (traditionally and organic farmed potato, and traditionally farmed tomato), having then the higher environmental impacts. This impact specifically represents 50% of all the impacts in the traditionally farmed potato.
- Organic tomato shows negative values linked to fertilizers exploitation, due to the use of manure as fertilizer. This is organically produced, while compost has several

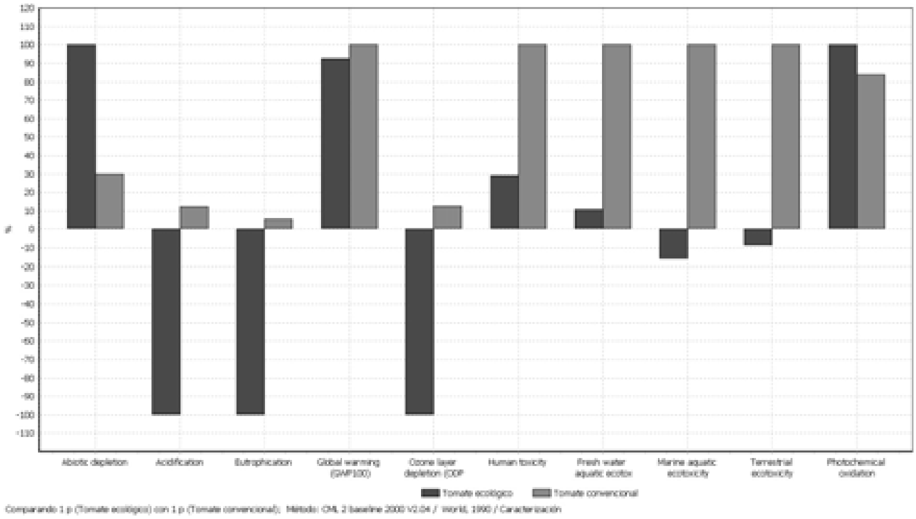

Figure 3: Comparative impact assessment between traditionally (hydroponic) and organic farmed tomato

processing phases involved in their production. Anyway, manure emissions are higher than the compost ones due to the fact that manure is not a stabilised fertilizer.

- High quantities of water consumption are used in the traditionally farmed potato.
- Environmental impacts of 'Land Works' for the organic potato are the highest. In order to produce the same quantity of potato, more arable land is needed for organic potato to get equal efficiency, consequently a higher consumption of fossil fuels are needed, increasing then environmental impacts.

Some improvement actions were identified in order to reduce the environmental impact in the whole system.

The first option is to **replace chemical fertilizers and pesticides by organic ones**, not coming from industrial processes. As an example, exploitation of manure coming from local farms minimises the impacts connected to the farms.

Another proposed action is to minimise tractors' exploitation by **optimising the routes**, especially in the organic crops where more place is needed for cultivation (Anton, *et al.,* 2005).

Reduction in transport distances for raw materials is also proposed, in order to focus the effort on local suppliers, It has to be mentioned that this phase has not the higher impacts,

Finally an important reduction in water consumption is likely to be achieved if some changes are carried out. For example, optimising the irrigating systems, adjusting the volumes of water depending on the crops and climatology, etc., the environmental impacts connected to water extraction and lixiviation will be minimised.

5. Conclusions

The obtained results provide some key sustainability factors to take the most suitable decisions when face a new agricultural project. After comparing the four crop types it can be concluded that:

- Organic tomato crop has lower environmental impacts due to manure use instead of inorganic fertilizers. Manure as organic fertilizer minimises environmental impacts overall.

- Traditionally farmed potato has lower influence in the Global warming than the organic one due to its higher efficiency of the arable land. Anyway, terrestrial ecotoxicity levels remain higher in the organic potato, due mainly to the production and exploitation of compost. The environmental impacts connected to production of compost are very high, as it has been considered as an industrial compost production.
- Due to the globalization of the chain of supermarkets, in order to make an appropriate decision when chosing between an organic or conventional production, the delivery distance is a factor key (Jungbluth, 2002).

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