Identification of the Main Factors Affecting the Environmental Impact of Passive Greenhouses

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Abstract
The objective of this study was to quantitatively evaluate the environmental impact of tomato production in passive greenhouses and to identify the most relevant environmental issues. The LCA approach was used in this study. A tomato crop was cultivated in a steel-framed greenhouse; plants were grown in a closed-loop irrigation system in which the substrate was perlite bags. With the exception of the toxicity indicators, the main sources of environmental impact were fertilizer production and the process for manufacturing the materials used for the greenhouse structure and the auxiliary equipment, substrate, irrigation and recirculation equipment. The relatively short life span of plastic covered greenhouse structures and the minimal input of external energy involved in the production process are the most important factors related with the production process. The study compared the use of two cladding materials: rigid PC sheet with a lifespan of 10 years and flexible LDPE film with a life of three years. The types of cladding compared in this study (PC sheet and LDPE film) are not particularly relevant for environmental analysis.

INTRODUCTION
Life Cycle Assessment, LCA, is a tool for assessing the potential environmental impact of a given product or a system and considers the entire life cycle of a product from resource extraction to waste disposal. According to ISO standardisation guidelines an LCA study can be divided into four steps: goal and scope definition, inventory analysis, impact assessment, and interpretation. When defining goal and scope, the aim and the subject of the LCA study are determined and a ‘functional unit’ - for instance, yield per square meter- is defined. In inventory analysis, all extractions of resources and emissions of substances attributable to the studied functional unit are listed. Impact assessment determines the magnitude of the potential impact of individual substances within each impact category. Impact categories correspond to particular environmental problems, such as human toxicity or ozone depletion. The final step in an LCA study involves interpreting the results obtained from the previous three steps, drawing conclusions and formulating recommendations (Antón et al., 2002).

When this procedure is applied to an agricultural product grown in a greenhouse, not only are the adverse environmental effects derived from the whole of the production process in question (these include: eutrophication, pollution associated with the use of pesticides, and waste generation) but other aspects must also be taken into account, such as the environmental impact associated with the manufacturing and transport of raw materials, energy use, the production of materials used for building greenhouses, the waste generated when the facilities are retired from use, and all of the other aspects that form part of the life cycle of the considered product and which may produce a negative environmental impact. All of them will have to be accounted for, by attributing a different environmental impact to each product unit (Antón, 2004).

Previous works on the application of LCA in protected horticulture relate to projects in northern Europe. They show that reducing heating requirements is a priority if environmental loading is to be limited (Jolliet, 1993, Bucher et al., 1996, Nienhuis et al.,
Artificial lighting is a technique that also has a major impact on the environment (Jolliet, 1993, Van Woerden, 2001). However, most greenhouses located in the Mediterranean basin could be considered as passive systems since they use very little external energy. As a result, factors other than heating and lighting are the cause of the environmental burden of these passive greenhouses.

The objectives of this study were to quantitatively evaluate the environmental impact of tomato production in passive greenhouses and to identify the most relevant environmental issues associated with the materials used throughout their life cycles; from their origins as raw material until their end as waste.

MATERIALS AND METHODS

The LCA approach (Audsley, 1997, Guinée et al., 2002) was used in this study assigning Life Cycle Inventory results to the different impact categories. The following category indicators, that are typically used in LCA, were assessed using the software TEAM (Ecobilan, 1999): climate change; depletion of the ozone layer; photochemical oxidant formation; air acidification; depletion of non-renewable resources; eutrophication; human toxicity; aquatic and terrestrial ecotoxicity.

Data from tomato crops cultivated in a steel-framed greenhouse were used. Plants were grown in a closed soilless system in which the substrate was perlite bags. The study also compared the use of two cladding materials: rigid polycarbonate, PC, sheets with a life expectancy of 10 years and a flexible low density polyethylene, LDPE, film with a working life of three years. This study only considers the means of production, so the analyses were ended when the tomatoes were harvested; “at the farm gate”. Non-yield biomass was composted and reused on other exploitations and the rest of the waste was disposed of in landfills. The functional unit describes the primary function performed by a product system: in this case, it provided a reference against which input and output data were compared and standardised in the mathematical sense (ISO-14040, 1997). As the main function of a greenhouse is to grow produce, tomato production in kg was selected as the functional unit.

1) Tomato production

Due to its complexity and in order to facilitate study, the tomato production was divided into five sub-systems:

1.a) Greenhouse management during tomato production
1.b) Fertilizer production
1.c) Fertilization and irrigation
1.d) Pesticide production
1.e) Pest management

2) Manufacturing

Two further subsystems were added in order to take into consideration the different process and materials used to manufacture the greenhouse structure and the auxiliary equipment, fertilization and irrigation system:

2.a) Greenhouse structure
2.b) Auxiliary equipment

3) Waste

A final system was analysed, which included the management of waste generated during and at the end of greenhouse crop cultivation.

RESULTS AND DISCUSSION

Table 1 shows the overall impact of the global process of tomato greenhouse cropping for the different impact categories and their percentage contribution to the different subsystems considered. With relation to climate change, it is important to point out that as a result of fixation of CO₂ by the crop, there is a reduction of total CO₂ releases.
Fertiliser production was the main stage in the cycle that contributed to climate change, 57.2%, eutrophication, 33.9% and air acidification, 30%. During crop production, pesticides were mainly responsible for the toxicity indicator scores, while the waste system was the main contributor to both eutrophication and climate change: it contributed 21% to both and also 5% to aquatic toxicity. Eutrophication generated by the fertirrigation subsystem, was low due to the fact that the crop system analysed was a closed-loop irrigation system in which leachates were re-circulated.

The main reason for the high rate of depletion of non-renewable resource was the consumption of more material: substrates, collecting pipes, benches, and plastics, in closed-loop irrigation systems. The use of perlite as a substrate, a natural resource that consumes natural gas in its process of thermal expansion, was a particular source of concern.

In previous work comparing closed systems with free drainage and soil cultivation (Antón, 2004), it was shown that while eutrophication clearly improved in closed systems, other factors, such as the depletion of non-renewable resources and the formation of photochemical oxidants, increased due to the greater quantity of material used in these systems.

The auxiliary equipment (substrates, fertirrigation and recirculation equipment) made the greatest contributions to the categories of air acidification, 76.6%, climate change, 50.6%, photochemical oxidant formation, 36.3% and air acidification, 27.2%. The greenhouse structure subsystem (steel frame and cladding) mainly contributed to the categories of climate change, 39.5%, photochemical oxidant formation, 36.1% and air acidification, 25.2%. The two subsystems constituted the total infrastructure of the tomato greenhouse crop and contributed the highest source for environmental impact. These results contrasted with those for industrial systems, where the impact of infrastructure equipment is negligible, and concorded with those presented by Cowell (1998) for agricultural systems. The reasons for this are to be found, on the one hand, in the characteristics of the materials used; which have a short life span in comparison with industrial equipment and, on the other, in the minimal consumption of fossil energy during crop production. It should be remembered that solar energy is the main energy source for horticulture in Southern Europe.

Comparisons between the two cladding materials; LDPE and PC sheets, reveal similar values from an environmental point of view. The use of PC sheets increases eutrophication and air acidification (by 6% and 5%, respectively) while it reduces damage such as photochemical oxidant formation and climate change (by 9% and 4% respectively).

Manufacture of polycarbonates makes greater contributions to eutrophication and the depletion of non-renewable resources (Fig. 1a and 1b). On the other hand the shorter life span of LDPE increases its environmental impact, particularly with respect to waste generation that contributes to air acidification and climate change (Figs. 1c and 1d).

**CONCLUSIONS**

The greenhouse structure has the greatest impact in all of the environmental categories except the toxicity indicators. This is due to the relatively short life span of plastic covered greenhouse structures and by minimal inputs of external energy in the production process.

The types of cladding compared in this study (PC sheet and LDPE film) are not particularly important as regards the environmental analysis.

Further research must be oriented towards reducing the environmental impact of the materials used in the facilities for passive greenhouse crops. Their substitution by recycled materials with a long life span could be a possible solution. Improving fertiliser use and looking for alternative local substrates, preferably derived from reused materials are other important points to take into account.
ACKNOWLEDGEMENTS

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Literature Cited


### Tables

Table 1. Total absolute values for tomato greenhouse crop in a closed system for each environmental category considered and percentage contributions to the overall process for the different subsystems studied.

<table>
<thead>
<tr>
<th></th>
<th>Tomato Production</th>
<th></th>
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<th>Manufacture</th>
<th>Waste</th>
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<tr>
<td></td>
<td>TOTAL</td>
<td>Greenhouse</td>
<td>Fertilizer production %</td>
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<tr>
<td></td>
<td>0.100</td>
<td>0.041</td>
<td>5.9</td>
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<td>0.021</td>
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<td>Eutrophication, g eq. PO₄</td>
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<td>0.004</td>
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<td>Depletion of non-renewable resources, year⁻³</td>
<td>0.027</td>
<td>0.013</td>
<td>12.7</td>
<td>30.0</td>
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<td>Air Acidification. g eq. H⁺</td>
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<td>0.045</td>
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<td>Photochemical oxidant formation. g eq. ethylen</td>
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<td>5.32</td>
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<td>Terrestrial toxicity. g eq. Zn air</td>
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Fig. 1. Comparisons between the two cladding materials. PC sheet and LDPE film. Contribution of the plastic manufacture subsystem to the eutrophication and depletion of non-renewable resource categories. Contribution waste management system to air acidification and climate change categories.