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Comparing the usefulness of assessment tools for environmental impacts evaluation of organic greenhouse horticulture

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Abstract

Organic farming is primarily meant to be sustainable; however, evaluating the sustainability of farming systems in a complete way is a complex issue. In recent years, a high number of sustainability assessment tools has been developed and used worldwide; nevertheless, even if they differ in terms of analysis depth, none of them seems comprehensive enough. Amongst all the existing tools we have chosen two of them, Life Cycle Assessment (LCA) and Public Goods Tool (PGT). In the case of specific farming systems such as organic greenhouse horticulture, a comparison between LCA and PGT has been done to evaluate the potential integration between both sets of results so that a single holistic assessment method could be obtained. This could help to understand which sustainability aspect these methods should focus on and which type and depth of data would be desirable. This paper mainly highlights the methodological differences and potential common points between the tools, referring to a chosen case study (Tolhurst Organic, a stockfree horticultural unit located near Reading, UK) that has been assessed with both, and then gives suggestions for future research. An updated and improved version of the LCA Excel tool, initially developed by the EUphoros project (2008-2012) and then integrated with data from PGT, was the main outcome of the comparison. While LCA gives quantitative results on impacts on key environmental categories, PGT shows ways to improve farming practices regarding a set of social, economic and environmental aspects through a simple scoring system. In this sense, trying to combine results from different assessment tools might be difficult because it highlights the lack of overall complementarity between them, but at the same time it could be a useful starting point for an integrated discussion on production, use of natural resources and improvements of practices among decision-makers.

Keywords: organic farming, vegetable production, protected crops, sustainability evaluation, life cycle assessment, public goods

INTRODUCTION

Organic agriculture assumes a central role in producing healthy food while avoiding excessive negative impacts on the environment.

Among the different farming systems, horticultural productions are major contributors to food production since fruit crops and vegetables are both integral constituents of a healthy human diet. However, even within the organic framework, they

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often are more intensive in terms of labour and used inputs (Raviv 2010), especially if crops are grown inside protected structures.

Globally, a core concept in organic protected horticulture is the development of more environmentally friendly applied techniques and technologies (i.e. advanced structures and growing methods), capable of facing resources shortage and increasing request for high quality food.

Growing crops in greenhouses has raised contrasting views among experts because on one hand, this system protects the plants from external agents and extends the living cycle of the crops, potentially improving their quality and allowing higher yields, not to mention providing products all-year round (Pardossi et al. 2004; Simson and Straus 2010). On the other hand, it is argued that protected horticulture requires a huge amount of energy and generates large quantities of wastes (Vox et al. 2010).

Nowadays, there is a lack of specific rules for this specific production system, so practices might differ widely from country to country; at the same time, there is a need to keep true to organic agriculture's basic principles specified in the regulations (i.e. maintenance of biodiversity and fertility, management of soil and crop health, rational use of resources, etc).

The European Union is also currently lacking reliable data on areas devoted to organic protected vegetable production; according to Tittarelli et al. (2014), it is estimated that approx. 4,500-5,000 ha of greenhouses are effectively managed organically within the EU.

Agricultural systems, especially organic greenhouse productions, are faced with changes triggered by population dynamics, global market forces, investments, advances in science and technology, climatic variability, consumers' demands, subsidies, social movements demanding food sovereignty, land reform and reduction of poverty. Identifying indicators to show performance, especially at farm level, uncover specific management problems, or highlighting unwanted impacts, and what action to take, is a major task, for the focus of change in practices is to improve the overall long-term health of farm businesses (Koohafkan et al., 2011).

On this note, it is recognised that there is a general lack of assessment tools focused on evaluating sustainability performances of organic protected production. In the case of organic greenhouse horticulture, assessing sustainability performance is a complex matter, for it is far more intensive than any other farming system. However, it is considered a key production system for the future, given the physical protection from the changing environmental conditions it provides to crops at any latitude.

This could open the way to possible on-farm data collection throughout the European Union either using existing tools (i.e. OCIS PG tool, Gerrard et al. 2011; LCA, U.S. EPA 2006) as references, or setting the foundations to develop new targeted methods to find suitable indicators for protected horticulture, and potentially create a standardised and adaptable system for performance evaluation of organic greenhouses in Europe.

MATERIALS AND METHODS

The main objective of this work was to compare different assessment tools and then try to evaluate the possibility of integration between them, so that a single comprehensive tool could be obtained, since there is no specific method to "measure" sustainability in organic greenhouse horticulture.

The first and main phase of the work has been focused on updating a simplified version of an environmental simulator, which was developed as an LCA Excel-based worksheet through the EUphoros project (2008-2012).

The LCA worksheet was updated expanding the set of available crops, reviewing both impact categories and characterization factors, and recalculating the data contained in the database, with the support of the SimaPro 8 software (i.e. addition of data on greenhouse structure materials and consequent emissions to air, water and soil).

The integration of LCA's initial data with those from PGT's worksheet has been evaluated and attempted and from a theoretical point of view, main drawbacks and possible improvements for both tools have been identified as a result.

Data collected during the assessment carried out in March 2015 at the farm used as "case study" (Tolhurst Organic, a stockfree horticultural unit based in Hardwick, Reading, UK) has been transferred into the LCA worksheet, to have a further example of its practical application and a means of comparison between the outcomes of the two methods.

The Case Study: Presentation

Tolhurst Organic Partnership C.I.C.[b] is based at the Hardwick Estate, just outside the village of Whitchurch-on-Thames, South Oxfordshire, UK, with 17 acres (approx. 7 ha) in two fields and 2 acres (approx. 1 ha) in the 500-year-old walled garden.

It is one of the longest running organic farms in England, holding the Soil Association certification and having been the first one to obtain the Stockfree Organic[c] brand in 2004. Iain Tolhurst is one of the founder members of the Thames Organic Growers[d] and has registered as a Community Interest Company in May 2014. It was also the first farm to be part of the Vegan Organic Network (VON)[e], which produced the world's first set of stockfree organic standards.

The farm produces high quality, locally available, organically grown food without using animal inputs (i.e. less land used, lower carbon footprint and energy requirements). In this case, soil fertility comes primarily from fertility building crops and well-designed rotations.

In an average year, Tolhurst Organic produces at least 85% of the value on its land and delivers fresh in-season vegetables and fruit through the Neighbourhood Rep Scheme, which runs the drop-off points.

According to Tolhurst, the farm grows 300 different crops, considering both species and varieties of vegetables, all-year round on approximately 6.5 ha of land, comprehensive of the fields, the garden and the greenhouses within the wall, and it manages to supply fresh produce for an average of 50 families per ha.

The farm is classed as an AONB (Area of Outstanding Natural Beauty), thanks to 500m of hedges planted with mixed indigenous species and shrubs, and a total 1800m of hedgerows that reduce pest attacks and keep a healthy balance of predators, without using any kind of spray.

All the plants are grown on-farm (over 140,000 per year) and an average of 120 tons of vegetables is directly produced and distributed yearly.

The farm also has a low energy storage system in the form of a well-insulated room, mostly used for squashes and potatoes, where the temperature stays naturally at 8ºC. There are also poly-tunnels on the farm, usually hosting lower-yielding vegetables (i.e. tomatoes, cucumbers, carrots, and lettuces) and seedbeds, and covering a total area of 0.17 ha.

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[b] http://www.tolhurstorganic.co.uk/
[c] http://www.stockfreeorganic.net/
[d] http://thamesorganicgrowers.org/
[e] http://veganorganic.net/

Since they represent a fundamental part of the farm management, a great care is put into rotation plans, both out in the fields and between greenhouses, and green manures have a dominant role in this matter. The farm uses a mix of 20 different crops as green manure, most of them legumes, and one third of the rotational period is devoted to fertility building (one year every 2.5-3). This way, green manures are present at all times keeping the soil constantly covered.

In terms of nutrient levels, it has been pointed out that leafy greens (i.e. kale, swede, celeriac, etc), are grown during the winter for their high N content and that there is a general K deficit, which could be solved by applying wood ash as a natural fertiliser.

An important point is the self-production and use of organic matter, which amounts to roughly 250m^3 per year (125 tonnes, possibly 4ha worth); all the organic waste produced on-site is then recycled as compost.

The farm is also showing a growing interest towards agroforestry, in terms of wood production and biodiversity management, and recently they have planted 7 acres (3 ha) with strips of mixed native tree species (i.e. alder, willow, birch, maple, hornbeam, oak, wild cherry) inter-planted with apple trees, which will be managed with short rotation coppice and used for firewood.

As an added measure to maintain biodiversity, ecological structures such as beetle banks, hedges and field margins are present and managed all around the farm, to serve as refuges for natural predators and a source of food for wild animals.

In regards to irrigation, the farm uses a total of 2240m^3 of water over a period of 20 weeks every year, and it accounts for most of the petrol used on farm because the water is pumped from the aquifer.

In 2007, the total carbon footprint of the farm has been calculated[f] and it is approximately 8 tons, same as the average household in the UK, with the farm being 90% more efficient than conventional supermarket products. In terms of consumptions, the total energy goes on fuel for tractors, delivery vehicles, and other machinery (2030 litres year^{-1}) and electricity is used for lighting buildings, providing facilities for plant growing, and other odd jobs (6400 units year^{-1}).

RESULTS AND DISCUSSION

The Case Study: Results from PGT

Tolhurst Organic is a specialised horticultural enterprise, so it was difficult to single out every cultivated crop and the related areas because the Public Goods tool has not been designed for organic greenhouse horticulture. This might suggest setting up a separated Excel worksheet, which would be created specifically for protected structures. Moreover, vegetable yields and requirements could be assessed through splitting the crops between families.

The same could be done for green manures, since they are used as a mix and the areas on which they are cultivated are limited, so it is difficult to make precise calculations.

As shown in Figure 1, the lowest scores of the assessment done via Public Goods tool were registered for spurs like *agri-environmental management (2.8/5)* and *water management (1.8/5)*, mainly because of a lack of agreement with some of the schemes currently in force (i.e. wildlife habitats, permanent pasture, conservation plan; joint character area; water audit, management plan). In these cases, key aspects such as biodiversity improvement and crop protection, are being managed in more alternative and

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[f]Audit carried out by Prof. Tim Jackson (BBC Climate Change Special, March 2007; source: www.tolhurstorganic.co.uk).

sustainable ways (i.e. natural structures, no use of pesticides, etc). The highest scores were registered for spurs like *soil management (4.8/5)*, *food security (4.8/5)* and *agricultural systems diversity (5/5)*. Once again, green manures are an integral part of all the rotations, so that the soil is never left uncovered. Moreover, an important part of the farm's philosophy regards growing local fresh produce, while minimising the use of external inputs, and all the vegetables produced are sold to local families and communities.

A weak point for greenhouses would be the amount and disposal of plastic wastes, and in this case Life Cycle Assessment could offer a more in-depth analysis.

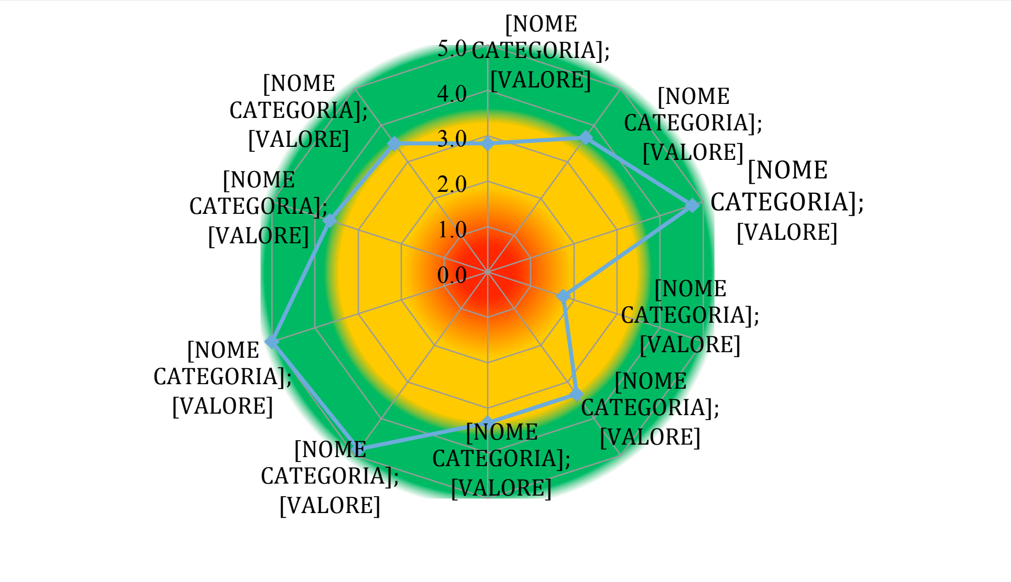

Figure 1. Graphic representation of the final results of the assessment done via Public Goods tool at Tolhurst Organic (March 2015).

The Case Study: Results from LCA

The total farm protected area amounts to 0.17 ha (1700 m^2), and since the LCA Excel tool considers different types of structures (i.e. multi-tunnel, glasshouse, parral, tunnel), a multi-tunnel was chosen for the analysis, to be as close as possible to reality. Further requested data comprises the dimensions of the structure, the materials used and their related lifespans, the eventual use of mulching, and the transport of said materials.

The initial data sheet requires information such as fuel use, water employed for irrigation, electricity consumption, and use of fertilizers, so data from the previous assessment have been recalculated and proportioned to the farm's protected area (Table 1).

Table 1. Data taken from the assessment via Public Goods tool, recalculated to be proportioned to the total on-farm protected area (1700 m^2) then used for LCA. Both sets of data refer to an average year of consumption.

Data Input	Total Quantity (from PGT)	Proportioned Quantity (in LCA)
Fuel usage (diesel)	850 l	0.014 l m^{-2}
Water for irrigation	2240 m^3	37 l m^{-2}
Electricity consumption	3400 kWh	0.0425 kWh m^{-2}
Compost (fertilizer)	125 t	2.08 kg m^{-2}
Wood chip (fertilizer)	125 t	2.08 kg m^{-2}
Wood ash (fertilizer)	1.5 t	0.025 kg m^{-2}

The integration between the two sets of results has been attempted and it had highlighted major drawbacks for the lack of overall complementarity between them. LCA gives quantitative results on impacts on key environmental categories while PGT shows ways to improve farming practices regarding a set of social, economic and environmental aspects through a simple scoring system.

The comparison between assessments was only experimental given some main gaps that were found, such as methodological dissimilarities between tools and lack of data for reference in LCA's case (Table 2; for more detailed results, see

Figure 2).

However, the use of different methods to assess the sustainability performance of a farming system would give stakeholders and decision-makers the chance to have an integrated discussion on possible improvements (i.e. tangible data on productions and use of natural resources and qualitative evaluation of farming and conservation practices).

Table 2. Total results of the case study via Life Cycle Assessment (supported by SimaPro 8 software; June 2015). Red and green cells respectively represent higher and lower values in comparison to the references used during the analysis.

Impact Category	Unit (per kg of tomatoes)	Own Results
Climate Change (CC)	kg CO_2 eq	147.31
Resource Depletion (RD)	k Sb eq	0.946
Acidification (AC)	molc H^+ eq	4.241
Terrestrial Eutrophication (TE)	molc N eq	16.85
Marine Eutrophication (ME)	kg N eq	0.231
Freshwater Eutrophication (FE)	kg P eq	-1.309
Particulate Matter (PM)	kg PM2.5	0.298
Water Use (WU)	m^3	0.04

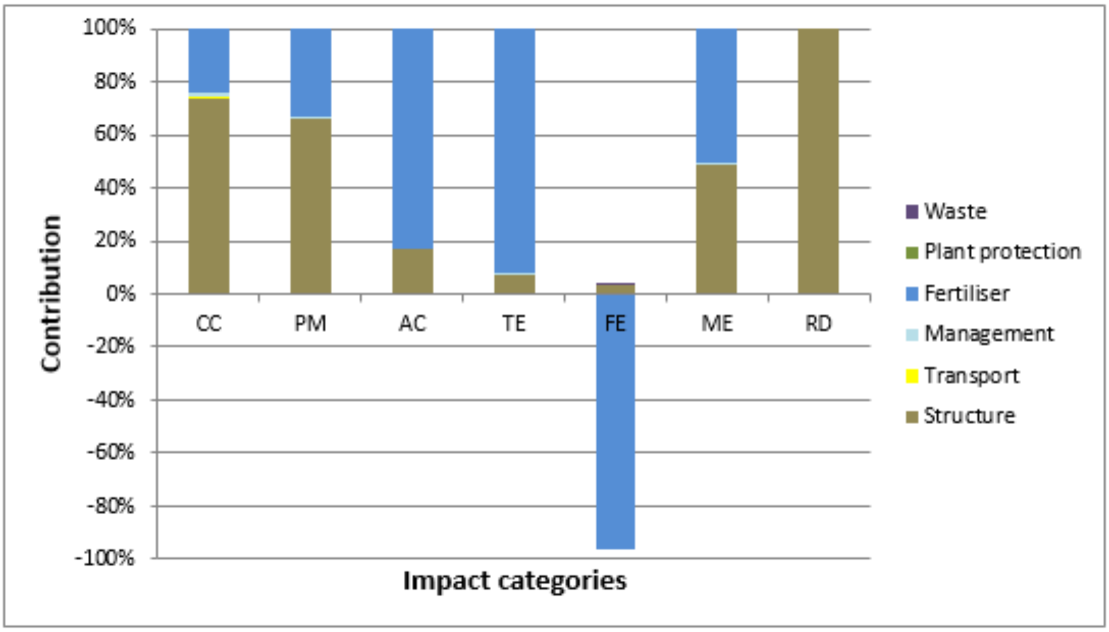

Figure 2. Detail of results from case study via LCA. Contributions from each group of activities (in %) are shown per impact category. In general, structure and fertilization are the largest contributors to soil, water and air emissions for all the impact categories considered.

DISCUSSION

Through the first stage of the work, an up-to-date and improved version of the LCA Excel-based tool has been obtained, comprising the following parts:

- Four main worksheets (i.e. Instructions, Input Data, Detailed Results and Total Results);
- A Database containing the default data, and an Inventory with all the information needed for the actual assessment;
- A set of basic impact categories (i.e. climate change, particulate matter, terrestrial and aquatic eutrophication, acidification, resource depletion) that could function as a starting point for future assessments of specific farming systems such as organic greenhouse horticulture (i.e. possible future integration of categories such as land use and biodiversity loss).

This Excel-based simulator would be used as a practical support to calculate the environmental impacts of protected production systems and could be helpful for both growers and advisors to compare different options in terms of efficient use of resources.

The presented case study has been evaluated with two different methods so far, comprising both a general qualitative assessment of the farm sustainability and a range of quantitative data on specific environmental impacts.

A few points for further research have been highlighted after the comparison:

- The potential addition of social and economic aspects to LCA;
- The integration of PGT with more specific data on organic greenhouse horticulture, possibly through an extra Excel worksheet or a dedicated "spur";
- The collection of more data on organic farming (greenhouse horticulture included) for LCA;

- The implementation of local and/or regional databases for LCA, potentially through representative case studies.

Also, some observations on both tools could be added to the discussion for further improvement:

- The main difference between them is in the type of data they employ (i.e. exclusively quantitative for LCA, mix of quantitative and qualitative for PGT);
- Initial data collection is a long and complex phase in both cases;
- The tools are both applicable to "industrial" farming systems (large productions);
- LCA showed some difficulties for application to local situations/small farms;
- Neither tool is dedicated to organic greenhouse horticulture, but could be "modifiable" according to the needs of the analysis (i.e. choice of data as "specific" as possible depending on the case, especially for LCA).

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