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ENVIRONMENTAL ANALYSIS OF SUSTAINABLE PRODUCTION PRACTICES APPLIED TO FLORICULTURE CROPS IN VENETO REGION

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Declaration

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

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Table of Contents

Riassunto

Le colture protette svolgono un ruolo decisivo nel panorama economico dell'agricoltura europea e mediterranea, sia sotto il profilo sociale, per numero di occupati, sia dal punto di vista economico, per PLV (Produzione Lorda Vendibile) e per il numero di attività correlate. Negli ultimi anni gli agricoltori si trovano ad affrontare una continua pressione al ribasso sui loro margini di profitto, a causa dei prezzi stagnanti e dei costi crescenti. Per le piccolo-medie imprese del settore, un'opzione per mantenere la competitività è concentrarsi su produzioni di nicchia, fiori e piante locali e prodotti stagionali. Un ulteriore strumento a disposizione dei produttori potrebbe derivare dalla crescente attenzione, e dalla disponibilità a pagare un prezzo maggiore, per fiori e piante con certificazioni sostenibili, come evidenziato da recenti lavori sul comportamento dei consumatori. La produzione sostenibile è un approccio olistico all'analisi ambientale di beni e servizi, che necessita di strumenti adeguati. La valutazione del ciclo di vita (LCA, Life Cycle Assessment) è una metodologia diffusa e riconosciuta a livello internazionale per l'analisi degli impatti ambientali di tutti i beni e servizi. Il primo obiettivo di questo lavoro di ricerca è stato la caratterizzazione di alcune catene produttive della floricoltura veneta sotto un punto di vista ambientale, attraverso l'applicazione della metodologia LCA, al fine di individuare punti critici e determinare l'impronta di carbonio (Carbon Footprint) per i prodotti finali. Nel corso del progetto FloSo è stata condotta una raccolta preliminare di dati relativi a tre specie ornamentali allevate in vaso, poinsettia (*Euphorbia pulcherrima* Willd.), geranio zonale (*Pelargonium ×hortorum* Bailey) e ciclamino (*Cyclamen persicum* Mill.). Le colture selezionate sono state scelte per la loro importanza economica, in quanto coprono una quota significativa (17%, 20% e 22%, rispettivamente) del mercato italiano di piante fiorite, e per analizzare una tipica sequenza colturale di un'azienda floricola. I primi dati sono stati acquisiti da due aziende pilota ospitanti alcune prove sulla sperimentazione di materiali alternativi, come i contenitori biodegradabili, che sono stati testati per la coltivazione delle specie sopracitate. Sono state inoltre utilizzate diverse quantità di lolla di riso come componente dei substrati di crescita, in sostituzione di perlite e torba. Delle prove di coltivazione hanno permesso di testare l'idoneità dei substrati formulati per la coltivazione in vaso. Il nostro primo obiettivo è stato la definizione di un primo inventario del ciclo di vita (Life Cycle Inventory, LCI) delle colture selezionate, cercando anche di identificare un set di

pratiche rappresentativo e una comune metodologia di acquisizione dati. Le pratiche generali di coltivazione per le specie studiate sono state raccolte durante le prove e attraverso una serie di interviste telefoniche, di e-mail e di comunicazioni personali con i responsabili della produzione. Queste comunicazioni sono state utilizzate per produrre e convalidare un questionario generale che è stato poi inviato ad un campione più ampio di aziende. Con i dati raccolti, è stata calcolata l'impronta di carbonio, confrontando le colture coltivate nel contenitore compostabile in lolla di riso e in vaso plastico tradizionale (capitolo II). I confini del sistema definiti per questa prima analisi vanno dall'arrivo delle giovani piante alla pianta commercializzabile (pianta fiorita e sufficientemente sviluppata). I valori per la categoria Global Warming Potential (GWP) comprendono l'elaborazione dei dati su produzione e trasporto dei materiali, e loro utilizzo durante la fase di coltivazione. Le emissioni associate alla produzione di strutture protettive e attrezzature non sono state incluse nell'analisi. In questa prima analisi abbiamo stabilito la dimensione relativa ad alcuni fattori nella fase di produzione, in particolare i materiali utilizzati per i vasi di produzione e per i componenti del substrato. Il combustibile utilizzato negli impianti di riscaldamento si è rivelato uno dei maggiori responsabili dell'impatto ambientale di poinsettia e geranio zonale. I risultati di questo studio sono paragonabili a quelli di studi precedentemente condotti per la produzione di piante di poinsettia. Abbiamo in seguito condotto un'analisi più specifica e approfondita su piante di ciclamino allevate in quattro differenti substrati contenenti quantità crescenti di lolla di riso (capitolo III). I confini del sistema includono la coltivazione dall'arrivo delle giovani piante al trapianto, includendo strutture e materiali di copertura della serra e attrezzature utilizzate. I dati sull'utilizzo d'acqua e fertilizzanti fanno riferimento a esperimenti specifici condotti per la prova sui substrati. I dati su materiali quali torba e lolla di riso provengono da Ecoinvent (ver. 2.2), e sono stati modificati in base a informazioni raccolte tramite questionari e interviste dirette con aziende e produttori, oltre che da dati pubblicati in letteratura. L'analisi degli impatti (LCIA) è stata condotta con il metodo CML 2001. In seguito, allo scopo di testare la validità delle analisi, si è deciso di sottoporre il questionario precedentemente sviluppato a un campione di 20 aziende appartenenti all'associazione Florveneto (Provincia di Treviso). Le aziende intervistate sono, in genere, a conduzione familiare, con una superficie media inferiore a 1,5 ettari. La maggior parte ha un garden center per la vendita diretta, mentre alcune sono specializzate per la vendita all'ingrosso. I dati raccolti descrivono la fase finale di coltivazione delle piante in vaso (dall'arrivo delle giovani piante alla pianta commercializzabile; il termine stabilito è la vendita del 70% della produzione). Durante la raccolta dati si notato come aziende con dimensioni e produzione simili differiscano, a volte significativamente, per tipologia di strutture, livello tecnologico degli impianti e pratiche di coltivazione adottate. Queste differenze si riflettono in un diverso approccio al tema della sostenibilità ambientale e, conseguentemente, in una diversa propensione ad adottare pratiche a minor impatto ambientale. Alcuni produttori ritengono che le loro imprese dovrebbero adottare ulteriori misure per migliorare la sostenibilità delle coltivazioni. Altri valutano sufficienti le misure già adottate per la tutela dell'ambiente, criticando apertamente le politiche restrittive imposte a livello nazionale o dall'Unione europea, in particolare per quanto riguarda l'impiego di prodotti fitosanitari. Una delle barriere all'adozione di pratiche sostenibili è la mancanza di informazioni circa l'attitudine dei consumatori verso queste produzioni e sui possibili vantaggi da esse derivanti. Fra i produttori con maggiore sensibilità verso la questione ambientale, abbiamo osservato alcune pratiche alternative che rispecchiano le diverse visioni della sostenibilità economica ed ambientale. Partendo da queste osservazioni, si sono valutate alcune alternative riguardanti le misure di conservazione del calore e le fonti energetiche utilizzate nei sistemi di riscaldamento. Sono state messe a confronto le performance effettive e teoriche di tre diversi impianti: bruciatore ad aria calda alimentato a gasolio; caldaia a biomasse (cippato) alimentante un sistema di distribuzione ad acqua; pompa di calore aria-acqua collegata a un impianto fotovoltaico (capitolo IV). Il calore necessario per assicurare la temperatura ottimale durante un ciclo di coltivazione di poinsettia (piante allevate in vaso 14) è stato utilizzato come unità funzionale. I risultati LCIA sono stati espressi per categorie mid-point e end-point, allo scopo di descrivere gli impatti per diversi comparti ambientali ed aree di protezione. Per le categorie d'impatto del metodo CML 2015, i potenziali benefici conseguibili dai sistemi alternativi si limitano a determinati indicatori (cambiamento climatico, consumo delle risorse, potenziale di acidificazione). Nelle aree di protezione calcolate con il metodo ReCiPe il sistema a biomasse ha performance migliori in due delle tre categorie (consumo delle risorse e salute umana). Infine, si è studiato come alcune scelte di gestione influenzino gli impatti nella coltivazione di geranio zonale e ciclamino, valutando anche le variazioni intorno ai valori medi ottenuti dal campione in analisi (capitolo V). Gli scenari valutati riguardano la gestione e il riutilizzo delle biomasse di scarto, la riduzione nell'uso di fertilizzanti e prodotti fitosanitari. I risultati evidenziano una maggiore uniformità delle pratiche colturali e del livello tecnologico nella coltivazione del geranio, che si traducono in una minore variabilità rispetto a quanto osservato per ciclamino. Per la prima specie i valori d'impatto sono considerevolmente superiori per tutte le categorie valutate, a causa del consumo di combustibili fossili per il riscaldamento delle serre. Per ciclamino, l'adozione di tecniche di controllo integrato e biologico e la sostituzione di una quota di fertilizzanti minerali attraverso l'utilizzo di compost nel substrato di crescita ha come risultato una significativa diminuzione nelle categorie di acidificazione potenziale, eutrofizzazione e tossicità per l'uomo. I benefici osservabili per il geranio si limitano al potenziale di eutrofizzazione, dato il contributo molto rilevante dell'energia necessaria per il riscaldamento nelle restanti categorie.

Summary

The widespread use of protected cultivation plays a decisive role in the economic panorama of European and Mediterranean agriculture, both under a social, by number of employed, and an economic point of view, by total GSP (Gross Selling Production) and number of satellite activities. In recent years, growers are facing a continuous downward pressure on their profit margins because of stagnant prices and rising costs. One option for small-sized companies to maintain competitiveness is to focus on specialty products, typical local flowers and plants, and seasonal products. The good responsiveness and significant WTP shown for organic and sustainable flowers and plants that emerged in recent works on consumers behavior, and a higher demand for such products especially in Northern European countries, can also represent strategic tools for the sector. Sustainable production is an holistic approach to goods and services that needs proper tools for its evaluation. Life cycle assessment is a widespread and internationally recognized methodology for the analysis of environmental impacts of all goods and services.

The first objective of this research has been the characterization of some productive chains of Veneto floriculture under an environmental point of view through the application of LCA methodology, with the aim of identifying critical points and determining a carbon footprint for the final products. A preliminary data collection, addressing three species of container-grown plants, poinsettia (*Euphorbia pulcherrima* Willd.), zonal geranium (*Pelargonium ×hortorum*) and cyclamen (*Cyclamen persicum* Mill.), was conducted during FloSo project. The selected crops were chosen for their economic relevance, since they cover a significant share (17%, 20% and 22% respectively) of Italian flower plants market (ISMEA, 2010), and in order to analyze an ideal crop sequence for the average floriculture farm.

The first acquired data came from two ornamental plant growers involved in the experimental trials. The project focused on the experimentation of alternative production inputs, such as biodegradable containers, which were tested in order to evaluate their feasibility during cultivation of the above mentioned species,. Furthermore, different amounts of rice hulls were introduced as a substrate component, substituting expanded perlite and increasing amounts of peat . Agronomic trials were conducted their suitability for plant growth. Our first goal was to define and carry out a first life cycle inventory (LCI) of

selected crops, also trying to define average production practices and a common data capture methodology. General production practices (foreground data) for the studied species were gathered during the trials, and through a series of telephone, e-mail and personal interviews with the production managers,. These communications were used to produce and validate a general questionnaire that could be submitted to a larger sample of enterprises. With the collected data, a Carbon Footprint was performed, comparing crops grown in the compostable rice hulls container and in a traditional polypropylene pot.

System boundaries were set from seedling arrival at the greenhouse to fully grown, marketable plants (plant is in flower and above-ground growth, sufficiently filling the container). Values for Global Warming Potential (GWP) category results from the characterization of raw material production, transport and use of cultivation inputs. Emissions associated with the production of capital goods (greenhouses facilities and mechanized equipment) were not considered. This first analysis showed the relative size of certain factors on the production phase, in particular the materials used for the production pots and growing media components. Fuel burned to heat the greenhouse environment turned out to be one of the major contributor to the environmental impact of Poinsettia and Pelargonium, and our results were comparable with previous studies carried out for Poinsettia plant production. Impact assessment results showed some limitations of the software databases and calculation methods, highlighting the need for more specific data.

A specific and more thorough assessment was conducted for Cyclamen plants grown in four growing media amended with different rates of expanded perlite or fresh rice hulls. The analysis included all inputs from transplant to market-ready flowering plants, also considering greenhouse structures and equipment. Data on water and fertilizer sourced from the growth trials. Data on specific processes (peat and fresh rice hulls production and transport) sourcing from Ecoinvent database (ver 2.2) were modified using information collected directly via questionnaires and interviews from different Italian enterprises, and from previous literature and studies. Impact assessment was conducted using CML 2001 method. In order to increase the knowledge of this floriculture sector in our region to confirm (or deny) the validity of the environmental analysis conducted so far, we expanded the data collection process to a sample of 20 greenhouse farms belonging to Florveneto organisation (province of Treviso). The average floriculture farm from which we collected our data has small acreage (average productive area < 1.5 hectares); most farms has a garden center for retail, and is mainly family-run. The sample also included a small number of more specialized wholesale farms. The collected data describe the production stage that concerns the final grower (system boundaries are set from seedling arrival at the greenhouse to the sale of 70% of marketable plants). During the data collection process we noticed how farms with similar size and production would differ, sometimes significantly, with regard to structure types, technological level of growing equipment, management decisions, and cultivation practices adopted for the same crops. These differences extended to the view, and consequently to the willingness to adopt, sustainable production practices. Some growers felt their enterprises should take steps to progress toward sustainable production, while other growers felt they already took care of the environment, and openly criticized the restrictive policies imposed at the national level or by the European Union, in particular regarding the use of plant protection products. Growers were also concerned about the consumer's perception of sustainable floriculture, and most of them question the benefits they would receive when adopting sustainable practices. Among the most environmentally concerned growers, different choices were made in the management practices of the studied species, according to their view of sustainability, which is intended both under an environmental and an economic point of view. Starting from these observations, a final frame of questions was formulated. The answers regarded the most important alternatives for energy conservation measures, systems to deliver heat and energy sources. Theoretical and actual performances of alternative heating systems, a wood chip boiler and an air-water heat pump powered by photovoltaic panels were compared to a conventional air heater. The impacts results were expressed for mid-point and end-point categories, in order to provide a complete set of values addressing different environmental compartments. Finally, while trying to define average impact results for of cyclamen and zonal geranium production, we investigated how different management choices and production practices affect final results. The scenarios we investigated concern typical environmental bottlenecks of protected cultivation, such as plant protection, waste management and reuse of biomass, and mineral fertilizers.

Chapter I Introduction

1. Floriculture

Protected cultivation of ornamental plants is an important sector for European and Mediterranean agriculture, from both a social, by number of employees, and economic point of view, by total GSP (Gross Selling Production) and number of satellite activities. Floricultural production includes a wide range of different types of plants and plant materials. They can be divided into cut flowers and foliage, potted plants, garden plants, nursery stock (trees), flowering leafy, annuals and perennials, bulbs and tubers (De Groot, 1999). Statistical data on worldwide floriculture are incomplete and not altogether homogenous. The total area of protected crops can be estimated at approximately 450,000 ha while the Mediterranean area covers more or less one-third of the total, around 130,000 ha, of which 15,500 ha is made up of glass-greenhouses and 110,0000 ha of plastic covered-greenhouses. Europe is the largest consumer market, absorbing approximately 50% of the worldwide production of cut flowers. Germany is the main consumer, followed by the United Kingdom, France and Italy. Italy is the second European country for flower production, having over 20,000 companies with a GSP of 2.5 billion €, 5.8% of total agricultural production (Eurostat, 2010). According to 2010 data (6th Agricultural Census), floriculture covered an area of 46,353 ha, 27,577 of which were constituted by plant nurseries (10,844 firms), 12,724 by flowers and ornamental plants (14,093 firms) and 6,052 by saplings and seedlings production (5,110 firms) (ISTAT, 2013a). Worldwide trade in floricultural production was estimated at 4 billion dollars in 1985, growing to 8.9 billion in 1990, and about 9.5? billion in 2001. This historically strong growth has experienced a halt and a less well-defined trend since 2009. In 2013, global export of cut flowers, foliage, living plants and bulbs amounted to 20.5 billion dollars, against 21.1 billion in 2011. In Italy, floriculture and plant nurseries are one of the economic sectors with an active balance of payments, worth around 118 million € in 2011, with ornamental plants leading the positive trend (ISTAT, 2013b). This latter segment also shows a high level of competitiveness, especially in some Central and Eastern European markets (Asciuto et al., 2008). One of the main structural changes currently taking place in the world of floriculture is the increase in international competition, particularly for cut flowers. With a combination of locally produced and imported flowers, the Netherlands is a dominant central market for the global cut flower trade. However, the Dutch share in global cut flower exports is decreasing, declining from 58% in 2003 to 52% in 2013. In the same period, Kenya, Ecuador, Ethiopia, Colombia and Malaysia have increased their share in global cut flower exports. Growers in these countries are able to achieve large-scale production of high-quality flowers at competitive prices (Evers et al., 2014).

Although the consumption of flowers and plants in the EU is still increasing, particularly in new markets like Russia and Eastern Europe, in traditional Western European markets expenditure on floriculture products has come to a standstill. Growers face a continuous downward pressure on their profit margins because of stagnant prices and rising costs. Flower prices have recently been under pressure, partly because of the increasing foreign supply and partly disappointing demand developments due to the economic crisis (Rikken, 2010). This is partly related to economic circumstances, in particular in the case of cut flowers that have a high correlation with disposable income. In certain markets, consumers seem to have moved to the low-value end of the market, which is mainly sold by supermarkets, discounters and DIY-stores. In the UK, the vast majority of cut flowers are sold by supermarkets, including discounters. In Germany, DIY-stores are popular outlets for buying indoor plants (Van Huylenbroeck, 2010). Recent studies (Schimmenti et al., 2010; 2013) investigated preferences and motivations of Italian consumers of flowers and ornamental plants. The motives for buying cut flowers are prevalently linked to special occasions, whereas the purchase of potted plants for personal use is prevalent, and in particular, as observed in other studies (Imanishi et al., 1992; Oppenheim, 1996), for home aesthetic purposes. These researchers found that ornamental plant purchases are still made in the traditional places: flower shops for cut flowers, and nurseries for potted plants. In the latter case a positive trend was found toward purchases from the large-scale retail trade. From this research and comparison with other studies in the same geographical area, it emerges that demand in this sector has reached maturity, and is no longer exclusively linked to purchases for special occasions. The diversification of sales channels, with the spread of the large-scale retail trade, especially in the north of Italy, shows a growing adaptation of the firms that operate in flower production and nurseries to changes in family consumption patterns. Growers operating in the high-cost regions of Europe will have to take action to remain competitive against increasing global competition and market stagnation. Many growers may opt to focus on cost leadership by means of scaling up and producing bulk products, which is a general trend that can be found in most agriculture sectors. Some growers will instead choose to relocate production abroad. Another option is to focus on products with a high weight/value ratio (e.g. potted plants), specialty products, typical local flowers and plants, and seasonal products. As regards organic ornamental products, purchases show a small degree of penetration, linked to the lack of knowledge of this market segment, as well as the limited supply. Nonetheless, the good responsiveness and significant WTP shown for organic flowers and plants that emerged in recent works (Schimmenti et al., 2009), and a higher demand for such products especially in Northern European countries, can represent strategic tools to sustain the growth of this market segment.

2. Sustainability

The term “sustain”, from the Latin sustinere (sus-, from below and tenere, to hold), means “to keep in existence” or to maintain and implies long-term support and permanence. Sustainability is essentially seen as a criterion for guaranteeing development based on ecological and social balance: “sustainable development is development that meets the needs of the current generation without undermining the ability of future generations to meet their own needs” (Hall, 2001).

Gafsi et al. (2006) have defined sustainable agriculture as —the ability of farming systems to continue into the future; i.e., sustainable agriculture means a maintenance of the adaptive capacity of farming systems, which allows preserving of the natural resources and the ability to farm and produce into the future without reducing the options available for following generations.

Originally, the concept of sustainability in agriculture mainly applied to food production, e.g. cereal crops, and secondarily vegetable and fruit farming systems. Nowadays, thanks to the improvement in economic status reached by the populations of Western countries, even ornamental plants production is called upon to give answers to the requests for sustainability. Several studies (Burchi, 2004; Ferrante, 2004; Bisaglia et al., 2008) confirm that demand for ornamental plants produced using environmentally-friendly techniques is rising among consumers.

In the last century, the birth and development of ecology led to the definition of the ecosystem concept (a self-organizing, self-maintaining and self-evolving structure) (Odum, 1969). The simplest and most widespread ecosystem model is: Input- Ecosystem-Output, where the system itself is treated like a “black box”. The ecosystemic approach has also been applied to agriculture and, by analogy with the ecosystem, the term agroecosystem (= ecosystem used for agricultural purposes) has been coined (Loucks, 1977). The sustainability of an agroecosystem is represented by its ability to maintain a given level of productivity over time and a given quantitative-qualitative level of environmental resources (Loucks, 1977).

The greenhouse is also a form of agroecosystem where, unlike other agroecosystems, the environment has been adapted to the crop in order to maximize its productivity. Other significant differences include greater production stability (smaller productivity fluctuations over time and smaller fluctuations in the quantity and quality of resources used) and reduced autonomy (measured in terms of dependence on inputs from outside the agroecosystem); starting from the latter observation, it is important to stress the difference between open field agriculture and intensive, protected cultivation, the latter being much more similar to industrial production systems.

The greenhouse system components are represented by the following inputs: natural resources (soil, water, air, organisms) and anthropogenic resources (chemicals, materials, seedlings). The system output is the useful product per covered soil surface unit (dry matter, energy, proteins, income). The output concept should also include modifications (positive or negative) of environmental resources associated to the production system.

Environmental issues linked to agricultural activities are usually grouped in the following categories:

- impacts related to energy consumption (global warming, resource depletion, etc.);
- surface and ground water pollution (nitrate and phosphorous fertilizers, pesticides);
- toxicity related to agrochemicals use;
- soil degradation;
- water depletion;
- decrease of biodiversity.

Some of the above-mentioned issues have been addressed by several studies, usually focusing on specific issues, such as integrated or biological crop protection (De Moraes and Tamai, 1999; Rose et al., 2004; Minuto et al., 2005; Slusarski, 2005), reduced pollution of aquifers through increased efficiency of fertilizer use (Verlinden et al., 2007; Alam et al., 2009), substitution of mineral with organic fertilizers (Peet et al., 2004; Panzacchi et al., 2008) , use of slow-release fertilizers (Penningsfeld, 1975; Kobel, 1975; Markus and Flannery, 1983; Nicese and Ferrini, 2003). Some researchers studied more efficient distribution systems (Klein, 2004; Yanni et al., 2004; Monaghan, 2010), irrigation plans based on crop needs (Incrocci et al., 2004), use of waste and/or low quality water (Maloupa et al., 1999; Williams et al., 2008; Karam et al., 2009).

More recently, the efficient use of energy in greenhouses received great focus (Bot, 2004; Bakker et al., 2008; Dieleman et al., 2016). Elings et al. (2005) showed how light efficiency can be improved with better transmittance; to further improve the light transmittance of the materials, many anti-reflective coatings have been developed that allow a 5-6% increase of light transmission (Hemming et al., 2012). Many trials aimed at reducing the energy consumption of greenhouses have focused on ventilation processes and the effects of thermal energy and mass transfer (Baeza et al., 2005; Molina-Aiz et al., 2005; Valera et al., 2005; Sase, 2006) using this knowledge in energy efficiency control operations (Körner et al., 2002).

The evolution of environmental analysis of agriculture has provided increasing levels of information and accuracy. However, some approaches still lack consistency, with problems of transferability and relevancy in different conditions, as subjective values affect the choice of indicators. In order to reach a more holistic view and increase transparency and possible comparisons, internationally recognized sets of tools and indicators have to be applied.

3. Life Cycle Assessment

Life Cycle Assessment is one of the most sophisticated tools for the analysis of environmental impacts of human activities. LCA is a management tool that allows a complete analysis of the impacts on the environment throughout a product's life cycle, including all the production, transport and use stages. Basically, LCA is a material and energy balance applied to the product system, which assesses the impacts related to all the system inputs and outputs. The origin of the LCA concept lies in the repeated energy crises between 1968 and 1973, which forced industrial production to improve energy efficiency, and brought public awareness to related environmental issues. During the 1980s resource consumption and waste minimization gained new attention, and different institutions (EMPA in Switzerland, CML in the Netherlands) developed methods for the aggregation of 'impact categories'. In the 1990s, use of LCA as a support tool for decision making took hold in industrial and public institutions, and the publication of different guidelines and definitions began to give consistency and consensus to the methodology (Audsley et al., 1997).

In 1993, SETAC defined LCA as “a process to evaluate the environmental burdens associated to a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment to affect environmental improvements” (SETAC, 1993).

The procedures to conduct LCA studies have been described in different standards published and reviewed by the International Organization for Standardization (ISO 14040, ISO 14042, DIN EN ISO 14040, DIN EN ISO 14043). According to these standards, an LCA study can be divided into four steps. The steps are interdependent, in that the results of one step will affect how other steps are completed (Rebitzer et al., 2004; Finnveden et al., 2009):

- **Goal and scope definition**: an LCA starts with an explicit statement of the goal and scope of the study, which sets out the context and explains how and to whom the results are to be communicated. This is a key step and the ISO standards require that the goal and scope of an LCA be clearly defined and consistent with the intended application. During this step, the following definitions should be given (Rebitzer et al., 2004):
    - functional unit, which defines what is being studied and quantifies the service delivered by the product system, providing a reference to which the inputs and outputs can be related. The functional unit is also an important basis that enables alternative goods or services to be compared and analyzed;
    - system boundaries, delimitations of which processes should be included in the analysis of a product system;
    - assumptions and limitations;
    - allocation methods, used to partition the environmental load of a process when several products or functions share the same process;
    - impact categories (examples: human toxicity, global warming, eutrophication, acidification, abiotic resource depletion).
- **Life cycle inventory**: is the creation of flows to and from nature for a product system. Inventory flows include inputs of water, energy and raw materials, and releases to air, land and water. Input and output data are collected for all activities within the system boundary,

including from the supply chain (inputs from technosphere). Data must be related to the functional unit.

- **Impact Assessment**: this phase is aimed at evaluating the significance of potential environmental impacts based on the LCI flow results, and consists of the following mandatory elements:
    - selection of category indicators and characterization models;
    - classification: inventory parameters are sorted and assigned to specific impact categories;
    - categorization: LCI flows are categorized in common equivalence units that are then summed to provide a total for the impact category.
- **Interpretation:** results from the inventory analysis and impact assessment are summarized, and a set of conclusions and recommendations is drawn. According to ISO 14040:2006, the interpretation should include:
    - identification of significant issues;
    - evaluation of the study, including sensitivity and consistency checks;
    - conclusions, limitations and recommendations.

4. LCA on protected crops

Predominantly, the LCA methodology has been applied to industrial products and processes, yet growing concerns about sustainable agricultural production have prompted different research activities, with particular focus on food production and distribution systems (Roy et al., 2009). Regarding protected cultivation, several LCA studies have been conducted mainly focusing on food crops, in particular tomatoes. Jolliet (1993) evaluated several tomato crop production systems in greenhouses, heating, artificial lighting, carbonic fertilization and transport to the market. Researchers in the Netherlands used LCA to analyze and evaluate different crop production systems; for instance, Nienhuis et al. (1996) compared soil and substrate crop with free drainage and with recirculation for round tomatoes and small-flowers; the study considered environmental effects linked to production inputs (excluding crop protection) from raw materials extraction, production, consumption at the greenhouse, to waste processing. Another research (Antón et al., 2004) also concluded that substrate cultivation with recirculation of drainage water is less impacting than soil cultivation and free drainage. Energy consumption (heating fuel and electricity) also had a major share in the total environmental pressure. Van Woerden (2001) applied LCA to Dutch glasshouse horticulture to describe environmental effects of future developments in crop production systems, showing that energy use was responsible for about 75% of the total environmental impact of a tomato crop, with the glasshouse structure contributing over 10%. Kramer et al. (1999) used part of the methodology to assess GHG emissions related to the Dutch crop production system. Munoz et al. (2008) compared the environmental impacts of tomato production in a greenhouse and open field in a Mediterranean region; results showed that most impact categories, related to 1 kg of tomato production were lower in greenhouse production, and that production of greenhouse structures had the greatest influence in the global warming category. Forced ventilation and heating considerably increased the environmental impact of greenhouse cultivation. A comparison of greenhouse crop production in the Netherlands and Spain was first conducted by Van der Velden and Janse (2004). Crop yield was significantly lower in Spain than in the Netherlands. However, primary energy consumption per kg of vegetables in the Netherlands was estimated to be 13 to 17 times higher than in Spain. The consumption of active ingredients for pest control was reported to be higher for Mediterranean crops. In the framework of the Seventh Framework Program (FP7) a major project (EUPHOROS) has investigated means for reducing the environmental impact of protected cultivation, accounting for the diversity of production systems in Europe. In a recent work (Torrellas et al., 2012), data from this project have been used to study the environmental burdens in four European scenarios: tomato crop in a multi-tunnel greenhouse in Spain, tomato crop in a Venlo type greenhouse in Hungary, tomato crop in a Venlo type greenhouse in the Netherlands and rose crop in a Venlo type greenhouse in the Netherlands. The environmental analysis was coupled to a complete financial assessment in order to uncover the potential for cost savings, so that suitable technologies could be developed to address the locally relevant bottlenecks and then be evaluated in practice. Results showed that the largest contributor by far to environmental impact of heated greenhouses is the burning of fossil fuel for heating, which is also the largest single item in the production costs. A recent study by Cellura et al. (2012) conducted an LCA of five different types of greenhouses in Southern Italy, highlighting the packaging step and greenhouse structures as relevant steps for the environmental burden of selected crops. The absence or limited use of auxiliary heating resulted in a lower impact of the analyzed systems compared to other European scenarios.

Ornamental crops, being non-food agricultural products, have received little attention compared to other protected crops. In recent years, some researchers investigated the environmental aspects of this sector applying LCA methodology. An initial study on LCA application for nursery production systems (Pistoia District) was conducted by ARPAT (2001) with the LIFE CLOSED project, in which the environmental compatibility of recycling farm green wastes was verified (ARPAT, 2001). Another research (Russo and De Lucia Zeller, 2008) funded by the EU project "Ecoflower Terlizzi" (LIFE04 ENV/IT/000480), with the participation of Italian ornamental growers and breeders, was conducted in order to gather information regarding the floricultural production process. The authors evaluated GHG emissions from a cut flower (rose) and a pot plant (cyclamen) greenhouse cultivation in the southern Italian region of Apulia. The study showed that the use of pots made of recyclable or degradable materials could reduce GHG emissions, along with the adoption of energy saving measures to reduce fuel consumption. Another study proposed by Lazzerini et al. (2016) was aimed at quantifying the environmental impact, in terms of GHG emissions of different nursery types and productions. An LCA study was conducted in seven different nurseries on eleven production lines. The square meter was used as functional unit to represent the differences between in-pot and in-field cultivation process, and in order to identify the most polluting steps, this was split into well-described processes. Results showed that in-pot systems are much more impacting than in-field production processes. These differences are mainly due to the peat used in substrate mixes and the plastic used for pots. The latter study is the only example of an environmental analysis using data collected from different companies, since the work by Russo cites data from a single nursery. In order to increase the representativeness of the environmental analysis and its observations and conclusions, further researches should include and exploit data and information from a larger sample of nurseries.

5. Aim and objectives of the research

This research started with some questions concerning the sustainability of ornamental crops at a local level, and others were formulated during the subsequent phases, as often happens in LCA studies. The first objective of this research was the environmental characterization of some production chains of Veneto floriculture, with the aim of identifying critical points and determining a carbon footprint for the end products. A preliminary data collection, addressing three species of container-grown plants, poinsettia (*Euphorbia pulcherrima* Willd.), zonal geranium (*Pelargonium ×hortorum* Bailey) and cyclamen (*Cyclamen persicum* Mill.), was conducted. The crops were selected for their economic relevance, since they cover a significant share (17%, 20% and 22% respectively) of the Italian flowering plants market (ISMEA, 2010), and in order to analyze an ideal crop sequence for the average floriculture nursery. The first acquired data came from two ornamental plant growers involved in the experimental trials. The project focused on the experimentation of alternative production inputs, such as biodegradable containers, which were tested in order to evaluate their feasibility during cultivation of the above-mentioned species.

Furthermore, different amounts of rice hulls were introduced as a substrate component, substituting expanded perlite and increasing amounts of peat. Agronomic trials were conducted on their suitability for plant growth. Our first goal was to define and perform a first life cycle inventory (LCI) of selected crops, also trying to define average production practices and a common data capture methodology. General production practices (foreground data) for the species were gathered during the trials, and through a series of telephone, e-mail and personal interviews with the production managers. These communications were used to produce and validate a general questionnaire that could be submitted to a larger sample of nurseries. A Carbon Footprint was performed with the collected data, comparing crops grown in the compostable rice hulls container and in a traditional polypropylene pot. System boundaries were set from seedling arrival at the greenhouse to fully grown, marketable plants (plant is in flower with above-ground growth sufficiently filling the container). Values for the Global Warming Potential (GWP) category result from the characterization of raw materials production, transport and use of cultivation inputs. Emissions associated with the production of capital goods (greenhouse facilities and mechanized equipment) were not considered. This first analysis showed the relative size of certain factors in the production phase, in particular the materials used for producing pots and growing media components. Fuel burned to heat the greenhouse turned out to be one of the major contributors to the environmental impact of poinsettia and pelargonium, and our results were comparable with previous studies conducted on poinsettia plant production. Impact assessment results showed some limitations of the software databases and calculation methods, highlighting the need for more specific data. A specific and more thorough assessment was conducted for cyclamen plants grown in four growing media amended with different rates of expanded perlite or fresh rice hulls. The analysis included all inputs from transplant to market-ready flowering plants, also considering greenhouse structures and equipment. Data on water and fertilizer were sourced from the growth trials. Data on specific processes (peat and fresh rice hulls production and transport) sourced from Ecoinvent database (ver 2.2) were modified using information collected directly via questionnaires and interviews with different Italian growers, and from the literature and previous studies. Impact assessment was conducted using CML 2001 method. In order to increase the knowledge of this floriculture sector in our region to confirm (or deny) the validity of the environmental analysis conducted so far, we expanded the data collection process to a sample of 20 greenhouse nurseries belonging to Florveneto organization (province of Treviso). The average floriculture nursery from which we collected our data has small acreage (average productive area < 1.5 ha); most nurseries have a garden center for retail, and are mainly family-run. The sample also included a few more specialized wholesale nurseries. The collected data describe the production stage that concerns the final grower (system boundaries are set from seedling arrival at the greenhouse to the sale of 70% of marketable plants). During the data collection process we noticed how nurseries with similar size and production would differ, sometimes significantly, with regard to structure types, technological level of growing equipment, management decisions, and cultivation practices adopted for the same crops. These differences extended to the view of, and consequently willingness to adopt, sustainable production practices. Some growers felt their nurseries should take steps to progress toward sustainable production, while others felt they already took care of the environment, and openly criticized the restrictive policies imposed at national level or by the European Union, in particular regarding the use of plant protection products. Growers were also concerned about the consumer’s perception of sustainable floriculture, and most of them questioned the benefits they would receive when adopting sustainable practices. Among the most environmentally concerned growers, different choices were made in the management practices of the studied species, according to their view of sustainability, intended under both an environmental and economic point of view. Here is a summary of the critical points that emerged:

- though the main steps during cultivation of the studied species are similar, we could not define an average set of production practices for all the nurseries, due to the specific management choices of each grower;
- none of the interviewed nurseries make use of alternative growing media or containers. Also, selected species are grown and marketed in a wide range of plant sizes, that differ from one nursery to another;
- integrated or biological control is applied by a very small fraction of the sample; most of the 'virtuous' companies have reached a good management maturity, both in crop protection and fertigation;
- data concerning energy consumption are fragmented and show some discrepancies;
- most of the installed heating systems have low efficiency; however some growers have begun to adopt practices to reduce heating needs in the cold season;
- biomass fueled heating systems are slowly spreading to medium-sized greenhouses, but smaller nurseries do not have access to the necessary capital investment.

Starting from these observations, a final set of questions was formulated, which will be answered in the final chapters of this thesis:

- Can we define a valid range for the environmental impact of our functional units?
- Which available best practices are already applied by virtuous growers? What benefits can be achieved by these practices?
- Which solutions might have a substantial effect on each functional unit?

After this introducing chapter, the thesis is structured in five chapters: the first presents and discusses the LCI data collection and preliminary characterization results concerning the main cultivation stage of cyclamen, poinsettia and pelargonium plants grown in conventional and compostable containers; a sensitivity analysis is included, assessing the impacts related to transport and raw materials extraction for the containers (Chapter II). The next chapter presents a 'gate-to-gate' life cycle of cyclamen cultivated in four growing media amended with different rates of expanded perlite or fresh rice hulls; a sensitivity analysis to assess the influence of initial choices on the environmental profile of the functional unit is performed. Results from environmental analysis and agronomic trials are provided and discussed (Chapter III). The following chapter explores some of the most important alternatives regarding energy conservation measures, systems to deliver heat and energy sources, drawing from technologies and management practices already applied by growers (Chapter

IV). Then we investigate how different production practices and choices influence the impact of our functional units, with particular regard to fertilizer use, plant protection and waste management (Chapter V). In the last chapter the general conclusions are presented.

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Chapter II - Environmental impact in floriculture: LCA approach at farm level

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1. Abstract

The issue of sustainable floriculture and the continuous and increasing demand for environmentally-friendly products have produced, in recent years, several studies that tried to answer these requests. Simultaneously there is a need to meet the companies requirements for cost reduction and more attractive products. Nowadays, studies with an holistic approach to the problem, for example the evaluation of product's life cycle, are not very common. A complete study requires, in fact, a huge amount of data acquired throughout the investigation of a statistically significant sample of companies. The Life Cycle Assessment (LCA) methodology was first used to determine the environmental impact of industrial products. In the last decades its applications in the agricultural sector have increased, though studies on floriculture productions are still rare. In this study we performed the first Life Cycle Impact Assessment (LCIA) of three species, poinsettia (*Euphorbia pulcherrima* Willd.), zonal geranium (*Pelargonium ×hortorum* Bailey) and cyclamen (*Cyclamen persicum* Mill.) and two type of containers, a traditional polypropylene pot and a compostable rice hulls pot. Life Cycle Inventory (LCI) data were sourced from interviews and published literature. The results showed that both type of pots are major contributor to the environmental impact of the assessed systems. Global Warming Potential (GWP) of plastic pot is mainly affected by the material used for its production, while rice hulls (RH) pot is only affected by transport process from the production site. The use of compostable RH pot could potentially be more sustainable, but to date its contribution is only slightly lower than the plastic one. Further assessments including end-of-life information, in particular for plastic materials, may lead to a better evaluation of the possible alternatives.

2. Introduction

Floriculture crop production is input-intensive and requires the use of non-renewable and petroleum-based products for pesticides, fertilizers, growth regulators, heating, greenhouse glazing, and packaging to make crops uniform and of high quality.

Nowadays, a few studies tried to assess the overall impact of floricultural crops in Italian scenarios (Russo and De Lucia Zeller, 2008; Nicese et al., 2012). These studies compared open field versus greenhouse grown plants, highlighted some of the main environmental burdens on the flowers 'production chain', and gave a first insight on some major issues related to this agricultural sector.

Among the environmental issues linked to pot flower plants, one of the most 'appealing' to both customers and growers, is plastic packaging (Hall et al., 2010; Yue et al., 2011). Commercial greenhouse and nurseries use many types of containers, trays and cell packs to propagate and produce annual and perennial plants. The majority of these crops are commonly grown in non-recycled plastic containers that are often disposed of by consumers, thus presenting a significant disposal issue. In Italy, the sole production of 20 million poinsettia plants (*Euphorbia pulcherrima* Willd.) generates about 55000 m^3 of plastic waste (Candido et al., 2008).

In this study we performed a preliminary Life Cycle Impact Assessment (LCIA) of three species, poinsettia (*Euphorbia pulcherrima* Willd.), zonal geranium (*Pelargonium ×hortorum* Bailey) and cyclamen (*Cyclamen persicum* Mill.), that together cover a significant share (17, 20 and 22%, respectively) of Italian flower plants market. All three species were grown in two different containers, a traditional polypropylene pot and a compostable rice hulls (RH) pot. The first objective was to determine the relative impact of inputs used in the main cultivation stage. A sensitivity analysis was then carried out to assess the impacts related to transports and raw materials for the production of RH pots in two different scenarios. Biocontainers as a whole are marketed as a mean of making the floricultural sector more sustainable. The aim of this study was to provide an initial assessment to evaluate these claims by identifying the extent to which the container impacts the carbon footprint of pot plants production.

3. Materials and methods

3.1. Goal, scope and functional unit

This paper assesses the inputs and impacts of three greenhouse crops, poinsettia, zonal geranium and cyclamen. It also serves as a first screening of a commercially available rice hulls compostable pot, which may be selected for a more thorough life cycle assessment that includes manufacturing inputs and impacts. As a model system, our assessment is based on production practices of two small commercial greenhouses that are representative of the average flower producing farm in the Province of Treviso, which is a main floricultural district of Veneto Region. They have small acreage (average productive area 1.5 ha), with a garden center for retail, and are mainly family-run. Global Warming Potential (GWP) linked to carbon emissions was selected as the primary environmental impact estimated to allow for comparison with past life cycle assessment (LCA) works in horticultural production (Nicese et al., 2012; Koeser et al., 2014). The functional unit is a single marketable plant in its container.

3.2. System boundaries and assumptions

The definition of system boundaries identifies which processes and flows are necessary to carry out the studied function, the ones that significantly contributes to its environmental impacts and are therefore relevant to the attainment of the study objectives. In our model system we describe the production stage that concerns the final grower and retailer. The system boundaries are set from seedling arrival at the greenhouse to the point of sale. This is a point at which a plant is in flower and above-ground growth is sufficiently filling the container. Environmental impact results from the characterization of raw material production and transport process of inputs used during this cultivation period. The use stage was not included within the system boundary given limitations of available data. The scope of this assessment does not consider emissions associated with the production of capital goods (e.g., the greenhouses facilities and mechanized equipment) used to produce the functional unit. This conforms to international guidelines outlined in PAS2050 (2011).

3.3. *Life cycle inventory and data collection*

General production practices (foreground data) for the studied species were identified through a series of telephone, e-mail and personal interviews with the production managers of the selected enterprises. These communications were used to produce and validate a general questionnaire, which could be used in the future to acquire specific and complete data from a larger sample of commercial greenhouses and nurseries. Basic material and background data sourced mainly from EcoInvent database (ver. 2.2). All processes and data sources for the life cycle inventory were managed through the SimaPro software. The database items used to describe the three model systems (except for the containers) are listed in Tables 1 to 3.

Table 1. Base inputs, name of the process from database, amounts and associated CO_2eq emissions expressed per one poinsettia plant.

Input	Process name	Amount	Unit	GWP
Diesel (Heating)	Diesel, at regional storage/CH	0.048	kg	0.0288
Growing medium	Peat, at mine/NORDEL	0.300	kg	0.0066
Peat transport	Transport, lorry 16-32t, EURO5/RER	2215	kg km^{-1}	0.0027
Irrigation water	Tap water, at user/CH	39.76	L	0.0066
Insecticides	Insecticides, at regional storehouse/RER	0.330	g	0.0055
Fungicides	Fungicides, at regional storehouse/RER	0.400	g	0.0042
Growth regulators	Growth regulators, at regional storehouse/RER	0.151	g	0.0012
Fertilizer (N)	Fertilizer (N)	0.620	g	0.0053
Fertilizer (P_20_5)	Fertilizer (P_20_5)	0.260	g	0.0003
Fertilizer (K_2O)	Fertilizer (K_2O)	1.020	g	0.0007

Table 2. Base inputs, name of the process from database, amounts and associated CO_2eq emissions expressed per one zonal geranium plant.

Input	Process name	Amount	Unit	GWP
Diesel (Heating)	Diesel, at regional storage/CH	0.024	kg	0.0132
Growing medium	Peat, at mine/NORDEL	0.300	kg	0.0066
Peat transport	Transport, lorry 16-32t, EURO5/RER	2215	kg km^{-1}	0.0027
Irrigation water	Tap water, at user/CH	10.46	L	0.0017
Insecticides	Insecticides, at regional storehouse/RER	0.049	g	0.0008
Fungicides	Fungicides, at regional storehouse/RER	0.000	g	0.0000
Growth regulators	Growth regulators, at regional storehouse/RER	0.000	g	0.0000
Fertilizer (N)	Fertilizer (N)	0.528	g	0.0038
Fertilizer (P_20_5)	Fertilizer (P_20_5)	0.535	g	0.0002
Fertilizer (K_2O)	Fertilizer (K_2O)	0.398	g	0.0005

Table 3. Base inputs, name of the process from database, amounts and associated CO_2eq emissions expressed per one cyclamen plant.

Input	Process name	Amount	Unit	GWP
Diesel (Heating)	Diesel, at regional storage/CH	0.000	kg	0.0000
Growing medium	Peat, at mine/NORDEL	0.300	kg	0.0066
Peat transport	Transport, lorry 16-32t, EURO5/RER	2215	kg km^{-1}	0.0027
Irrigation water	Tap water, at user/CH	15.35	L	0.0017
Insecticides	Insecticides, at regional storehouse/RER	0.042	g	0.0008
Fungicides	Fungicides, at regional storehouse/RER	0.976	g	0.0042
Growth regulators	Growth regulators, at regional storehouse/RER	0.017	g	0.0012
Fertilizer (N)	Fertilizer (N)	0.190	g	0.0052
Fertilizer (P_20_5)	Fertilizer (P_20_5)	0.216	g	0.0002
Fertilizer (K_2O)	Fertilizer (K_2O)	0.230	g	0.0004

3.4. Assumptions associated with pots production and transport

In this study we assessed the environmental burdens associated with two kinds of pots, a traditional plastic pot (PP) (14.0 cm diameter, 1.2 L volume, 37.5 g, polypropylene), and a compostable pot made of RH pressed and bonded with starch based glues (14.6 cm diameter, 1.2 L volume, 92.0 g). Since no specific data were available about materials (other than RH) and the energy required for the manufacturing of the compostable pot, the assessment was carried out considering only raw materials production and the transportation processes. The patent for RH pot has been developed by the Agricultural Scientific Research Center of Zhuhai (Ceresa, 2014). At the present time, RH pots are manufactured in China and then imported and marketed by an Italian company (FuturePower s.r.l., Turin, Italy). In this baseline scenario RH are considered as a waste product of rice cultivation with no economic value, therefore no environmental burden was attributed to their production and processing. We assumed that RH pots are transported by train (Transport, freight, rail/RER) for 6000 km, and by truck (Transport, lorry, 16-32 t, EURO5/RER) for the remaining part of the route (3000 km). We hypothesized a second scenario, in which RH pots are manufactured in Italy, starting from local raw materials. For this scenario, rice cultivation, harvesting, drying and refining were modeled using data and assumptions from Blengini and Busto (2009). The model describes a typical farm in the Vercelli district in Italy; the average yield is 7.03 t ha-1 of paddy rice, roughly corresponding to 6.12 t ha-1 of dried paddy rice. To allocate environmental impacts related to rice cultivation and processing, an economic allocation factor, based on relative market value, was adopted: 84% of the overall impact was allocated to refined rice and 16% to RH. We assumed that RH pots are transported by truck for 400 km. We assumed that plastic pots are acquired from local retailers (average distance 30 km) and transported by truck.

4. Results and discussion

4.1. Baseline assessment of plants production

The GWP for all the contributing inputs is expressed as kilograms of CO2 equivalents (kg CO2 eq) in Figure 1. The cut-off is set at 0.5%, meaning that only processes contributing 0.5% or more toward the overall environmental impact of each plant are included. The major contributors to overall impact for each of the plants considered in the assessment are the containers. Diesel fuel burned to heat the growing environment also accounts for a major share of the impacts of the two species with higher temperature requirements, poinsettia and zonal geranium (≈23 and 14%, respectively). The plastic pot accounts from 56% (poinsettia) to 75% (cyclamen) of the total environmental impact of this stage. The contribution of RH pots is only slightly lower, making up from 51 to 72% of the total. The remainder of the inputs had minimal impact given the small quantities used to obtain the related functional units. The species with higher demand of chemical products (pesticides and growth regulators) and fertilizer is poinsettia, where zonal geranium is the less demanding one.

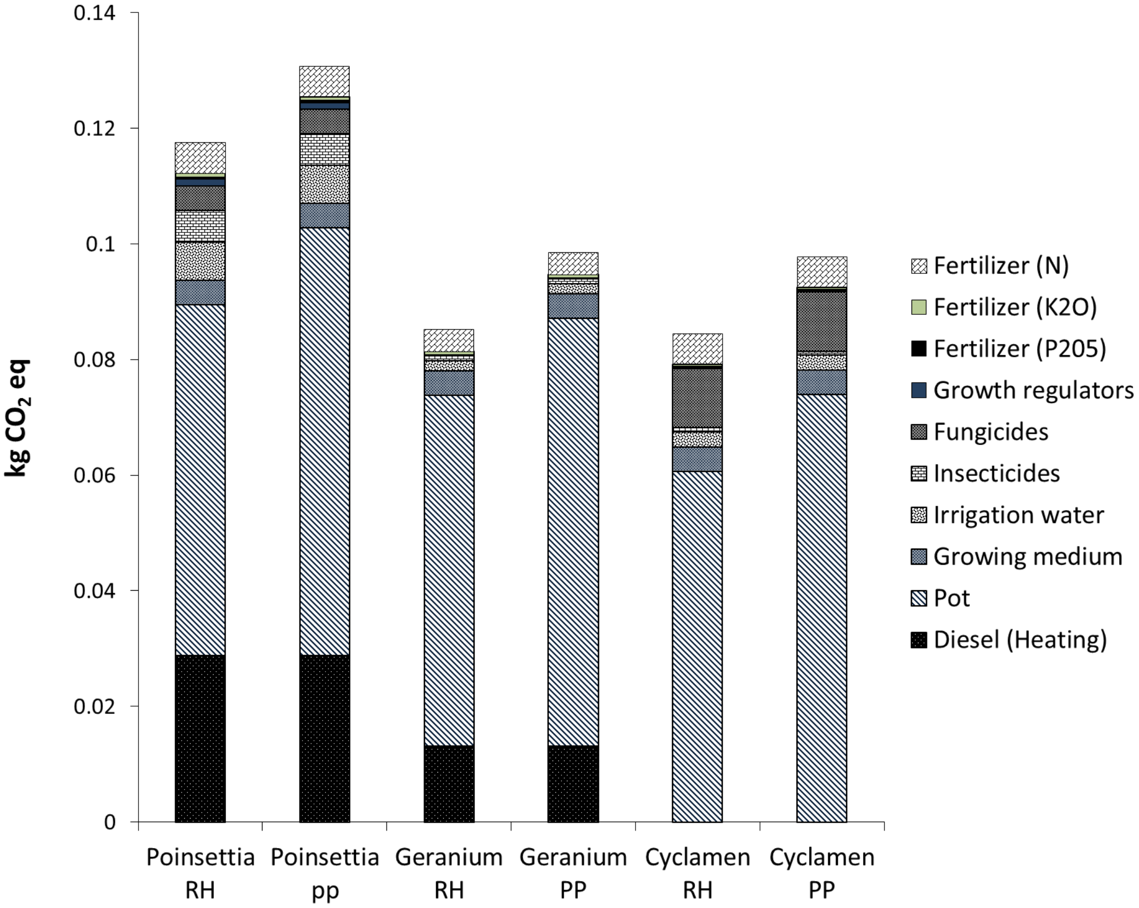

Figure 1. Comparison of Global Warming Potential (GWP) of the three species grown in rice hulls (RH) and plastic pot (PP).

4.2. Impacts associated with containers production and transport

Figure 2 shows the GWP associated with the containers' production and transport. The impact of the PP pot is entirely attributable to the material used for its production (polypropylene, granulate, at plant/RER). The current scenario for RH pots involves the importation from China, where they are manufactured. In this case the only contributor to their carbon footprint is the transportation process. In the event that production is moved to Italy, the transport costs sensibly decrease. However, in this scenario, RH may not be considered a waste product, since they are used for various purposes (e.g., poultry litter, heat generation) and have therefore their market. According to ISO 14044 (2006), when allocation is necessary, the criteria should reflect the physical relationship between the environmental burdens and the functions delivered by the system. We chose to perform an economic allocation to assign an environmental impact to the refined rice and its by-products. Allocation factors refer to 2014 prices. The chart shows that in this scenario the RH pot results the most impacting container, the main contributor being the rice production process.

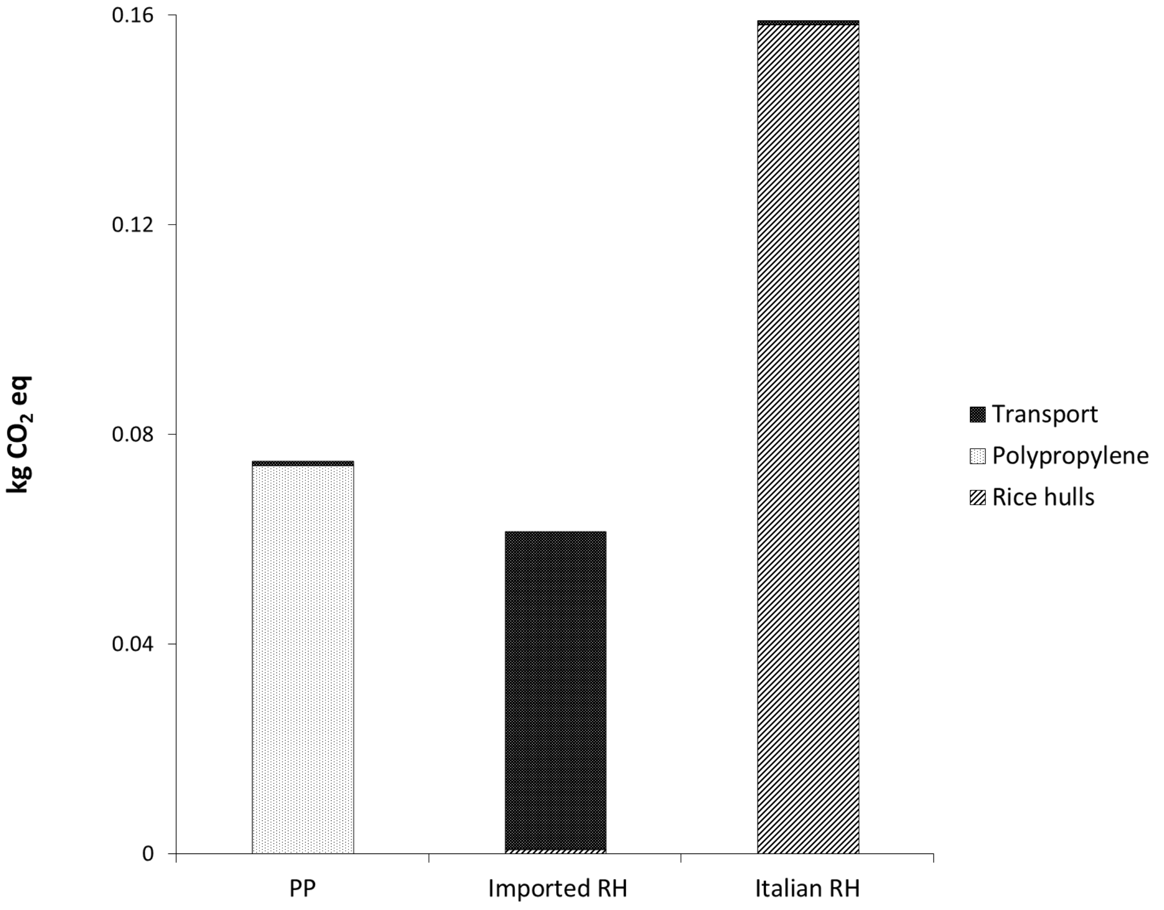

Figure 2. Comparison of Global Warming Potential (GWP) associated with containers raw material production and transport.

5. Conclusions

This first assessment highlighted some critical points of the cultivation stage of the studied plants, with particular regard to containers. From the environmental point-of-view, substitution of plastic with biodegradable materials that are considered as waste products of other agricultural activities is highly desirable. However, the increasing demand for this kind of products could affect their market value, or the import needs, in which case it may be preferred to reconsider their environmental compatibility. In this study we did not consider the secondary impacts related to the use of different containers, like reduced performance, shipping success, breakage rate, and irrigation demand. The differences may not cause a dramatic change of production sustainability from a GWP perspective, however, it may still be desirable to include these factors in future studies. Also, we excluded the use and waste disposal stages, for we could not obtain sufficient data to model a realistic disposal scenario. A complete life cycle assessment implementing information on end-of-life fate, in particular for plastic materials, may further help in the evaluation and decision process.

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Chapter III - Environmental and agronomic performance of fresh rice hulls used as growing medium component for *Cyclamen persicum* Mill. pot plants

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[1] Corrected with respect to published format

1. Abstract

The issue of environmental compatibility of some specialized agricultural sectors is becoming more appealing to both consumers and growers. Growing medium components that are non-renewable, or partly renewable, such as perlite and peat, are among the production factors which can be modified by growers in the short term.

In this study a 'gate to gate' life cycle assessment was performed for a floral commodity, *Cyclamen persicum* Mill., grown in four different substrates formulated by blending expanded perlite (EP) (at 10% v/ v) or fresh rice hulls (FRH)(10%, 30% and 50% v/v) with sphagnum peat. Results of the LCIA show that growing media components have a relevant share of impact for this production phase, along with greenhouse materials, plastic pots, fertilizer and plant protection products. Peat and EP replacement with a small amount of FRH can slightly improve the environmental performance for AD and GWP categories. Growth trials showed that substitution of EP with equal amount of FRH does not affect plant quality, but higher amounts increase water and fertilizer requirements not only reduces plant performance but also worsen the ecoprofile of the functional unit for most impact categories.

2. Introduction

Floriculture crop production is one of the most specialized and intensive agriculture sectors, where many non-renewable re- sources are depleted in order to achieve crop uniformity and high quality standards. Many issues linked to the environmental compatibility of the industry are becoming more and more appealing to consumers and public opinion in general. To address this growing concern, several studies have tried to assess the overall impact of some pot plant and cut flower productions in Italian scenarios (Vecchietti et al., 2013; Lazzerini et al., 2016), and have highlighted some main environmental burdens of the flower production chain. Among these issues, some appear to be more relevant to customers, and theoretically modifiable by growers, such as in the case of peat use as growing medium. Peat is the main organic constituent of growing media in the EU (Schmilewski, 1996; Schmilewski and Falkenberg, 2000; Reinikainen, 2001; Bohlin, 2002). The main reasons that lead the research for peat substitutes are its role as soil carbon reservoir in wetlands, which is instead emitted into the atmosphere as CO2 (carbon dioxide) and CH4 (methane) during extraction, processing and decomposition, and the need to ship the material from areas of production (Baltic States, Germany, Finland, Ireland) to the areas of utilization by road transport or freighter (Gorham, 1991; IPCC, 2003; Butler and Hopper, 2010). As one of the outstanding floriculture producing countries, Italy is highly dependent on peat imports, even if minor percentages (10e30%) of other materials are commonly used in the cultivation of a number of crops (Altmann, 2008).

Many waste or by-products from industrial or agricultural activities have been evaluated in order to find a substitute for peat. Compost deriving from the organic fraction of municipal solid waste (MSW compost), from sewage sludge, or biodegradable materials from gardening and landscaping maintenance (green compost) has been evaluated under both the agronomic and environmental profile by several studies (Verdonck and Gabriels, 1988; Perez-Murcia et al., 2006; Mancini and De Lucia, 2011; Mininni et al., 2012). In a recent study, De Lucia (De Lucia et al., 2013) conducted an environmental and agronomic assessment of nursery growing media, where substitution of peat with sewage sludge compost reduced the environmental burden of substrate, except in terms of global warming. In another study (Vecchietti et al., 2013), compost amended growing media were used to grow potted Rosemary plants; results showed that while environmental impact was reduced for some treatments, only one growth medium guaranteed good productive performance.

Another agricultural by-product that may be eligible for entering growing media composition is rice hulls (RH), a residue obtained in the rice processing industry and consisting of the outer protective covering of the rice caryopsis. This material seems to be very interesting for the Italian context; indeed, Italy produces 1.44 million tons of paddy rice per year, this amount being fully 50% of production in the EU (Blengini and Busto, 2009). Chemical, physical and agronomic features of this material have been assessed by numerous studies. Aged, carbonized and composted RH have been tested as a substitute for peat and pine barks (Einert, 1972; Cadell, 1988; Laiche and Nash, 1990; Kampf and Jung, 1991). Fresh RH (FRH) and parboiled RH have total and air-filled pore space similar to or higher than perlite and vermiculite (Dueitt et al., 1993; Hanan, 1998; Sambo et al., 2008), and have been tested with good results in different mixes for container grown productions (Einert, 1972; Dueitt et al., 1993; Evans and Gachukia, 2004; Tsakaldimi, 2006; Bassan et al., 2011), and also for producing cut flowers (Einert and Baker, 1973). A study conducted by Quantis Switzerland

(Quantis Sàrl, 2012) compared the environmental impact of different mixes grouped on an area of application basis. Mixes containing RH were evaluated for the tree nursery and hobby market area. Although RH have been widely characterized, none of the previous studies have assessed the environmental benefits achievable from the grower adopting them as a sustainable practice. In this paper we evaluated, by means of a life cycle assessment (LCA) method, the environmental impact of a floral commodity, *Cyclamen persicum* Mill., cultivated in four growing media amended with different rates of expanded perlite or FRH. We also conducted an agronomic trial of the different mixes, in order to provide foreground data for the life cycle inventory (LCI) and to assess their suitability for plant growth.

3. Materials and methods

3.1. Goal, scope and functional unit

The goal of this study is to describe and analyze a gate-to-gate life cycle of a floral commodity (*Cyclamen persicum* Mill.). We also wish to determine the relative load linked to materials and processes for the chosen functional unit, in order to assess the environmental advantage achievable by adopting particular practices, such as substitution of growing media components. Additionally, we assess the viability of a specific growing media component (FRH), from both an agronomic and environmental point of view. The scope of our study includes production of capital goods (greenhouse structure and cover), production, transport and use of cultivation materials, and energy use for greenhouse operations.

The method used for LCIA is CML 2001, developed by the Centre for Environmental Studies (Guinee et al., 2001). The following impact categories are assessed: abiotic resources depletion (AD), stratospheric ozone layer depletion (ODP), global warming potential for a time horizon of 100 years (GWP100), marine aquatic ecotoxicity (MAET), fresh water aquatic ecotoxicity (FAET), terrestrial ecotoxicity (TE), human toxicity (HT), photochemical ozone creation (PO), acidification (AP), and eutrophication (EuP).

3.2. System boundaries and functional unit

System boundaries include all operations and inputs from transplant to market-ready flowering plants. Data for this assessment came from various sources. Information on greenhouse operations and general production practices came mainly from interviews with the production manager, in order to ensure their representativeness of the chosen system. Data on water and fertilizers use were obtained from direct experimentation, conducted to assess specific substrate requirements. LCI data describing basic materials and processes were sourced from the Ecoinvent (ver. 2.2) database. Data on peat and FRH production and delivery were modified and adapted using information from the literature, previous studies, or collected directly via questionnaires and interviews from different Italian enterprises. Use and end of life stage are not included because their impact is mostly influenced by consumer behavior (Soode et al., 2013), which is not investigated.

Our chosen functional unit is a single plant in its 14-cm pot. The model system for our assessment is based on the production practices of a small commercial greenhouse. The enterprise is family-run, has relatively small covered area (1.5 m2). The green- house for Cyclamen cultivation has steel structure and glass cover (Hortiplus), with 4 spans, length 100 m, span width 5 m, 3 m eaves height, 4.2 m ridge height. The same structure houses a garden center for plants retail.

3.3. System description

Cyclamen seedlings grown in a 91-cells polystyrene plug tray, are transplanted into 14 cm pot (1.2 L volume). Plants are irrigated using overhead spray irrigation (no added fertilizer) for 6 days. After the first week, a fertilizer solution (1 g L^{-1}; 17N-7 P_2O_5-38K_2O + micronutrients) is applied with overhead spray irrigation for two weeks. From this stage to marketable size, cyclamen plants are fertigated every 3 to 4 days with ebb-and-flow irrigation system. Three fertilizer solutions are applied during the growing period: 1 g L^{-1} 17N-7 P_2O_5-38 K_2O + micronutrients, 1.5 g L^{-1} 20N-19 P_2O_5-28 K_2O + micronutrients, 0.8 g L^{-1} 20N-19 P_2O_5-28 K_2O + micronutrients. Common cyclamen irrigation practice involves close observation of foliage, especially during the hottest hours of the day. When a slight withering is noticed, water is administered. This method allows for a indirect but quite effective control of foliage growth. Since a closed system is used for fertigation, with plants grown on aluminum and plastic benches, no water and nutrient loss is assumed.

After one month plants are spaced manually to allow better air circulation and canopy growth. Cyclamen plants are grown from May to September in shaded greenhouses without forced heating or cooling in this phase. The materials for the glass greenhouse were modeled using data modeled according to Anton (Anton, GH material modeling) and are referred to the unit surface per year (m^2 $year^{-1}$); this unit was divided by the fraction of the year referred to cyclamen cultivation, and by the number of plants grown per m^2; this number varies during the cultivation, for plants are spaced two to three times during this period, from an initial 49 plants m^{-2} to a final 10 plants m^{-2}.

During the cultivation stage, cyclamen plants are treated with fungicides: iprodione (Rovral, BASF) rate 3 ml L^{-1}, prochloraz (Octave, BASF) rate 0.8 g L^{-1}, thiophanate-methyl (Enovit-Metile, Sipcam) rate 1 g L^{-1}, chlorthalonil (Daconil, Bayer) rate 1.5 ml L^{-1}. Insecticides treatments are also applied: imidacloprid (Kohinor, Adama) rate 0.75 ml L^{-1}, abamectine (Vertimec, Syngenta) rate 0.75 ml L^{-1}. The plants are sprayed one to two times with clormequat (Cycocel, BASF) and daminozide (Alar Gold, Chemtura) growth regulators, rate 0.7 ml L^{-1}. Production of pesticides impact was evaluated considering only total energy consumption for manufacturing of active ingredients. Missing active ingredients were modeled using active substances of the same chemical family or use type (insecticides, fungicides or growth regulators).

Electricity consumption to operate water pumps and other greenhouse equipment, as well for the garden center, was estimated through meter readings and average operating hours of the irrigation system. Table 1 reports the amount of input referred to one functional unit. Variations of growing media components, water, fertilizer and electricity use for the different treatments is also reported in table 1.

Table 1. Main inputs in the cultivation process referred to 1 potted plant.

	Substrate			
Input	**EP10**	**RH10**	**RH30**	**RH50**
Irrigation Water (kg)	15.04	14.21	15.71	16.54
Peat (kg)	0.162	0.162	0.126	0.09
N fertilizer (g)	2.25	2.13	2.35	2.48
K_2O fertilizer (g)	2.98	2.82	3.11	5.68
P_2O_5 fertilizer (g)	5.16	4.88	5.39	3.28
Insecticides (g)	0.069	0.069	0.069	0.069
Fungicides (g)	0.355	0.355	0.355	0.355
Growth regulators (g)	0.137	0.137	0.137	0.137
Fresh Rice hulls (kg)	-	0.0132	0.0396	0.066
Expanded perlite (kg)	0.0132	-	-	-
14-cm plastic pot (kg)	0.013	0.013	0.013	0.013
Glass Greenhouse (m^2)	0.0313	0.0313	0.0313	0.0313
Electricity, low voltage (kWh)	0.0017	0.0017	0.0017	0.0017

3.4. Inputs and assumptions associated with growing mix components

Peat extraction and processing. There are many literature works that provides information on the different peat extraction/mining methods, describing the single harvesting stages and the machineries used; however, none of the available works provides enough data to quantify affected area, number of operations and energy requirements for the extraction of a given amount of peat. The only available set of data is found in Clearly et al., (1990), and it refers to Canadian peat extraction techniques and peatland management practices. The inventory data for this stage were hence taken from the Ecoinvent unit process 'Peat, at mine'. ["The module quantifies directly affected area, electricity requirements and diesel for mining operations and extraction of groundwater."] The specific peat mix used in cyclamen cultivation is usually composed of white and brown peat with medium texture. According to Italian and International statistics (Istat, 2015; IPS, 2016) and import data retrieved from Italian growing media enterprises (Vigorplant Italia, Geotec), peat with this particular feature is mainly imported from Baltic Republics (Latvia, Lithuania and Estonia), Ireland and Germany. In recent years, due to stricter regulation on peatland exploitation and rehabilitation processes, peat extraction in Germany is decreasing. Consequently, growing media manufacturers are increasing their use of peat extracted from Lithuanian and Latvian sites (Eurostat, 2010).

Delivery. Information about amounts and provenance of white peat where provided by an Italian growing media enterprise. White peat from tile is mainly imported from Baltic Countries, and shipped by lorry; transportation distance was calculated from the main facility in Latvia (Baltic Peat Moss) to the Italian producer (Geotec s.r.l, Domenico Masiero, Cavanella Po, RO - Italy: personal communication). For Irish peat an average distance from two extraction site to Galway port was calculated; from Galway peat is delivered to Genoa by ship, and is then transported by lorry to the Italian growing media factory.

Rice Hulls extraction and processing. Rice cultivation, harvesting, drying and refining were modelled using data and assumptions from Blengini and Busto (2009). The model describes a typical farm (average cultivated area: 50 ha) in the Vercelli district in Italy; the average yield is 7.03 t ha^{-1} of paddy rice, roughly corresponding to 6.12 t ha^{-1} of dried (15% humidity) paddy rice. The conventional cultivation techniques for production of white milled rice were used as a model system, since it is most representative for the Italian scenario and has the most complete set of available data (Ente Risi, 2010).

Delivery. RH are assumed to be transported for 200 km by lorry (distance between rice processing facility and the growing media producer).

We chose to perform an economic allocation to assign an environmental impact to the refined rice and its co-products; 90.75% of total impact was attributed to refined rice and 9.25% to RH, as suggested in Blengini and Busto (2009).

Expanded Perlite. Data for this material source from Ecoinvent unit process Expanded Perlite (EP). Specific data from an Italian enterprise were not available.

Delivery. EP is assumed to be transported for 100 km by lorry (distance between the growing media producer and the nearest processing facility).

3.5. Growth trials

Agronomic trials were conducted to evaluate cyclamen growth, cultivar Latinia, in peat based substrates mixed with fresh RH or EP, and to provide specific fertilizer and water requirements for the selected growing mixes. The experiment was conducted from June to October 2011, and from June to October 2012 in a glass glazed greenhouse located in Treviso Province, Veneto Region, Italy. The structure has openings on the roof and at the side walls; temperatures for automatic vents opening was set at 24 °C and closing at 20 °C. Four growing media were prepared by blending FRH in different proportions (10, 30 and 50% by volume) with a peat mix (30% Irish white peat and 70% Baltic white peat). The fourth growing medium, which served as control, blended 10% EP with the peat mix. Greenhouse operations and treatments do not differ from those previously described. Plants were irrigated using overhead spray irrigation during the first week, and then fertigated with spaghetti tubing irrigation system. The number of irrigations was recorded for each treatment. Randomly picked plants were weighted before and after watering, once per week in order to evaluate water and fertilizer use.

The experimental design was a randomized block design with two replications, and a bench serving as an experimental unit. The experiment was concluded four months after transplant; plant growth index [(height + widest width + orthogonal width)/3] was calculated and number of flowers and leaves were recorded on a sample of ten plants per each treatment. Then, substrate was separated from the roots, and plant organs were separately dried in a forced-air oven (105 °C) for 48 hr and recorded as dry weights. To make the discussion plain and intelligible, we will refer to the treatments with the following abbreviations: EP10, RH10, RH30, RH50. Data were analyzed by mean of analysis of variance (ANOVA) and means separated according to Tukey's HSD test (P 0.05).

4. Results and discussion

4.1. Impact assessment of plants production

Results of CML 2 Baseline 2000 impact assessment characterization indicators are presented in Fig 1. Since one of the goals of our study was to assess the viability of FRH substitution to peat and perlite in the composition of a light-weight growing medium, set to 100% the impact of one cyclamen plant grown in the EP amended substrate, we analyze how substitution with FRH affects total impacts and relative contribution of materials and processes. Normalization of impact assessment results to 1995 values for Western Europe (Fig. 2) shows that impact for Ozone Depletion (ODP) and Photochemical oxidation (PO) categories are not relevant. We choose to discuss the results of four impact categories: fresh water aquatic ecotoxicity (FWAE), marine aquatic ecotoxicity (MAET) and abiotic depletion (AD) for their relevance, and global warming (GWP100) to provide a measure of comparison with other studies. The cut-off is set at 1%, meaning that only processes contributing for 1% or more toward the overall environmental impact of each functional unit are included.

For AD and GWP100 impact categories, plastic pot, greenhouse structure and peat transport are major contributors, accounting for about 64% (EP10) to 66% (RH50) of the total impact. Greenhouse contribution is linked to float glazed glass for cover and side walls and galvanized steel for the frame. Impact of plastic pot is mainly due to raw material consumption for its production (Polypropylene granulate), while peat transport contribution is directly linked to road transport. Expanded perlite contributes for 6.8% to AD and for 8.5% to GWP. Fresh rice hulls accounts for 3.1% in the AD category and for 8% in GWP category for RH10, and their use allows to reduce the environmental impact of RH10 when compared to EP10 in the AD and GWP categories by 4.1% and 0.8% respectively. When higher amounts of FRH are used in the growing mix, their relative contribution increase, thus reducing the positive results in the AD category (-3.7% for RH30 and -3.4% for RH50, compared to EP10) and leading to an aggravation of the impact for the GWP category (+8.2% for RH30 and +16.9% for RH50, compared to EP10). FWAE and MWAE categories are also influenced by the amount of plant protection products, growth regulators and fertilizers, due to release of toxic substances during the production phase. Separate management of fertigation observed in the growth trials did not translate in significant differences in the relative impact of fertilizers, their contribution ranging from 7.5% (EP10) to 6.8% (RH50) for FWAE category, and from 10.8% to 10.2% for MWAE category. FRH accounts for a significant share of the impacts in FWAE category, ranging from 6% (RH10) to 25% (RH50); their use lead to an increase of the environmental burden of the FU for this indicator (+11% for RH30, +19% for RH50). MWAE impact assessment results are also affected by the amount of FRH, and performance of treatments amended with this material is similarly affected (+9% for RH30, +17% for RH50). Comparing our results with previous life cycle assessment of floricultural commodities (Koeser et al., 2014) and other container grown plants (Aldentun, 2002; Kendall et al., 2012) we noted that, similarly with other cultivation phases where no artificial lighting, heating or cooling is required, GWP is mainly affected by materials like plastic, growing media components, and fertilizers. Previous studies (Russo and De Lucia Zeller, 2008, Bonaguro et al., 2016) assessed the environmental impact of *C. persicum* production in Italy. In the first study, the authors carried out an assessment of the nursery production phase; our assessment does not include a thorough evaluation of plug production phase, which is modeled using a process from Ecoinvent database (Seedling production, at plant). However, our findings concerning relative impact associated with other production inputs such as greenhouse structures, plastic pots and peat are comparable. The second study focused on the comparison between three species, *Euphorbia pulcherrima* Willd., *Pelargonium* ×*hortorum* Bailey and *Cyclamen persicum* Mill., and two different containers. Fertilizers and plastic pot were identified as main contributors to GWP of a potted cyclamen plant. For the chosen FU, peat and EP have a large share of the environmental burden, accounting for 30% to 40% of total impacts for AD and GW categories, and for about 25% in FWAE and MAET categories. Their replacement with alternative growing media component could theoretically reduce the environmental burden of cyclamen production. However, in our scenario, substitution with FRH leads only to a slight reduction in AD category results, while values are substantially unchanged or even worse when looking to other categories.

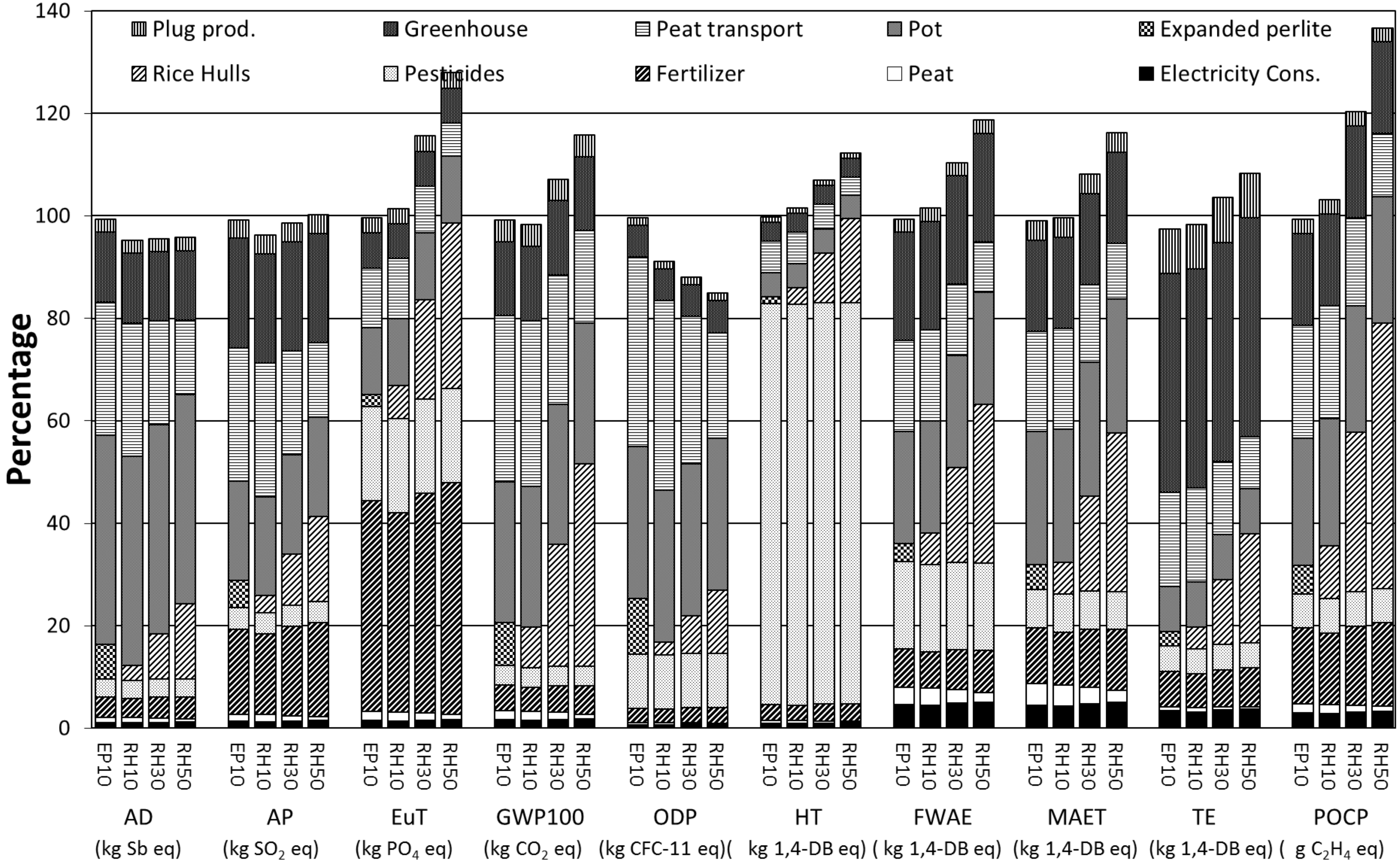

Fig. 1. Contribution of each production input to the characterization results for CML baseline categories.

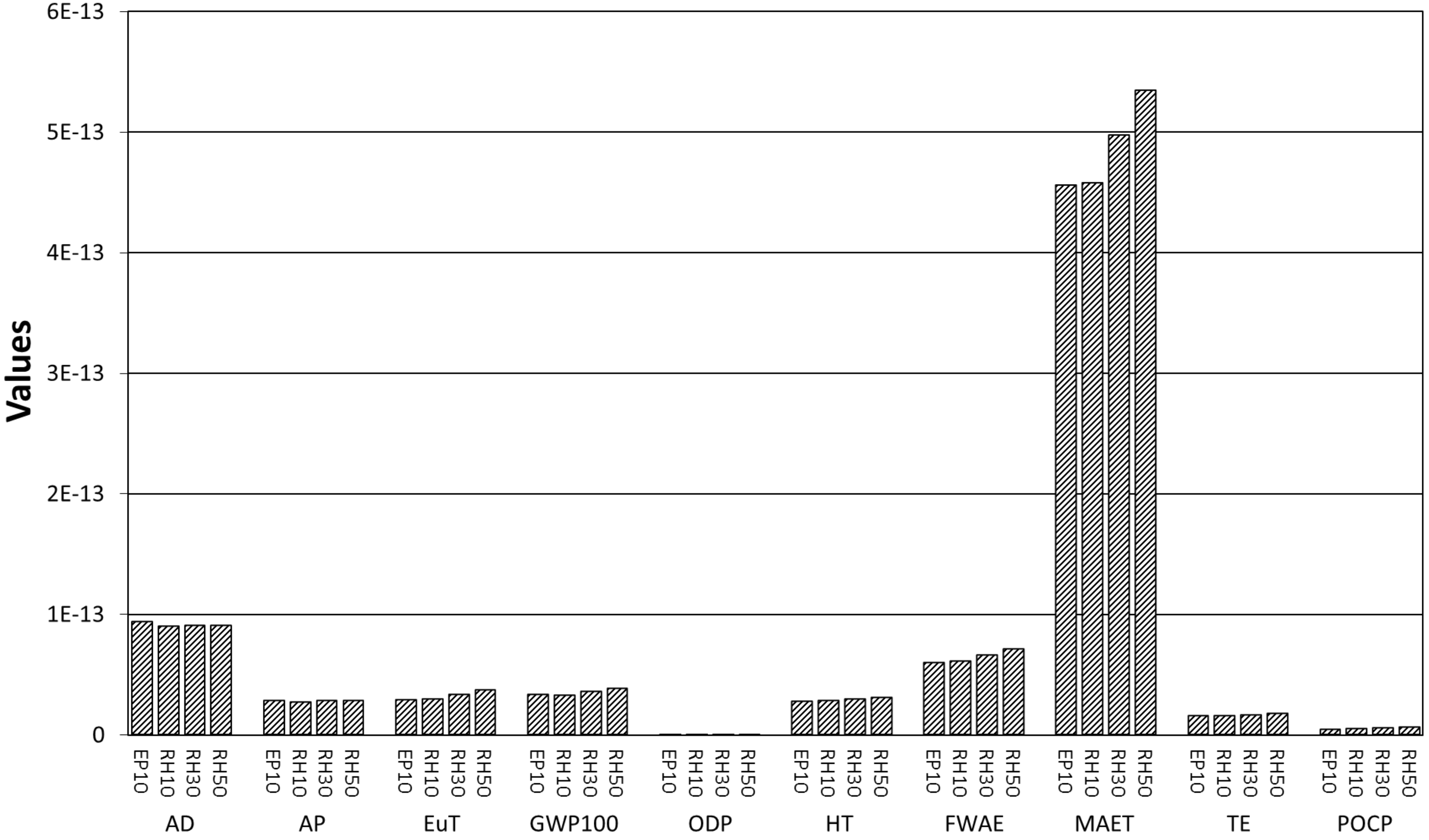

Fig. 2. Normalization of LCIA results according to Western Europe 1995 values.

4.2. Sensitivity analysis

The results of a LCA study can be affected by different sources of uncertainty, usually related to subjective methodological choices, such as assumptions on allocation rules, system boundaries definition, and data quality (Cellura et al., 2011).

Growing media components, such as FRH and peat, are important elements in this study. Since we use secondary data to model these materials, and several assumptions are made regarding peat means of transport and distance, and the allocation rules for FRH, in the following sections we perform a sensitivity analysis in order to assess the influence of initial choices on the environmental profile of the FU.

4.2.1. Peat transport

Two scenarios are formulated and analysed to measure the extent of the variation from our base scenario:

- Scenario 1: peat is shipped by lorry from processing facilities located in three different German regions (Rhineland-Palatinate; Saxony-Anhalt, Schleswig-Holstein) ; average distance from the extractions sites to the processing facilities is an estimate based on information provided by the exporting company (Klass-Deilmann).
- Scenario 2: peat is shipped by lorry from processing facilities located in Lithuania (Klaipėda County, Utena County) and Estonia (Pärnu County, Tartu County); average distance from the extractions sites to the processing facilities is an estimate based on information provided by the exporting companies (Lietuviškos durpės, Eesti Turbaliit).

Table 3 shows the results of impact assessment of the different FU for baseline and modified scenarios. In the first scenario, values show an impact reduction for all categories, in particular for AD and GWP. It can also be noted that EP10 and RH10 are the most affected, since the amount of peat in growth medium is higher for these treatments. Finally, the trend of baseline scenario does not change, and the differences observed between EP10 and RH30 and RH50 are greater in this scenario. This option involves shorter transport routes, but is the less realistic scenario in the present peat market situation.

Regarding Scenario 2, results show an aggravation of impacts for all categories, in particular for AD and GWP. Final results for the relevant categories show that the trend observed for the baseline scenario is not reversed, for RH30 and RH50 still perform worse in most categories compared to EP 10, even though the differences are diminished. This scenario involves longer transport routes, and is the most realistic in the present peat market situation.

4.2.2. Fresh rice hulls

In the Italian scenario, RH cannot be considered a waste product of rice production, since they are used for various purposes (e.g. poultry litter, heat generation) and have therefore their own market. According to ISO 14044 (2006), when allocation is necessary, the criteria should reflect a physical relationship between the environmental burdens and the functions delivered by the system. Since we decided to choose an economic allocation factor, the share of rice production process costs and impact is linked to the product market value in relation to the price of main product, i.e. rice. Market price of rice and of its side products is quoted on various stock exchange markets (Vercelli, Milano, Bologna, Mantova) and is subject to change during the year and over different years, due to market request, import and export needs. Comparing the average prices in the last three years (2014-2016), we found that rice hulls has a relative value of 4,51% compared to the common types of rice. Since this proportion is significantly different from the value suggested in Blengini and Busto (2009), we perform a sensitivity analysis to test the influence of this assumption on final results. Final results (Table 3) show that the trend observed for the baseline scenario is inverted. RH10 have better or similar performances compared to EP10 for all relevant categories. RH30 and RH50 a substantial reduction can be observed for GWP, MAET and FWAE categories results compared to base scenario; moreover, these treatments achieve better performance than EP10 and RH10 in AD and GWP categories, while values for MAET and FWAE categories are similar.

Table 2a. Sensitivity analysis for one Cyclamen plant. For scenario 1 and scenario 2, environmental impact values and differences from baseline scenario are presented. For the alternative FRH allocation impact values, differences from baseline scenarios and percentage of total impact in relation to EP10 are presented.

	base scenario	**scenario 1**		**scenario 2**		**rice halls allocation**		
Impact category	**value**	**value**	**diff. (%)**	**value**	**diff. (%)**	**value**	**diff. (%)**	**diff. (%)^**
EP10								
AD (kg Sb eq)	1.39E-03	1.53E-03	10.49	1.26E-03	-8.93			
AP (kg SO_2 eq)	7.58E-04	7.74E-04	2.14	6.60E-04	-12.91			
EuP (kg PO_4 eq)	3.56E-04	3.71E-04	4.16	3.41E-04	-4.31			
GWP100 (kg CO_2 eq)	1.57E-01	1.77E-01	13.07	1.39E-01	-11.11			
ODP (kg CFC-11 eq)	2.73E-08	2.85E-08	4.29	2.25E-08	-17.66			
HT (kg 1,4-DB eq)	2.05E-01	2.09E-01	1.81	2.00E-01	-2.48			
FWAE (kg 1,4-DB eq)	2.99E-02	3.07E-02	2.68	2.74E-02	-8.31			
MAET (kg 1,4-DB eq)	5.17E+01	5.50E+01	6.24	4.78E+01	-7.55			
TE (kg 1,4-DB eq)	7.18E-04	7.32E-04	1.85	6.54E-04	-8.96			
POCP (kg C_2H_4 eq)	3.52E-05	3.61E-05	2.47	3.15E-05	-10.62			
RH10								
AD (kg Sb eq)	1.33E-03	1.48E-03	10.94	1.21E-03	-9.31	1.31E-03	-1.57	94.4
AP (kg SO_2 eq)	7.36E-04	7.52E-04	2.20	6.38E-04	-13.30	7.23E-04	-1.76	95.3
EuP (kg PO_4 eq)	3.63E-04	3.77E-04	4.09	3.47E-04	-4.23	3.51E-04	-3.26	98.5
GWP100 (kg CO_2 eq)	1.56E-01	1.76E-01	13.18	1.38E-01	-11.20	1.49E-01	-4.09	95.1
ODP (kg CFC-11 eq)	2.50E-08	2.62E-08	4.69	2.02E-08	-19.29	2.46E-08	-1.38	90.3
HT (kg 1,4-DB eq)	2.09E-01	2.13E-01	1.78	2.04E-01	-2.43	2.06E-01	-1.65	100.1
FWAE (kg 1,4-DB eq)	3.05E-02	3.13E-02	2.62	2.80E-02	-8.14	2.96E-02	-3.11	99.0
MAET (kg 1,4-DB eq)	5.20E+01	5.52E+01	6.21	4.81E+01	-7.52	5.03E+01	-3.16	97.3
TE (kg 1,4-DB eq)	7.25E-04	7.38E-04	1.84	6.60E-04	-8.89	7.09E-04	-2.16	98.7
POCP (kg C_2H_4 eq)	3.66E-05	3.75E-05	2.38	3.28E-05	-10.23	3.47E-05	-5.11	98.5

Table 2b. Sensitivity analysis for one Cyclamen plant. For scenario 1 and scenario 2, environmental impact values and differences from baseline scenario are presented. For the alternative FRH allocation impact values, differences from baseline scenarios and percentage of total impact in relation to EP10 are presented.

	base scenario	**scenario 1**		**scenario 2**		**rice halls allocation**		
Impact category	**value**	**value**	**diff. (%)**	**value**	**diff. (%)**	**value**	**diff. (%)**	**diff. (%)^**
RH30								
AD (kg Sb eq)	1.34E-03	1.45E-03	8.47	1.24E-03	-7.20	1.27E-03	-4.69	91.8
AP (kg SO_2 eq)	7.54E-04	7.67E-04	1.67	6.78E-04	-10.09	7.15E-04	-5.16	94.3
EuP (kg PO_4 eq)	4.13E-04	4.25E-04	2.79	4.01E-04	-2.89	3.78E-04	-8.57	106.0
GWP100 (kg CO_2 eq)	1.70E-01	1.86E-01	9.40	1.56E-01	-7.99	1.51E-01	-11.26	96.0
ODP (kg CFC-11 eq)	2.42E-08	2.51E-08	3.77	2.04E-08	-15.50	2.32E-08	-4.27	84.8
HT (kg 1,4-DB eq)	2.20E-01	2.23E-01	1.31	2.16E-01	-1.80	2.10E-01	-4.69	102.2
FWAE (kg 1,4-DB eq)	3.32E-02	3.38E-02	1.88	3.13E-02	-5.82	3.03E-02	-8.57	101.5
MAET (kg 1,4-DB eq)	5.65E+01	5.90E+01	4.44	5.35E+01	-5.38	5.16E+01	-8.73	99.7
TE (kg 1,4-DB eq)	7.63E-04	7.73E-04	1.36	7.13E-04	-6.57	7.16E-04	-6.15	99.6
POCP (kg C_2H_4 eq)	4.27E-05	4.33E-05	1.59	3.97E-05	-6.82	3.71E-05	-13.15	105.1
RH50								
AD (kg Sb eq)	1.34E-03	1.42E-03	6.03	1.27E-03	-5.13	1.24E-03	-7.80	89.1
AP (kg SO_2 eq)	7.67E-04	7.76E-04	1.18	7.12E-04	-7.09	7.02E-04	-8.46	92.6
EuP (kg PO_4 eq)	4.57E-04	4.65E-04	1.80	4.49E-04	-1.86	3.98E-04	-12.91	111.8
GWP100 (kg CO_2 eq)	1.83E-01	1.95E-01	6.21	1.74E-01	-5.28	1.52E-01	-17.37	96.6
ODP (kg CFC-11 eq)	2.33E-08	2.40E-08	2.79	2.07E-08	-11.47	2.16E-08	-7.37	79.2
HT (kg 1,4-DB eq)	2.31E-01	2.33E-01	0.89	2.28E-01	-1.22	2.14E-01	-7.45	104.1
FWAE (kg 1,4-DB eq)	3.57E-02	3.61E-02	1.25	3.43E-02	-3.87	3.10E-02	-13.28	103.6
MAET (kg 1,4-DB eq)	6.07E+01	6.24E+01	2.96	5.85E+01	-3.58	5.24E+01	-13.55	101.4
TE (kg 1,4-DB eq)	7.98E-04	8.05E-04	0.93	7.62E-04	-4.49	7.19E-04	-9.80	100.1
POCP (kg C_2H_4 eq)	4.85E-05	4.90E-05	1.00	4.64E-05	-4.29	3.91E-05	-19.29	111.0

4.3. Growth trials

Plant height (Table 3) and growth index (Fig. 3) were higher in plants grown in 10% EP and 10% RH, than those grown at higher percentages of FRH: in the latter plant growth was, in both case, reduced by nearly 9%. Neither number of flower nor number of leaves were affected by treatments and were, on average 6.7 and 45.3, respectively (Table 4). Flowers dry weight ranged from 1.76 g for plants grown in 10% perlite to 1.87 g for plants grown in 50% FRH. Compared to the control (10% EP), only plants grown in 50% FRH had lower flower dry weight. Shoot dry weight ranged from 13.9 g for plants grown in 10% perlite to 8.5 for plants grown in 50% FRH. Plants grown in 10% FRH or 10% EP had similar leaf dry weight (on average 9.5 g); compared to 10% EP plants, values were reduced by 16.0% in plants grown in 30% FRH and by 30.0% in those grown in 50% FRH. Corm dry weight was not significantly different across substrates (on average 0.98 g), while only 50% FRH plants had lower root dry weight compared to the control. At last, the overall plant dry weight ranged from 14.4 g for plants grown in 10% FRH to 11.1 g for plants grown in 50% FRH. Cyclamen grown in 10% RH or 10% EP had comparable total dry weight, while this was significantly lower in plants grown in 30% FRH (-11.1%) and the lowest in 50% FRH (-22.8%).

These results are in line with another study (Zanin et al., 2016) that investigated the behavior of other species, such as *Euphorbia pulcherrima* Willd. and *Pelargonium ×hortorum* Bailey, grown in substrates amended with FRH, were plant growth was negatively affected by percentages of FRH of 30% or higher. Cyclamen grown in substrates with high amount of FRH dried out faster as compared to the control. Even though this was counteracted by more frequent irrigation, growing medium with 50% FRH, in particular, resulted in smaller plants, thus increasing production costs and reducing market value.

Table 3. Effects of the evaluated substrates on plant growth parameters.

Parameter	**Substrate**			
	EPP10	**RH10**	**RH30**	**RH50**
Plant height (cm)	12.7 a	112.7 a	11.6 b	11.5 b
Flower number	7.13	7.04	6.96	5.38
Leaves number	47.5	46.7	44.0	43.1
Dry flower weight (g)	2.45 a	2.76 ab	2.11 bc	1.87 c
Dry leaves weight (g)	9.65 a	9.35 a	8.11 b	6.76 c
Dry corm weight (g)	0.86	1.06	1.08	0.93
Dry root weight (g)	1.31 b	1.31 b	1.42 ab	1.57 a

Column values with the same letter are not statistically different according to Tukey's HSD test ($P \leq 0.05$).

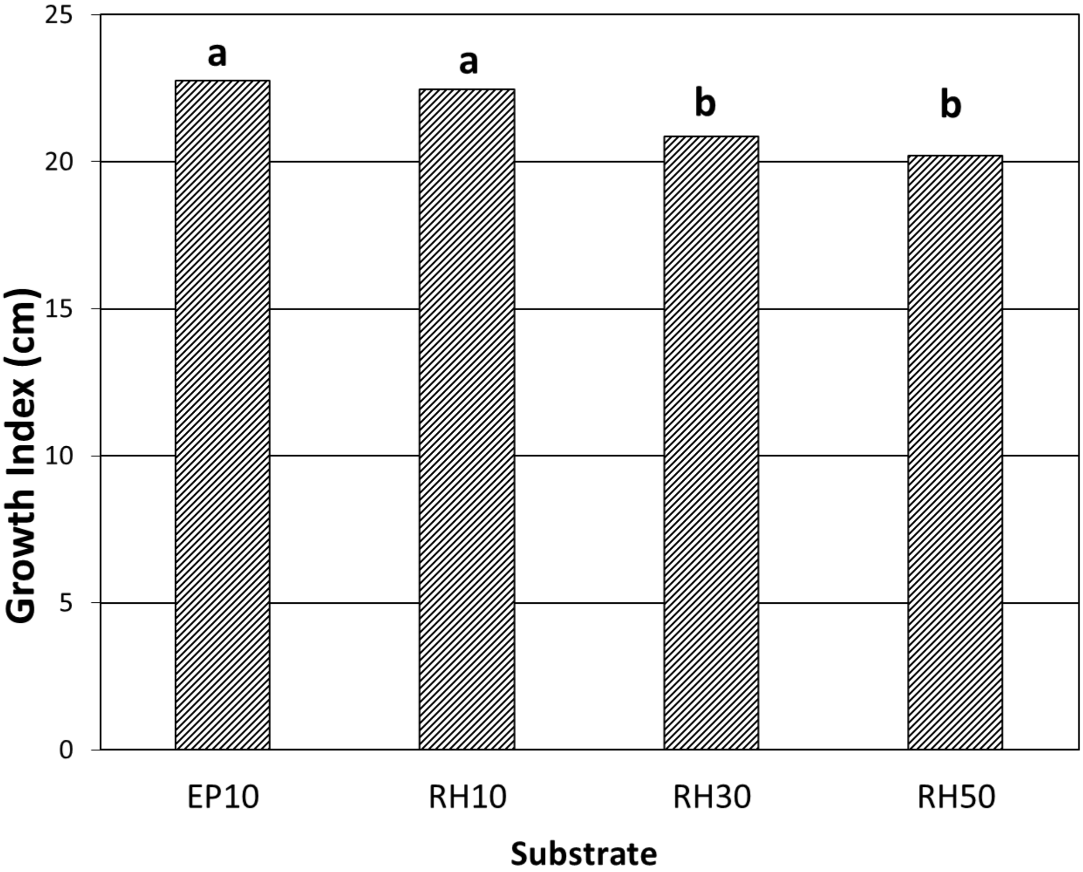

Fig. 3. Effects of the evaluated substrates on plant growth index. Histogram values with the same letter are not different according to Tukey's HSD test ($P \leq 0.05$).

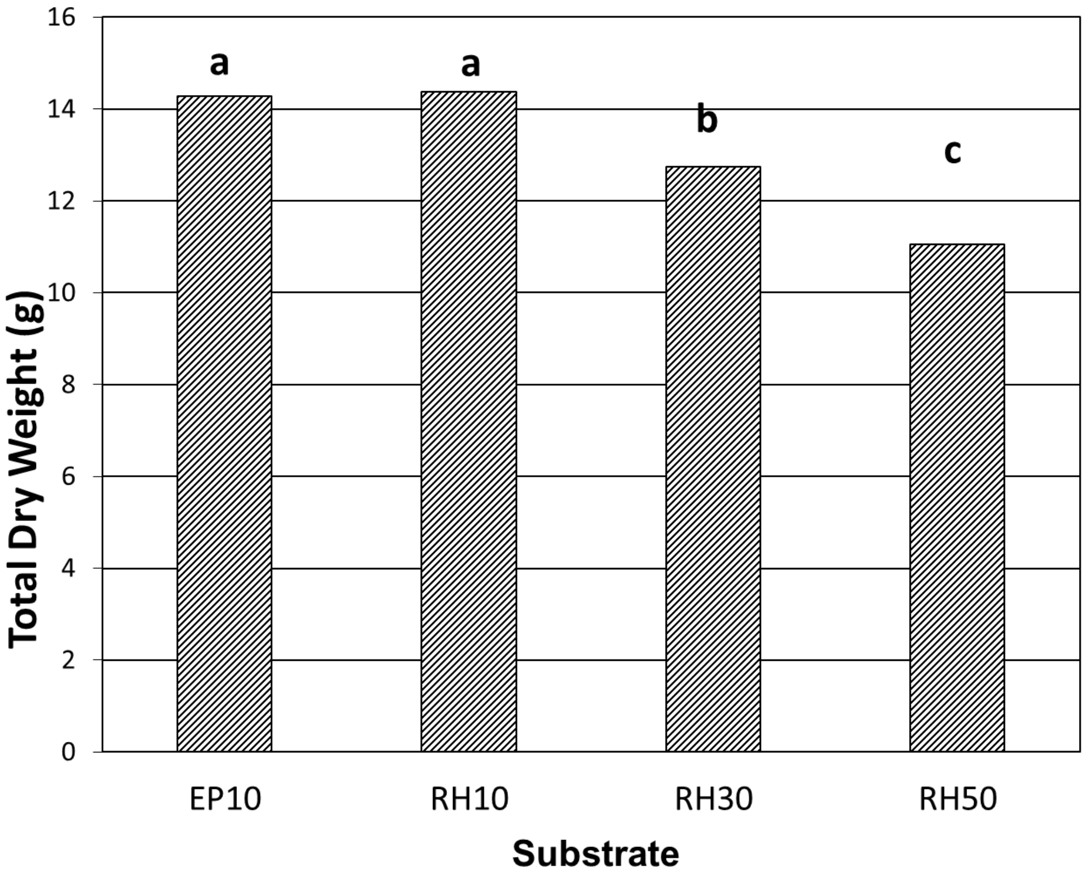

Fig. 4. Effects of the evaluated substrates on plant total dry weight. Histogram values with the same letter are not different according to Tukey's HSD test ($P \leq 0.05$).

5. Conclusions

The results of this study showed that replacement of 10% expanded perlite by 10% fresh rice hulls can lower the environmental impact of cyclamen pot production without affecting final product quality. LCIA showed which variable production factors are relevant to the final stage of cyclamen production for the considered scenario. Since the studied cultivation phase does not require energy intensive inputs like artificial lighting, heating or cooling , AD and GWP are mainly affected by plastic pot, peat transport, and greenhouse structure, while fertilizers and plant protection products affect mainly FWAE and MAET categories. Unfortunately, impact assessment also highlighted that a further increase of FRH is the preparation of growing substrates is not desirable as it slightly increases the environmental impact while reducing plant performances. Sensitivity analysis results indicate that relevant choices like allocation rules have an important role when assessing secondary products of a multi output process, as in the case of FRH. Substitution of peat and other non renewable resources such as expanded perlite is a desirable achievement from an environmental point of view. However, agricultural and industry waste products are experiencing an increase in their market demand for a wide range of alternative uses, thus affecting their market value and their share of environmental burdens. An environmental assessment based on life cycle methodology needs to take into account these changes, for they influence the effective share of environmental burdens in a production process, and can eventually reduce the real environmental benefits that can be achieved.

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Chapter IV - Environmental assessment of heating systems applied to ornamental greenhouse farms in Veneto region

To be submitted

1. Abstract

Life cycle assessment studies on protected crops highlighted different materials and processes with major contribution to the overall impact. When considering crops with active control of greenhouse environment, the energy required is a major contributor in most of the investigated environmental indicators. Hot air generators powered by fossil fuels are the most widespread heating technology for small and medium-sized for greenhouse farms in Italy, due to their low installation costs. The research for alternative energy sources, triggered by rising fuel cost and by pollution reduction policies, has so far explored the economic and environmental feasibility of different solutions. Boiler systems powered by biomass, solar or photovoltaic energy are among the most interesting and viable alternatives. Starting from observations on the contribution of conventional heating systems of the environmental impact of Poinsettia (*Euphorbia pulcherrima* Willd.), we chose to assess, by means of life cycle assessment, the environmental viability of alternative systems operating in our region. The theoretical (Scenario 1) and actual (Scenario 2) performances of a wood chip boiler and air-water heat pump powered by photovoltaic panels are compared to a conventional air heater. The functional unit is the heat necessary to ensure the required temperature for the growth of Poinsettia plants grown in a 14-cm pot. Impact assessment results for CML baseline categories highlighted how for both the investigated systems operating in ideal conditions, the potential benefits are limited to certain indicators (climate change, resource depletion, acidification potential). The potential reductions were limited to global warming potential when analyzing the actual operating scenarios. Interpretation of ReCiPe end-point categories allowed to identify the wood chip boiler as the preferable system, since it reduces the impact on climate change and air emissions, while ecosystems indicator are comparable to the conventional system. We also highlight how thermal insulation, vector and positioning of heating sources are efficient measures to reduce energy requirements and environmental burdens linked to greenhouse heating.

2. Introduction

Ornamental plant production is characterized by highly intensive processes and the use of resources that have the potential to negatively impact the global environment (Marble et al., 2011). Recent studies (Russo and De Lucia Zeller,, 2008; Nonhebel et al., 2010; Sahle and Potting, 2013; Abeliotis et al., 2016) approached the issue of floriculture environmental impact holistically, applying life cycle assessment (LCA) methodology to different crops and production systems. Some studies analyzed container grown crops under protected cultivation (Koeser et al., 2014; Bonaguro et al., 2016): when considering crops grown with little or no control of the growing environment, researchers identified material inputs as major contributors to environmental impact, such as plastic pots and containers, and the peat used in growing media mixes; it was also noted that production phases with higher energy inputs (artificial lighting, active temperature and humidity control), such as plug production of petunia (Koeser et al., 2014) or cyclamen seedlings (Russo and De Lucia Zeller, 2008) have an important share of total environmental burdens.

Energy consumption to ensure microclimate conditions for crops grown during winter months also have a large share of environmental burdens of protected crops (Russo and De Lucia Zeller, 2008; D'Arpa et al., 2016). Hot air generators powered by diesel fuel, LPG or natural gas are the most common heating systems for small and medium-sized greenhouses in Italy. It is estimated that heating greenhouses with fossil fuels creates emissions of about 1.3 Mt CO_2 per year (Campiotti et al., 2010). The high diffusion of hot air generators is due to their low installation cost and small size.

In recent years, rapidly rising costs of fossil fuels challenged the economic feasibility of this solution, triggering the research for alternative fuels and solutions. This research is also driven by the need for air pollution reduction and environmental policies. Studies looking for alternative energy sources have explored various alternatives, the most important being solar collectors, heat pumps, biomass and cogeneration systems. In a review of greenhouse applied heating technologies, Sethi and Sharma (2008) pointed out that passive solar energy collected by water (tanks or pipes) involves little cost, but is very space consuming and can achieve low to medium heating performances. Ground source heat pumps (GSHP) have been used for greenhouse heating in different studies (Ozgener and Hepbasli, 2005; Benli and Durmus, 2009; D'Arpa et al., 2016 Russo et al., 2014). However, major economic and technical constraints, such as cost of soil digging and burying of pipes affect the viability of these systems. High installation costs are common to other alternatives, such as rock bed storage (Kurklu et al., 2003) or phase change material storage systems (Sari and Kaygusuz, 2006). An extensive study on a combined biogas, solar and ground source heat pump heating system was conducted in Turkey by Esen and Yuksel (2013), investigating the technical performance of the three systems for standalone or combined use. An experimental application of a solar-assisted heat pump was studied by Ozgener and hepdasli (2005), who performed an energy and exergy analysis of the system. Conclusions showed a good efficiency of the system, while highlighting its operating limitations with very low external temperatures. Tong et al. (2010) compared energy balance, heat distribution pattern and efficiency in greenhouses heated with ten household-size heat pumps or with a conventional oil heater, concluding that heat pumps may prove an efficient and reliable technology when used for greenhouse heating.

Most studies have so far focused mainly on technical and/or economic aspects of alternative technologies, while thorough environmental analyses of applied systems are scarce. In a recent study, Russo et al. (2014) compared a photovoltaic-geothermal heat pump with a conventional hot air generator using liquefied petroleum gas, two technologies currently encouraged by Italian policies for the reduction of greenhouse gases emissions. The chosen functional unit was the unit of thermal energy produced by the systems; system boundaries included all structural components and operating costs. Data came from pilot plants operated in an experimental context.

The environmental analysis results showed that the geothermal heat pump system has greater impact, with the exception of the global warming potential (GWP) category. Within the framework of Rural Development Plan 2007-2013 - measure 124, we conducted a study on 20 floriculture farms in Veneto Region, collecting data on the cultivation of three pot-grown species (*Cyclamen persicum* Mill., *Pelargonium ×hortorum* Bailey and *Euphorbia pulcherrima* Willd.). A Carbon Footprint was conducted on the available data of the studied phase; impact assessment results highlighted some inputs contributing most to the GWP of crops. In particular, heating fuel consumption greatly affects the impact of poinsettia plants (Bonaguro et al., 2016). Starting from these observations, we investigated how different systems for heating greenhouses may affect the final impact of an ornamental species. We chose to compare systems and structures that are already installed and operating in two enterprises of Padova Province. The objective of this study is the environmental analysis, by means of life cycle assessment (LCA), of different heating systems applied to greenhouse environment, comparing three heat generating technologies: air-water heat pump (HP), wood chips boiler (WCB) and air heaters (CH), exploiting different energy sources, namely photovoltaic (PV), biomass (wood chips) and fossil fuel (diesel), respectively. The system performances are first studied in a theoretical scenario, which is then compared to actual operating conditions.

3. Materials and methods

3.1. Goal and scope

Our assessment aims at comparing alternative heating systems currently operating in two ornamental greenhouse farms sited in Padova Province. Heating requirements are first calculated for a model greenhouse (Scenario 1), with climatic data based on average weather conditions for the Province (Veneto, Italy). To provide a comparison between the theoretical model and the actual situation, we collected information on the real operating conditions of the plants over a two year period. Data on energy consumption during two poinsettia (*Euphorbia pulcherrima* Willd.) growing cycles in 2014 and 2015 were collected to determine energy requirements. The method used for LCIA is CML 2015, developed by the Centre for Environmental Studies. The following impact categories are assessed: abiotic resources depletion (AD), stratospheric ozone layer depletion (ODP), global warming potential for a time horizon of 100 years (GWP100), marine aquatic ecotoxicity (MAET), fresh water aquatic ecotoxicity (FAET), terrestrial ecotoxicity (TE), human toxicity (HT), photochemical ozone creation (PO), acidification (AP) and eutrophication (EuP).

3.2. System boundaries and functional unit

The functional unit is the heat production necessary to ensure the required temperature for the growth of a poinsettia plant, sold as a Christmas decoration, ready-for-sale in a 14 cm diameter pot.

Main materials inputs for the manufacturing of the heating system components, as well as the materials for the heat distribution system are considered in the inventory. System boundaries include production, installation, operation to end of life treatment for all components. The investigated systems are a photovoltaic-assisted air-water heat pump (PV-HP), and a wood chip boiler (WCB), both employing a basal heat distribution system with low-temperature hot water, compared with a conventional hot air generator powered by diesel fuel (CH). Data for background processes such as material manufacturing and disposal activities sourced from Ecoinvent 3.3 database, and were modeled with OpenLCA ver. 1.5.0.

3.3. *Greenhouse model and heating requirements calculations (Scenario 1)*

Outdoor climate is a key factor in greenhouse production. To characterize local climatic conditions in the investigated area, regional data sources were consulted: average air temperature and solar radiation intensity for the considered period computed from long-term (30 years) series were provided by the regional meteorological network (ARPAV). The greenhouse model was based on information acquired from a sample of 20 ornamental plants growers (Bonaguro et al., unpublished data), and built on the average characteristics of greenhouses used for poinsettia cultivation in the area of investigation. The model is a circular roof pavilion greenhouse, with galvanized steel structure, covered by air-inflated double layer, outside polyethylene (PE) film, 200 µm thick, inside ethylene-vinyl acetate (EVA), 100 µm thick. The 2-span greenhouse has a span unit 60 m long and 12 m wide, a side wall height of 3.50 m and ridge height of 4.5 m. Longitudinal axis is assumed to be oriented in the E–W direction. Total heating requirements are calculated by summing heat losses by conduction, convection and radiation, and the solar or artificial contributions (Impron et al., 2007; Hepbasli, 2011). A truss-to-truss thermal curtain layout is installed to provide additional energy savings (porous aluminized material, 50% shading factor, 25% nominal energy savings). In this study, a simplified greenhouse thermal modeling was performed for heating requirements calculation, which is an intermediate approach between a static and a dynamic model (Sethi et al., 2013). Calculating heat losses is the first step when determining the heating system capacity. Heat loss for a greenhouse is usually the sum of two components: heat loss through the walls and roof and ventilation and infiltration losses. Infiltration is analyzed via the air change method, which is based upon the number of times per hour that the air in the greenhouse is replaced by cold air leaking in from outside. The number of air changes which occur is a function of wind speed, greenhouse construction, and inside and outside temperatures (Rafferty, 1986). Heat losses through the cover material (Qc) were quantified according to Eq. 1 (NGMA, 2000):

$Q_c = A_b \cdot K_r \cdot (T_e - T_i)$ Eq. 1

where Ab is the covered area, Kr (W · m-2 · °C-1) is the heat transmission coefficient of the covering material, equal to 305 for the double layer PE film assuming a low wind speed, which takes into account both conduction losses occurring between walls and roof and radiation losses due to the passage through the cover material of a part of the far infrared radiation from soil; Te and Ti are greenhouse external and internal temperatures (°C). The infiltration heat losses (Qi) were determined using Eq. 2 (NGMA, 2000):

$Q_i = N_{ac} \cdot V \cdot \rho_a \cdot C_p \cdot (T_e - T_i)$ Eq. 2

where N_{ac} is the estimated number of air changes per hour (0.6), V is greenhouse volume, ρ_a is air density (1220 kg $\cdot m^{-3}$), C_p its specific heat capacity (1,005 kJ · $kg^{-1} \cdot °C^{-1}$), T_e and T_i are greenhouse external and internal temperatures (°C). To account for the effect of the thermal curtain, a reduction factor for the value of K_r equal to 0.8 was used. A different value of N_{ac} (0.9) was used to account for higher convective heat exchanges determined by the hot air generator. The amount of incoming solar radiation inside the greenhouse (Q_s) was calculated from Eq. 3 (Benli, 2013):

$Q_s = \tau \cdot I \cdot A_c$ Eq. 3

where τ is the transmissivity of the greenhouse cover, I is the solar radiation striking the horizontal surface, and A_c is the greenhouse floor area (m^2). The transmissivity value of 0.8 was used. Internal temperatures (T_i) were set to match optimal values for an average poinsettia cultivar during its growing period (18 °C during daytime, 16 °C at night). With average weather conditions, the heating season is considered to last from September 20th to December 15th. The seasonal energy requirement calculated for the model greenhouse with air heating is 258 kWh $\cdot m^{-2}$, while the requirement with basal heating is 212 kWh $\cdot m^{-2}$.

3.4. *Description and assumptions for heating systems scenarios*

WCB

The plant was realized through economic incentives (known as "White Certificates") introduced in Italy by National Decree n. 28/2012, which addressed greenhouses heating systems in order to promote the shifting of boilers to wood biomass types. A 700 kW wood chip boiler (steady state efficiency 75%), with two buffer tanks with 10,000 l total capacity provides hot water for the basal radiant system operating at low temperatures (45 °C). The wood chips are stored in an underground concrete shed with a 100 m^3 capacity; a screw system feeds a roller grate, two-phase combustion chamber. Exhaust gases are filtered by a vertical plates precipitator installed in the chimney. The heat distribution system consists of underground insulated pipelines (HDPE, 63 mm diameter) conveying hot water to radiant pipes (LDPE, 25 mm diameter) running under ebb-and-flow benches. Heat distribution efficiency is assumed equal to 85%. Assumed lifetime for boiler components and structures, as well shed, is 30 years. For distribution system components an average lifetime of 15 years is considered. The biomass fuel classes chosen to model this scenario belong to the A1 category (UNI EN 14961-2:2012), which includes only firewood produced by stem wood and whole trees without roots. For the analysis, the wood burned was assumed to belong to deciduous species, representing those most used in northern Italian regions (ISTAT, 2012). Bulk density value of 250 $kg \cdot m^{-3}$, an average lower heating value (LHV) of 12.5 $MJ \cdot kg^{-1}$, and moisture class (MC) of 30% . Wood chips are supplied by various local producers and transported over an average distance of 200 km.

PV-HP

The PV-HP scenario analyses a system combining photovoltaic panels for electricity production combined with an air-water heat pump. A basal system (LDPE pipes, under cultivation benches) operating at low temperatures (35-40 °C) is used for heat distribution.

The grid-connected monocrystalline photovoltaic modules (mounted power 800 kW) are mounted on a 800 m^2 raised shelter, angled 30° to the ground, placed next to the greenhouse. The electric energy produced powers a 20 kW air-water heat pump, nominal coefficient of performance reported by the manufacturer (COP) equal to 4.5, refrigerant fluid R404A. The HP is installed in the greenhouse in a separate room from the growing area; average room temperature with this setup rarely falls below 0 °C, and frequency of reverse cycle defrosting is very low (2-4 times every 24 hours). Average operating COP in the described operating conditions is assumed as 3.4. The power output of the HP is connected to a thermally insulated buffer tank with 1 m^3 capacity, which stores the hot water that is circulated through the radiant system. The heat distribution system consists of main pipelines (HDPE, 50 mm diameter) conveying hot water to radiant pipes (HDPE, 25 mm diameter) running under cultivation benches. Heat distribution efficiency is assumed as 80%. Assumed lifetime for the PV modules and support structures components is 30 years. For heat distribution system, buffer tank and HP, a lifetime of 15 years is considered.

3.5. Scenario 2

The second scenario is modeled in order to compare the theoretical situation with the actual operating situation of the described heating plants. The reason for this comparison is the complex reality of small-medium floriculture farms operating in the area. Technological innovations such as biomass or photovoltaic plants need to adapt to the operational reality and to existing structures that can deviate from the ideal scenario. The biomass-powered plant serves the heating needs of a medium-sized (covered area 6000 m^2) greenhouse farm mainly producing ornamental potted plants. The WCB system heats 4 single span tunnels, unit floor area 1500 m^2, ridge height 3.5 m, single-layer PE cover 200 µm thick, galvanized steel structure. Even though truss-to-truss thermal curtains made of porous aluminized material are installed, radiation losses through the covered surface are considerably higher, and the radiant system, because of its limited maximum output, cannot cover the heating requirements during cold nights, requiring activation of the back-up system (air heaters). Fuel consumption for their operation therefore also needs to be accounted for. Seasonal requirement for this scenario, inferred from total fuel consumption, was calculated as 286 $kWh \cdot m^{-2}$ (11.87 $kWh \cdot plant^{-1}$). The PV-HP system is installed to meet the heating needs of a small floriculture enterprise (covered area 3000 m^2). The plant currently heats the central volume of a three-span tunnel, gutter height 2.5 m, ridge height 3.5 m, with air-inflated double layer cover, exterior polyethylene (PE) film, 100 µm thick, interior ethylene-vinyl acetate (EVA), 100 µm thick. The central volume is separated by movable side walls made of

PE film. Aluminized thermal curtains with a truss-to-truss layout are installed at gutter height. Also in this case the limited output of the radiant system is not able cover the heating requirements during winter nights, and requires activation of the back-up system, which covers about 15% of total heat requirements. Seasonal requirement for this scenario, inferred from total fuel and electricity consumption, was calculated as 236 kWh · m^{-2} (10.75 kWh · $plant^{-1}$).

3.6. Assumptions regarding electricity production

While total energy produced by the PV modules is theoretically adequate to cover the demand of the heat pump and other equipment, production is not evenly distributed throughout the year, with a production surplus during summer and a deficit in the winter months. Moreover, the PV system produces the energy required for daytime operation of the heat pump, when thermal demand is reduced; but, given the small storage volume of the buffer tank, the heat pump operates almost continuously at night during the winter, and electricity is supplied by the grid. For this scenario we assume that 20% energy for the operation of HP is supplied by the PV modules, while the remaining 80% is supplied by the national electricity network.

4. Results and discussion

Results of the impact assessment are presented in Table. 1. We chose to discuss the results of the following impact categories: acidification potential (AP), global warming potential (GWP), depletion of abiotic resources (RD), eutrophication (EP), fresh water aquatic ecotoxicity (FWAE), marine aquatic ecotoxicity (MAET), human toxicity (HT) and terrestrial ecotoxicity (TE). Impact results for these categories from the analysis of modeled scenarios are compared with the LCIA results for the reference system (CH) in the following paragraphs. PV-HP Scenario 1: In our first scenario, the PV-HP system has lower values in the AP (-74.4%), GWP (-86.3%), RD (-94.4%) and TE (-21.2%) categories, achieving a considerable reduction of the environmental load for these indexes, when compared to the CH system. GWP results mainly entail ethane emissions during HP operation. When looking at MAET, FWAE and HT categories, the PV-HP has a much greater impact than the CH system; in particular, values for MAET and FWAE are 2 and 4 times higher, respectively. Considering the relative contribution to the overall impact of this system (Table 2), we see how the photovoltaic modules have a major share of the impact, mainly due to their production process (e.g. nearly 90% for RD, over 80% for FWAE and MAET). For HT, heat pump manufacture also has a relevant share of potential loads, mainly linked to manufacturing and disposal of steel and copper components, and refrigerant production.

PV-HP Scenario 2: in the second scenario, the system still maintains better performances in GWP and RD categories (-32.0% and -33.1%, respectively); the increased impact for these categories can be attributed to the consumption of fossil fuels used to power the back-up heating system. For all other categories the impact results are notably higher. In particular, results for MAET, TE, HT and FWAE categories are 4 to 8 times higher when compared to the CH system. This dramatic increase is mainly related to the shift in the main electricity supplier (national grid instead of solar energy from the PV modules).

WCB Scenario 1. WCB system performs better than CH system in four out of eight categories: AP (-28.3%), GWP (-82.0%), RD (92.1%) and MAET (-27.9%). Values for the HT category are only slightly higher; the system scores worse performances than CH for TE, FWAE and ET categories. In particular, the second impact category is 157% higher. Table 3 shows that emissions linked to the combustion of wood chips are responsible for a large share of impacts in the AP (67.0%) and GWP (73.4%) categories, and, to a lesser extent (28.1%), in the HT category (particulate matter and NO_x formation). More than 75% of the ET results are due to emissions of ammonia, nitrogen monoxide and phosphorus from the combustion process and ashes disposal. Logging and chipping operations, as well as transport of wood chips by lorry, contribute almost 50% to RD category results. FWAE receives the highest contributions from electricity consumption and , in particular, from boiler and furnace manufacture (60.9%). Wood chip production and electricity consumption are also major contributors to TE (34.9%) and MAET (48.5%) categories.

WCB Scenario 2. In this scenario, nearly 30% of heat requirements is supplied by the back-up system (diesel air heaters). The increased impact in AP (+40.8%) and MAET (177.6%) categories is linked to the production and combustion of diesel fuel for their operation. The greater heating requirements as well as additional materials and energy for maintenance operations cause a slight increase in FWAE (+6.9%) and TE (+12.4%) values. This is probably due to operation phases with lower efficiency and subsequent rise in electricity and wood chips consumption.

Table 1. LCIA results for CML impact categories of the investigated systems in the theoretical (Scenario 1) and actual operating scenario (Scenario 2).

		Scenario 1			**Scenario 2**	
Impact category	**Reference unit**	**CH**	**PV-HP**	**WCB**	**PV-HP**	**WCB**
Acidification potential	kg SO_2 eq.	0.00730	0.00187	0.00523	0.01197	0.00733
Climate change - GWP100	kg CO_2 eq.	3.47989	0.47648	0.62597	2.36773	1.73775
Depletion of abiotic resources	MJ	46.42337	2.61382	3.67790	31.04302	18.78455
Eutrophication	kg PO_4^{3-} eq.	0.00091	0.00095	0.00130	0.00190	0.00152
Freshwater aquatic ecotoxicity	kg 1,4-DB eq.	0.09041	0.45840	0.23251	0.77044	0.24867
Human toxicity	kg 1,4-DB eq.	0.34974	0.62331	0.38097	1.95990	0.47400
Marine aquatic ecotoxicity	kg 1,4-DB eq.	335.725	1040.377	241.928	1724.982	338.506
Terrestrial ecotoxicity	kg 1,4-DB eq.	0.00420	0.00331	0.00759	0.02323	0.00853

Table 2. Relative contribution to LCIA results of system components and phases of PV-HP system (Scenario 1).

Impact category	**PV**	**HP**	**HP**	**Other**
Acidification potential - average Europe	77.51	21.51		0.98
Climate change - GWP100	51.69	23.12	20.74	4.45
Depletion of abiotic resources - fossil fuels	89.65	8.21	1.7	0.44
Eutrophication - generic	71.61	28.12		0.27
Freshwater aquatic ecotoxicity - FAETP inf	83.65	16.24		0.11
Human toxicity - HTP inf	60.20	39.60		0.2
Marine aquatic ecotoxicity - MAETP inf	80.50	19.14		0.36
Terrestrial ecotoxicity - TETP inf	63.43	36.18		0.39

Table 3. Relative contribution to LCIA results of system components and phases of WCB system (Scenario 2).

Impact category	**Combustion**	**Electricity**	**Wood Chips**	**Boiler and**	**Ashes**	**Other**
Acidification potential - average Europe	66.98	16.37	8.53	3.41	1.5	3.21
Climate change - GWP100	73.39	17.62	6.05	2.94		
Depletion of abiotic resources - fossil fuels		46.05	48.65	5.16		0.14
Eutrophication - generic	76.05	9.05	8.18	4.1	2.62	
Freshwater aquatic ecotoxicity - FAETP inf		23.61	8.43	60.92	5.85	1.10
Human toxicity - HTP inf	28.13	37.30	10.71	21.52		2.34
Marine aquatic ecotoxicity - MAETP inf		48.52	13.71	33.69	3.06	1.02
Terrestrial ecotoxicity - TETP inf		36.18	34.97	26.28	2.47	

Comparing the studied systems in the different scenarios, we notice that, even in ideal conditions (Scenario 1), the potential reduction of environmental impacts is limited to certain categories. For WCB system, this is due to the higher share of structures and materials necessary for the construction of the plants, and the higher consumption of electrical energy for their operation. The direct emissions related to wood combustion are greatly reduced, as compared for example with values reported in the literature (Cespi et al., 2014), in particular, for domestic installations, due to the cooling and filtering of the fumes; state-of-the-art air-filtration systems are mandatory for plants funded under the White Certificates scheme. Wood chips coming from sustainable forest management also considerably reduce the proportion of impacts associated with the production, in particular with regard to biogenic CO_2. If we consider other wood sources, emissions ought to be reconsidered accordingly. Analyzing the actual operating scenario, the achievable advantages are significantly reduced by the frequent operation of the combined heating systems, increasing the power consumption and heat dispersion by convection. In the PV-HP system, manufacture and disposal of the components is entirely responsible for the potential impacts. The results from the second scenario show how the electric energy source used to power the heat pump greatly affects the overall impact. The market for electric energy production in Italy includes various high emission processes, such as energy from combined heat and power plants exploiting incineration of municipal solid wastes. An improvement in this scenario may be achieved by using the HP for air conditioning during summer, thus reducing the share of poinsettia production infrastructure.

Results from an LCA study on heating systems applied to greenhouses (Russo et al., 2014), where two scenarios with a geothermal heat pump (GHP) and a liquid petroleum gas (LPG) powered air heater were analyzed, with different sources of electric energy for the heat pump (grid connection and photovoltaic), confirm the importance of the electric energy source. Indeed, the GHP scenario had lower impacts for GWP category when electric energy was provided by PV modules, but when energy was sourced from the national grid LCIA results increased for all categories, making GHP the most impacting of the analyzed systems. The GHP system potentially reduced impact values for GWP by 50%, but for AP and ET categories higher environmental burdens were associated with this system, heat pump manufacturing and drilling operations for the borehole heat exchanger being the most important contributors.

4.1. Results for ReCiPe endpoint indicators

To provide further information and a better interpretation of the assessment results, we chose to include impact analysis results obtained with the ReCiPe method (Goedkoop et al., 2012). The main objective of the ReCiPe method is to provide an LCIA method that combines Eco-Indicator 99 and CML. ReCiPe distinguishes two levels of indicators: eighteen midpoint indicators, which include those we considered from CML baseline, and Endpoint indicators grouped into the three areas of protection: Human Health, Resources and Ecosystems. The reason for calculating the endpoint indicators is that the large number of midpoint categories are very difficult to interpret because they have a very abstract meaning. The indicators at the endpoint level are intended to facilitate interpretation. Units of measurement are as follows: disability adjusted life years for human health, potential disappeared fraction of species (species year^{-1}) for ecosystem quality, and increased cost ($) for resource consumption. Figures 1, 2, 3 show LCIA results of the studied systems for the three endpoint categories. For Human Health (HH) (Figure 1), we can see how the PV-HP system has the best performance (6.63 e-06), considering the theoretical scenario, and the worst performance (2.46 e-05) in the actual operating scenario. This result confirms the importance of the assumption concerning the electric energy source, since off-site emissions linked to its production (grid electricity) or to the manufacturing and disposal of infrastructure (PV modules) entail major contributions to the indicator's results. The WCB scenario scores better results for both scenarios compared to CH system. The increase observed for the second scenario (+71.8%) is almost entirely attributable to direct emissions related to operation of the secondary heating system. Emissions of heavy metals to water due to landfilling of ashes is also a major contributor (28.2%), while air emissions of particulate matter and NO_x give a minor contribution to the overall result.

Looking at Ecosystems (ES) indicator results (Figure 2), we see how PV-HP system again shows the best (5.02 e-09) and worst (8.71 e-08) performance for the alternative scenarios. While in the first scenario, ethane released to air during heat pump operation is one the main contributors along with land transformation (24.7% and 27.3%, respectively), CO_2 emissions from fossil sources (45.4%) and land occupation (58.7%) give major contributions when considering the second scenario. WCB system has lower impacts in the first scenario, while in the second one the system has worse performance (+4.2%) than the CH system.

Land occupation (48.3%) and fossil carbon dioxide (26.2%) emissions are the main contributors. We highlight how the quality of wood chips should be considered a source of uncertainty, affecting results both for air emissions and land occupation. For Resource Consumption (Figure 3), both alternative systems perform better than the CH system in all considered scenarios (-96.7% for PV-HP and -90.8% for WCB in Scenario 1; -26.8% for PV-HP and -58.7% for WCB in Scenario 2); since results for this indicator are mainly affected by consumption of fossil fuels and extraction of metals, an expected increase can be observed for scenarios where the operation of conventional heaters is taken into account.

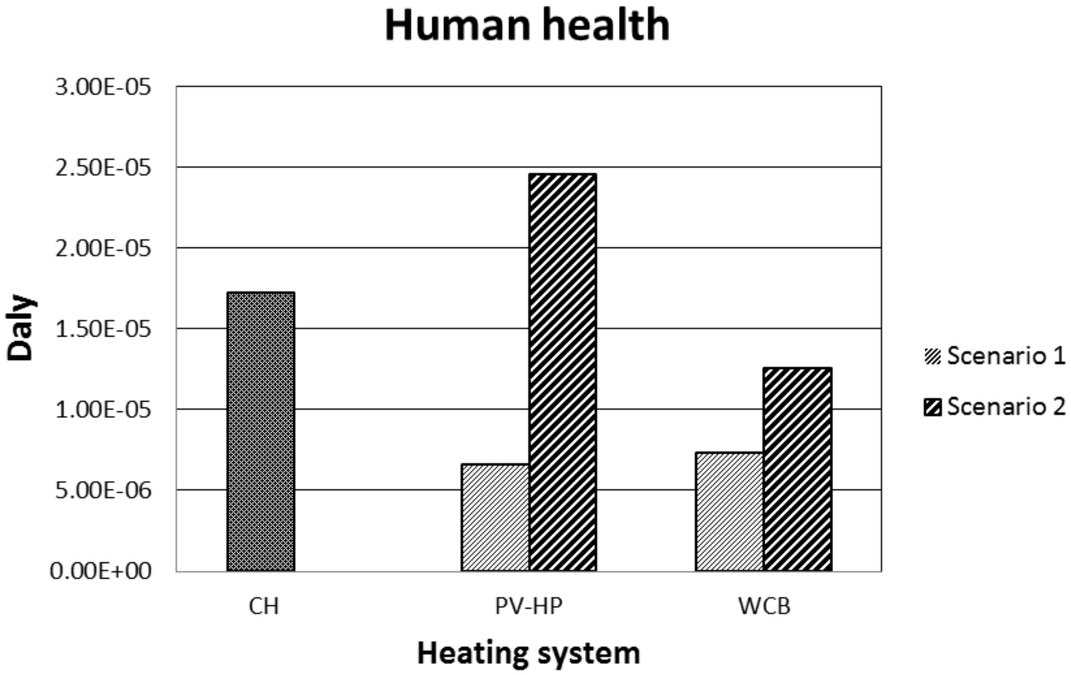

Figure 1 LCIA results for ReCiPe endpoint category Human Health, expressed as Disability Adjusted Life Year.

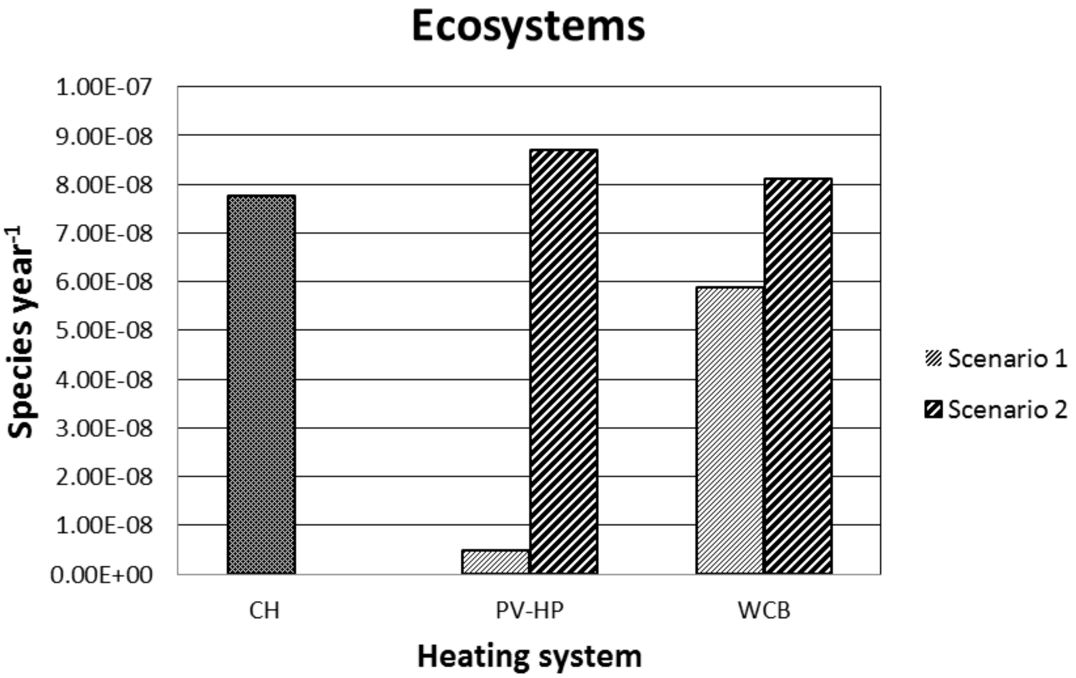

Figure 2. LCIA results for ReCiPe endpoint category Ecosystem quality, expressed as potential disappeared fraction of species.

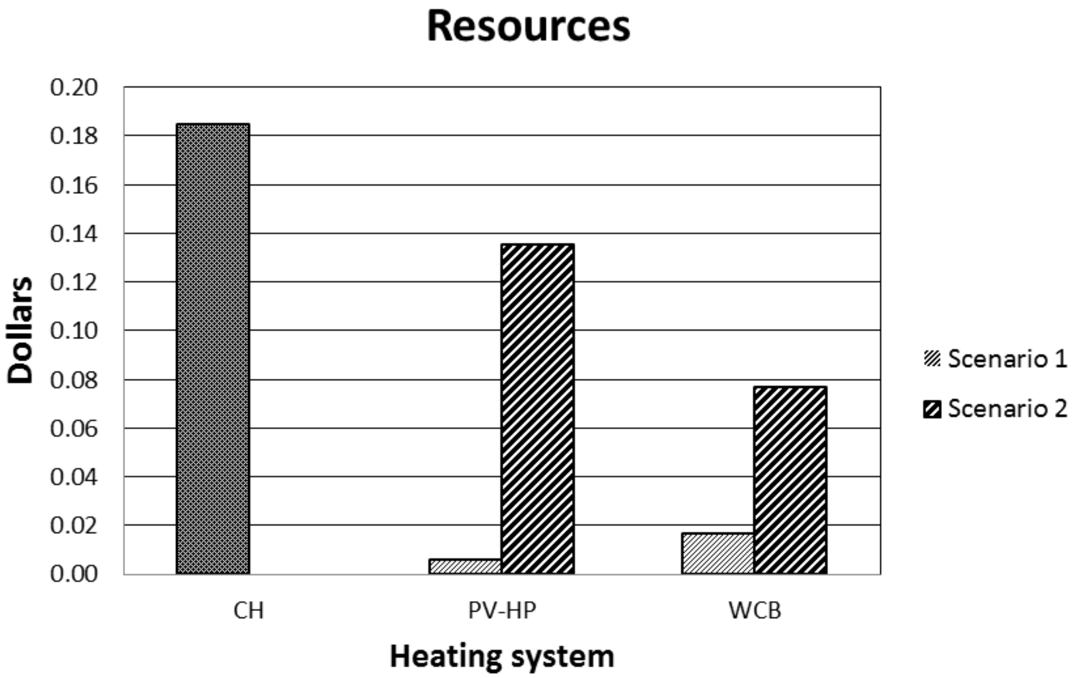

Figure 3. LCIA results for ReCiPe endpoint category Ecosystem quality, expressed as additional cost.

Comparing the overall performance of the studied heating systems, we highlight how bottom-located heating installations, with an increased thermal inertia (in the case of water-filled pipes) can result in significant reductions of energy requirements, when coupled with devices (e.g. aluminized thermal curtains) that minimize radiation to the transparent cover and at the same time reduce the heated air volume. These results have been confirmed by some previous studies addressing the issue of energy efficiency in greenhouses (Teitel et al., 1999 Fabrizio, 2012). However, the positive effects that can be achieved, in terms of energy saving, are still very limited if these systems are applied to structures with poor thermal insulation of the greenhouse cover, as in the case of Scenario 2 for WCB system. Other studies on basal heating systems operating in the Mediterranean area (Ozgener and Hepbasli, 2005; Fabrizio, 2012) showed that reductions of heating requirements in the order of 15-20% can be achieved, but because of their slow response to control action and their limited thermal output they might not cover the overall heat loss when caused by a sudden temperature drop, requiring combined operation of central and secondary systems to meet the peak heating load. The result is a decrease in the potential reduction of environmental impacts and operating costs that could be achieved by these alternative solutions. Looking at general sustainability of energy systems, a study by Dincer and Acar (2015) reviewing current applications of clean energy solutions ranks the overall performances according to three sets of indicators. When production costs, capacity factor and GHG emissions are compared, biomass systems rank higher than solar PV, which has the worst performance among compared systems, the best ones being nuclear and geothermal. Considering non-air pollution environmental criteria, solar systems perform better than biomass, which in this case have the worst performance. Indicators considering investment costs and design lifetime assign the higher rank to biomass systems and the lower to solar. A critical issue found among renewable systems is the mismatch between supply and demand, the crucial solution being thermal energy storage. This finding is in line with our observations on the assessed plants, in particular the PV-HP. With regard to economic sustainability, previous studies (Bisaglia et al., 2010; Bibbiani et al., 2016; Dincer et al., 2015) have confirmed that replacement of diesel-powered systems with WCB can be a feasible and cost-effective solution, considering the present situation and future evolution of energy systems.

5. Conclusions

In this study LCA methodology was applied to assess the environmental impacts of different heating systems applied to greenhouses. Theoretical and operational performances of two alternative heating plants, an air-water heat pump and a wood chips boiler, exploiting renewable energy sources (photovoltaic energy and wood chips), were compared with a traditional air heater powered by diesel fuel. A life-cycle approach allows a thorough investigation of several environmental aspects, and could support policy initiatives on a more consistent basis. Results for the investigated plants in their actual operating scenario (Scenario 2) indicate that WCB is the preferable system, reducing the impact on climate change and air emissions harmful to human health, while overall impact on the ecosystem is comparable to traditional systems. However, as highlighted by results obtained in the first scenario, the global impact of the system could be greatly reduced by decreasing the peak load due to excessive heat loss through the covered surface, thus limiting the need to activate the support system. Similarly, the high environmental burdens associated with the actual operating situation of PV-HP system could be reduced by increasing the buffer volume, allowing hot water to be stored during the day to meet night heating requirements. In this case, a large share of electric energy would be covered by photovoltaic modules, leading to a situation similar to that assumed in the first scenario. A shift toward renewable sources in power production should be encouraged by policies that aim to reduce impact on climate change and negative human toxicity effects. To increase the efficiency of these measures, funding should also include the study of measures for the reduction of thermal energy requirements, such as improved heat distribution systems and cover insulation.

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Chapter V – LCA analysis of potential benefits deriving from sustainable practices applied to zonal geranium and cyclamen productions.

To be submitted

1. Abstract

Italian floriculture is facing structural changes as a consequence of economic crisis, increased international competitiveness and shifts in consumers interests and purchase preferences. Possible options to maintain competitiveness include promotion of added values, from local productions to environmental sustainability. To quantify value and benefits of cleaner production processes and choices, an holistic view is necessary, and could be provided by life cycle assessment (LCA) methodology, a material and energy balance applicable to production of goods and services. Previous studies on ornamental products generally focused on data from one company or a small sample. The aim of this study was a gate-to-gate life cycle assessment of two ornamental species (*Cyclamen persicum* Mill. and *Pelargonium ×hortorum* Bailey) using data from a sample of 20 companies belonging to a floriculture district in Treviso, Veneto region. We also assessed the potential benefits for the environmental impact of the selected species of alternative management choices regarding plant protection and reuse of composted waste biomass. Life cycle impact assessment showed the higher impact scores for the zonal geranium, mainly as a consequence of greenhouse heating with fossil fuels. This factor, along with higher uniformity of production practices and technological level of equipment, translated in lower variability observed in comparison with cyclamen production, which shows a wider results range, in particular for eutrophication, acidification and human toxicity potentials. The application of integrated pest management had significant benefits in terms of impact reduction for acidification and human toxicity of cyclamen, while reduced use of mineral nutrients through compost amendment of growing media resulted in a reduced eutrophication potential. The achievable benefits for zonal geranium were not observable because of the dominant contribution of energy inputs.

2. Introduction

Ornamental plants production is a specialized and intensive agricultural sector that includes a wide range of outputs, such as cut flowers, nursery stock, potted flowering or leafy plants, bulbs and tubers. Europe is the largest consumer market, with Germany, the United Kingdom, France and Italy as leading consumers. Italy is also an important producer, having 20,000 companies with a GSP of 2.5 billion €. This sector has a complex structure, with a few regions having districts specialized in some sections of the production chain.

Veneto region is home to some important districts, located in Padova, Treviso, Vicenza and Rovigo provinces. Data from 2016 (Veneto Agricoltura) show a total of 1490 companies, with a total area of 2730 ha, and a GSP of 206 million €. The overall trend compared to the previous five years highlights how the sector is facing structural changes to cope with the ongoing stagnation in domestic demand as a consequence of the current economic crisis; the number of companies is steadily decreasing, averaging -2% per year, with 4-5% peaks in some districts (Rovigo, Vicenza). GSP value of marketable potted plants is slightly decreasing (-0.5%), while nursery production of ornamental, vegetable and orchard plants is stable (+0.1%). Related activities, mainly linked to landscaping and garden laying out and maintenance, are slowly but steadily growing (+2%). Regarding marketing areas, local and regional sales are falling (-11%) or stagnating (-0.8%), in favor of an increasing share of sales to other Italian regions (+6%) or EU countries (+2.5%). Indeed an increased number of companies have obtained the Certificate of Conformity required for sales in EU member countries, 225 (+5%) in 2016. The changes highlighted by these data are partly related to increased competitiveness from emerging countries (Evers et al., 2014), and partly to the shift in consumer preferences. Recent studies (Schimmenti, 2009; Schimmenti et al., 2010) investigating preferences and motivations of Italian consumers of flowers and ornamental plants have shown how purchases of potted plants are prevalently for personal use, and while flower shops and nurseries are still the traditional places in the majority of cases, a positive trend toward purchases at large-scale retail stores was found for this market segment. Italian flower nurseries operating in the northern, high-cost regions are generally small, family-run enterprises that cannot tackle sudden changes in international markets with cost reductions and technological improvements. Possible options for maintaining competitiveness could focus on the promotion of added value, such as typical/local productions, range and variety of choice, seasonal products, and "eco-friendly" choices in production systems. For countries within the EU, sustainable or cleaner productions are becoming a requirement rather than an encouraged practice, also in the agricultural sector, which is often regarded as a polluting activity (Marble et al., 2011).

Cleaner production is defined by the United Nations Environmental Program (UNEP, 1999) as the continuous application of an integrated preventive environmental strategy to processes, products and services, to increase overall efficiency and reduce risks to humans and the environment. Five main components of cleaner production are related to conservation of raw materials, water and energy, eliminating toxic and dangerous emissions, and reducing waste. To quantify the potential impacts and assess the efficiency of reduction measures, a life cycle methodology should be used. LCA is a material and energy balance applied to the production of goods or services (ISO 14040, 2006). This methodology has been applied to some ornamental commodities and production systems. Previous studies on potted plants under protected cultivation highlighted some of the processes and materials involved in the production of certain emissions, such as energy for heating and artificial lighting, greenhouse frame and cover, plastic containers and peat (Russo and De Lucia Zeller, 2008; Koeser et al., 2014 Lazzerini et al., 2016; Abeliotis et al., 2016). Assessments, except for a study on nursery production conducted by Lazzerini et al. (2016), analyzed data sourced from one representative company and from specific literature or databases. The aim of this study is to assess the environmental aspects of the cultivation of two ornamental species, using data from a sample of nurseries in the Treviso production district. While trying to define average impact results for the most important categories, we will analyze how different management choices and production practices affect final results. In the following sections we present the functional units, data collection processes, and the alternative scenarios we chose to assess.

3. Materials and Methods

3.1. Goal and scope

The goal of this research is to characterize the final cultivation phase of two potted flowering plants, zonal geranium and cyclamen, from an environmental point of view, trying to define a results range representative of the most common practices in the investigated floriculture district. We also wish to assess the potential environmental benefits achievable with specific practices or management choices that have been adopted by individual growers independently. Other practices that apply to all the investigated companies, such as collection and recycling of plastic materials, have been implemented in the system models. The scenarios we investigated concern typical environmental bottlenecks of protected cultivation, such as fertilizer use, plant protection, waste management (biomass). The scope of our study includes production, installation, use and disposal of capital goods (greenhouse frame and cover, as well as heating systems and auxiliary equipment for fertigation), production, transport, use and disposal of crop inputs. The model system we describe is based on the production practices of a sample of nurseries sited in Treviso province. Since our goal is to describe and assess common practices and average structure and technology, comparison of different company size or sale type is outside the scope of this study. The method used for impact assessment (LCIA) is CML 2015, developed by the Centre for Environmental Studies (Heijungs et al, 1992). The following impact categories were assessed in order to provide a set of indicators that covers different environmental compartments and emission pathways: acidification potential (AP), global warming potential (time horizon of 100 years) (GWP100), fresh water aquatic ecotoxicity (FAET), terrestrial ecotoxicity (TE), human toxicity (HT), and eutrophication potential (EP).

3.2. Data collection

Data were collected from a direct survey conducted through questionnaires and direct interviews with 20 nurseries belonging to the Florveneto association, representing ornamental plant growers in Treviso province. A questionnaire, which had previously been submitted to and validated by two pilot companies, was used to collect information on general production practices, greenhouse structures and equipment.

Functional units and system boundaries

Our functional unit is a single marketable plant in a 14-cm pot. The investigated species, zonal geranium and cyclamen, were chosen for several reasons: first, their economic relevance (they cover 20% and 22% of the Italian flower market respectively); second, they represent part of an ideal crop sequence for our average nursery. Lastly, given the seasonality of their production cycles, they are crops with different climate control needs and energy demands. System boundaries include all operations and inputs from transplant to market-ready flowering plants. Plug production phase is also included, even if specific information on seedling or cutting production for the considered species were not collected. This is also motivated by considerable differences concerning the choices of young plant breeders found among the surveyed companies.

3.3. System description: Zonal geranium

Pelargonium is a genus of plants belonging to the *Geraniaceae* family, originating from an area extending from South Africa to the Mediterranean, Australia and Western Asia. Zonal geranium (*Pelargonium ×hortorum* Bailey) is a hybrid between *Pelargonium zonale* and *Pelargonium inquinans* (James et al., 2004). They have zones or patterns, typically with a horseshoe-shape, in the center of the leaves. Basic hybrids usually have mature plants with foliage height exceeding 18 cm, and are grown in medium-sized pots (diameter between 12 cm and 16 cm). Zonal geranium plants are usually grown in structures with a plastic cover (double layer, air inflated) and galvanized steel frame, or in glasshouses with a steel frame. Average replacement rate of a plastic cover is 6 years, while glass and supporting structures lifetime often exceeds 30 years, which was the value assumed for calculations. The most widely used heating system consists of diesel powered fan-burners generating hot air, while only two companies use gas boilers and a network of polypropylene pipes to deliver hot water under cultivation benches. In the first 10-15 days after seedling transplant optimal temperature is around 18 °C in the daytime and 16 °C at night. After this phase, diurnal temperatures are kept around 16 °C and night temperatures around 14 °C . No artificial lighting is applied during this growth phase. Growing media are usually constituted of peat (80-85% v/v) blended with porous materials such as perlite or expanded clay (10-15% v/v). Plants are fertigated using overhead spray irrigation for a period ranging from 6 days to three weeks, depending on the individual choices made by growers. After this period, until marketable size is attained, plants are placed on benches and fertigated with ebb-and-flow or with spaghetti-tubing irrigation systems. Fertilizer solutions applied during the first period have a NPK ratio of 1-0.5-1. To promote flower quality, potassium concentration is increased during the final growth phase (NPK ratio 0.8-0.3-1.2). As a typical spring crop, zonal geranium is very sensitive to thrips attacks; aphids (*Acyrthosiphon malvae*) can also be a problem and cause small, distorted leaves and black sooty mold. Insecticides are applied preventively in 40% of cases; most common active ingredients belong to the carbamate, organochlorine, pyrethroid classes. Along with other ornamentals such as petunias and calibrachoas, pelargoniums can be affected by budworms (Geraniums bronze, *Cacyreus marshalli*) during the last growth stages. These worms can devastate geraniums by tunneling into young buds and eliminating the flower. Neonicotenoid or pyrethroid insecticides are applied to control this pest. Common diseases are *Xanthomonas campestris* pv. *pelargonii* (wilt and spots), *Ralstonia* (wilt), *Pythium*, *Botrytis*. Bacterial diseases are best fought with prevention practices and early detection, yet also soil-borne fungal diseases can be prevented by avoiding excessive air and substrate humidity, facilitating canopy air movement and raising night temperatures. Beside prevention practices, plants are usually treated one to three times with fungicides (active ingredient classes: dichlorophenyl dicarboximide, aromatic organic compounds, amide).

3.4. System description: Cyclamen

Cyclamen persicum Mill. is a species of perennial flowering herbaceous plant growing from an enlarged hypocotyl, native to rocky hillsides, shrubland and woodland, up to 1200 m above sea level.

Cyclamen is usually grown in structures with plastic cover (single layer) and galvanized steel frame. Average plastic cover replacement rate is 6 years, while supporting structures lifetime is 30 years. Potting of young plants starts from May. With an average growing period of 14-16 weeks, early plants bloom in September. Optimal temperature in the first period is around 18-20 °C. During flower development normal temperatures should be between 15 and 20 ° C. To promote cooler temperatures, shading from 30 to 50% is applied in summer months, together with lateral and roof ventilation. Active cooling systems, like fogging or fan-and-pad, are installed and operating in only three nurseries. Cyclamen seedlings are transplanted into 14-cm pots, filled with a substrate composed of white peat with a coarse, porous texture (40% v/v), black peat (45-50% v/v) and expanded perlite (10-15% v/v). Plants are irrigated using overhead spray irrigation (no added fertilizer) for 1-2 weeks, then a fertilizer solution (NPK ratio 1:0.4:1.2) is applied. In some cases overhead spray irrigation is still preferred at this stage, while most growers (14 out of 20) start fertigation with spaghetti tubing system. Fertilizer solutions applied during the growing period have increasing ratio of potassium and phosphorus to promote flowering and plant resistance (typical formulations: 17N-3.05P-14.2K; 20N-8.29P–23.3K). Plants are spaced after one month to allow air circulation and canopy growth. Fungal diseases include *Botrytis* and *Fusarium*, anthracnose and powdery mildew. Most are limited by prevention practices and improved breeding, yet between one and three (fungicide treatments are reported by most growers (classes: carbamate, thiadiazole, amide, aromatic organic compounds). Common cyclamen pests are thrips (*Frankliniella occidentalis; Echinotrips americanus*), aphids (*Aphys gossypii, Aulacortum circumflexum*), vine weevil (*Otiorhynchus sulcatus*) and mites (*Steneotarsonemus pallidus*, *Tetranichus urticae*). Insecticides are applied from 2 to 5 times during the growing cycle (active ingredient classes: neonicotinoids, organophosphate, pyrethroids or avermectine). Growth regulators (chlormequat or daminozide) are applied once or twice by 14 growers.

3.5. Assumptions

Data for background processes such as material manufacturing and disposal activities were sourced from the Ecoinvent 3.3 database, and modeled with OpenLCA ver. 1.5.0. Direct emissions were calculated by using estimation models, which are flexible and allow for an estimation of mitigating options. For fertilizer use, we estimated nitrate (NO_3^-) emissions with the Swiss Agricultural Life Cycle Assessment (SALCA) method, assuming a draining fraction of 25% for open-loop systems, which is a common leaching value applied to prevent root zone salinization. Phosphate (PO_4^{3-}) emissions were calculate according to SALCA-P emission model (Prasuhn et al., 2006). Plant protection products applied were modeled as emissions to agricultural soil.

3.6. Description of alternative practices

As mentioned earlier, during the data collection it was noticed that, even if close similarities were recorded in most of the interviewed nurseries regarding structure types, technological level of growing equipment, management decisions, and cultivation inputs for the studied crops, the choices made by some growers led to significant differences in the reported input levels. Other management decisions could instead lead to different emission patterns and levels. These practices mainly concern plant protection practices, fertigation management and recycling of waste biomass.

3.7. *Integrated pest management and biological plant protection*

Monitoring of insects presence (with chronotropic traps, visual inspection) is a known, yet not very widespread practice. Objective assessment of infestation and potential damage is also very difficult for crops with aesthetic value as their main feature. Despite this, the application of integrated pest management (IPM) and biological control agents is receiving growing attention, also because many active ingredients registered for use on ornamental species have recently been revoked or are no longer applicable (Reg. (EC) 1107/2009).

Due to the greater effort required, and uncertainties linked to these practices, most growers are delaying their application and still rely heavily on chemical control.

Starting from information collected from 4 growers already applying IPM strategies, we assessed the potential impact reduction arising from less use of chemical inputs (manufacturing of raw materials and soil emissions).

3.8. Management and reuse of waste biomass

Protected soilless crops generate a significant amount of waste, due to material requirements for growing media, containers, benches, irrigation pipes, plug trays. These materials need to be disposed of at their end-of-life, and several options are available, from incineration to landfilling, or composting, depending on material segregation practices, regulations, and grower's choices. Recycling of plastic material is a common and well-established practice among the interviewed growers, thanks to good awareness and coordinated efforts by the Florveneto association. Management of biowaste is decided by single growers. The amount of non-yield biomass in ornamental containerized crops is lower than in other protected crops, yet a certain amount of unsold or discarded plants is produced and must be disposed of. Confined windrow composting and reuse *in situ* could be an option, and one grower reported to have adopted this practice. However, in this case chemical and physical properties as well as direct emissions are probably highly variable and difficult to measure, and we therefore chose to model an alternative option, where compost is produced from miscellaneous green waste in a composting facility and used in growth media preparation as a substitute for peat. The considered rate of compost addition to the growth medium is 20% (v/v); this was chosen in accordance with growth trials of containerized plants on compost amended substrates reported in several studies

(Ribeiro et al., 2000; Perner et al., 2007; Vecchietti et al, 2013). Supporting effect on growth for different plant species with compost rates up to 20% was reported in all these studies, but different effects were found for higher substitution rates. Chemical composition and nutrient content of garden waste compost came from an analysis of samples from a local composting plant (Table 1). Two options are considered for the offset of mineral fertilizers: NPK content of compost does not replace fertilizers (option 1); NPK content replaces part of the mineral fertilizers applied through fertigation (option 2). The following rates of nutrient content available for the crop were considered: 20% for N, 50% for P, and 50% for K. These values are taken from Boldrin et al. (2010), and were reduced to account for the limited length of growing period for the considered species.

Table 1. Chemical and physical properties of the garden waste compost considered for the evaluation of the impacts.

Compost characteristic	**Value**
Bulk density (kg m^{-3})	404
Water holding capacity (v/v)	64.8
Dry matter (%)	66.5
Organic matter (%)	38.7
pH	8.70
Electrical conductivity (mS cm^{-1})	3.78
NO_3^- (mg L^{-1})	108
PO_4^{3-} (mg L^{-1})	40.6
Na^+ (mg L^{-1})	200
NH_4^+ (mg L^{-1})	19.7
K^+ (mg L^{-1})	603
Mg^{2+} (mg L^{-1})	22.8
Ca^{2+} (mg L^{-1})	115

4. Results and discussion

The considered inputs were grouped in six main categories, which include production, use and end-of-life phases: greenhouse structures (GH), fertigation (Fert), protection products (PP), containers (Pot), growing media (GM) and heating (H). Looking at absolute values (Table 2) for the assessed impact categories, we can notice how the heated crop (zonal geranium) scores higher results for all indicators, even by several orders of magnitude for AP and GWP categories,. As highlighted in the analysis of relative contributions (Fig. 1 and Fig. 2), the overwhelming share of burdens is due to heating by fossil fuels. This factor, together with the greater uniformity found for some management choices in zonal geranium, also influences the observed variability, which shows minor fluctuations around average values compared to cyclamen.

Table 2. Absolute values and standard deviation (in percentage) for the assessed impact categories for flowering potted plants of cyclamen (*Cyclamen persicum* Mill.) and zonal geranium (*Pelargonium ×hortorum* Bailey).

		Cyclamen		**Zonal geranium**	
Impact category	**Reference unit**	**mean**	**stand dev (%)**	**mean**	**stand dev (%)**
Acidification potential	kg SO_2 eq.	3.58E-04	11.63	1.75E-03	1.28
Freshwater aquatic ecotoxicity	kg 1,4-DB eq.	0.01934	4.35	3.49E-02	3.48
Climate change	kg CO_2 eq.	0.07459	3.32	0.7721	1.29
Terrestrial ecotoxicity	kg 1,4-DB eq.	6.62E-04	4.63	1.44E-03	0.79
Eutrophication	kg PO_4^{3-} eq.	2.72E-04	23.01	4.18E-04	11.02
Human toxicity	kg 1,4-DB eq.	4.41E-02	15.60	1.02E-01	1.03

Relative contributions in the impact categories is depicted graphically in Fig. 1 and Fig. 2. The reported percentages refer to sample average values. The contribution of some materials or structures show little variation, given the relative uniformity of supply chain and input choices among the growers. Other inputs with less standardization show significant differences in their contribution to impact categories, which will be discussed in the following paragraphs.

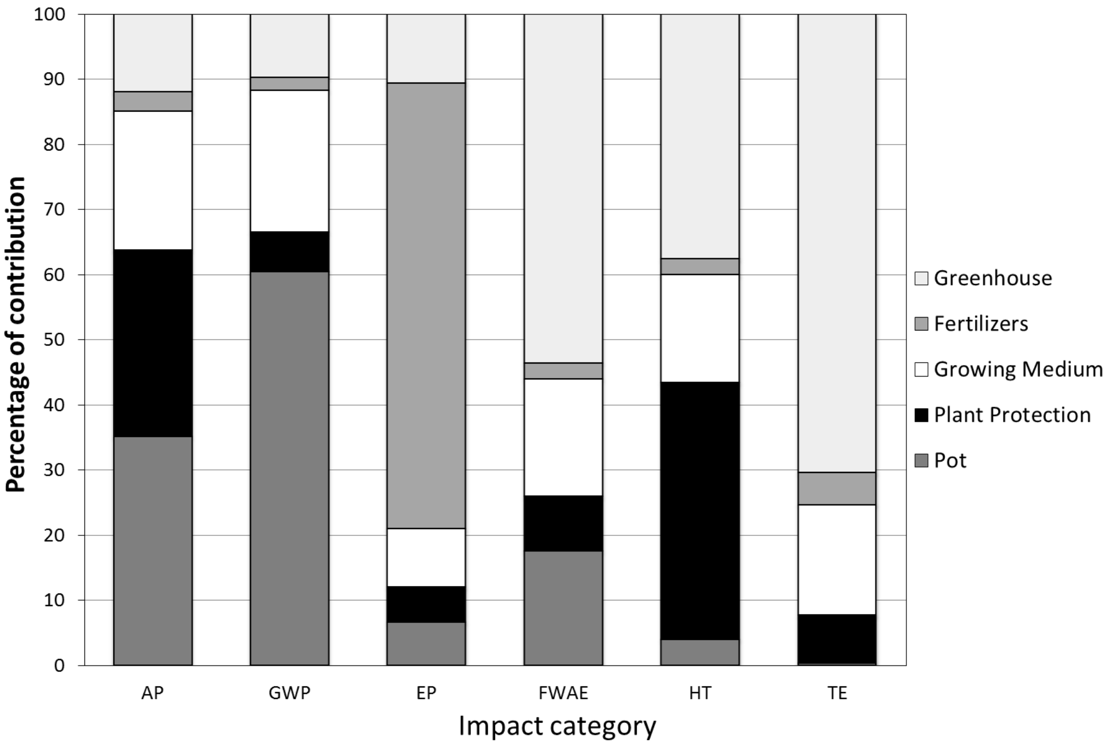

Figure 1. Relative contribution of different inputs for cyclamen potted plant production. The impact categories assessed are: acidification potential (AP), global warming potential (time horizon of 100 years) (GWP100), fresh water aquatic ecotoxicity (FAET), terrestrial ecotoxicity (TE), human toxicity (HT), and eutrophication potential (EP).

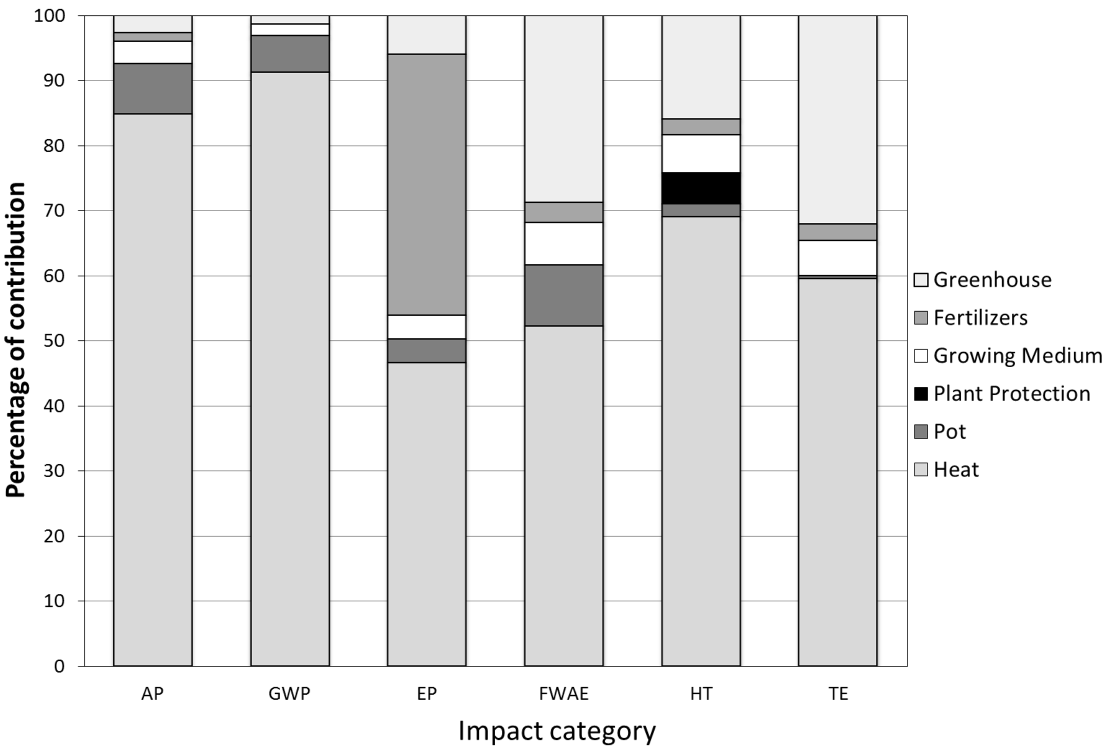

Figure 2. Relative contribution of different inputs for zonal geranium potted plant production. The impact categories assessed are: acidification potential (AP), global warming potential (time horizon of 100 years) (GWP100), fresh water aquatic ecotoxicity (FAET), terrestrial ecotoxicity (TE), human toxicity (HT), and eutrophication potential (EP).

4.1. Cyclamen

Plastic container is the major contributor (60.5%) for GWP categories, also accounting for a significant share of impacts in AP (35.2%) and FWAE (17.6%). All burdens are associated with material production, since no emissions are considered for use and end-of-life phases. Growing media components have an important share of impacts in AP (21.3%), GWP (21.6%), FWAE (181%), HT (16.5%) and TE (17%) categories. Expanded perlite production and disposal is an important source of emissions for HT,TE and FWAE; emissions related to peat road transport from Baltic countries contribute mainly to GWP and AP categories. Greenhouse structure shares major burdens in FWAE (53.5%), HT (37.6%) and TE (70.4%) categories, mostly linked to production and disposal of steel frame and electricity consumption. Emissions related to production and use of plant protection products mainly influence HT (39.4%) and AP

(28.6%) categories; depending on chemical products type and frequency of treatments their contribution can vary between 35.6% and 22.7% for AP, and between 43.8% and 32.5% for HT. Emissions related to fertilizer and water use contribute mainly (68.5%) to EP category results. Ground and surface water release of nitrate and phosphate is directly linked to fertigation method and discharge mode and rate of nutrient solutions: overall contribution of this phase varies between 44.6% for closed systems with no overhead application to 72% for open systems with frequent overhead applications. Fertigation management of cyclamen plants with the latter method is prevalent among the interviewed growers. Most studies on the environmental impact of potted plants focused mainly on climate change (GWP) (Koeser et al., 2014; Lazzerini et al., 2016), while few studies conducted complete LCIA including other impact categories (Russo and De Lucia Zeller, 2008; Bonaguro et al., 2017). In accordance with our results, when referring to unheated crops with no artificial lighting factors influencing GWP are mainly linked to manufacturing of plastic materials (containers and greenhouse cover) and growing media components (peat and expanded perlite). Fertilizer contribution to EP category on the overall production process of cyclamen potted plants was also highlighted by Russo and De Lucia Zeller (2008). This finding is in line with our results, suggesting that management practices aimed at reducing fertilizer use and leaching have the best chances for impact reduction in this category. The significant contribution of greenhouse structures to TE and FWAE categories is in line with similar studies on ornamental productions (Bonaguro et al., 2017)

4.2. Zonal geranium

Emissions deriving from production and use of diesel fuel burned to heat the greenhouse have a major share of impacts in all considered categories, accounting for over 91.3% of overall emissions in GWP and 84.7% in AP. Production and disposal of greenhouse frame contributes significantly to FWAE (28.7%), HT (17.9%) and TE (32.1%) categories. Fertilizer and water use contribute 40% of impacts in EP category. Since zonal geranium is often fertigated with ebb and flow systems, which allow for a reduction of direct emissions and fertilizer losses, contribution of this step is less variable than in cyclamen and goes from 36.4% to 43.9%. Plastic pot contribution is observed for FWAE (9.7%), AP (7.7%) and GWP (5.6%) categories. The share of environmental burden from application of plant protection products and fertigation is not relevant for the selected impact categories. These results are in line with other studies on protected crops that require energy inputs to actively control the greenhouse environment (light, temperature) or for preservation purposes (Abeliotis et al., 2016); the overall impact dramatically increases (Bonaguro et al., 2016) and is almost entirely attributable to energy demand, as in the case of zonal geranium.

4.3. *Effect of alternative practices on cyclamen and zonal geranium impact assessment results*

Table 3 shows the results for the chosen categories of average production practices and for the alternative scenarios for cyclamen plants, highlighting the achievable impact. The reduction in chemical inputs attained through the application of integrated pest and pathogen management programs for cyclamen plants results in an overall reduction of potential impacts, which is relevant in particular for HT (-25%) and AP (-16.3%) categories. For HT, this result is due primarily to reduction of soil emissions and manufacturing of active ingredients with fungicide activity, achieved through application of biological control agents and careful fertigation management.

Table 3. Sensitivity analysis for one cyclamen plant subjected to alternative practices. In relation to garden waste compost addition to the growing medium in option 1, NPK content of compost does not replace fertilizers and in option 2 NPK content replaces part of the mineral fertilizers applied through fertigation. IPM = integrated pest management.

		Compost		
Impact category	**Reference unit**	**Option 1**	**Option 2**	**IPM**
Acidification potential	kg SO_2 eq.	3.49E-04	3.44E-04	3.00E-04
Freshwater aquatic ecotoxicity	kg 1,4-DB eq.	1.81E-02	1.78E-02	1.85E-02
Climate change	kg CO_2 eq.	0.0698	0.0691	0.0726
Terrestrial ecotoxicity	kg 1,4-DB eq.	6.30E-04	6.28E-04	6.40E-04
Eutrophication	kg PO_4^{3-} eq.	2.65E-04	2.19E-04	2.69E-04
Human toxicity	kg 1,4-DB eq.	4.18E-02	4.10E-02	3.29E-02

Use of compost as growing media component, without changes in fertilizer application rate, shows relatively small reduction potential, linked mostly to reduced peat extraction and transport. Another study in which the environmental aspects of compost substitution was assessed (Boldrin et al., 2010) reported lower impact values for different categories, including climate change, acidification potential, eutrophication potential and photochemical ozone formation. In the same study, leaching tests for soil application suggested a potential higher impact of composts when considering potential impacts on human toxicity via water and soil, because of high release rates of heavy metals.

These considerations partly support our results, since application of compost, that substitutes a 20% volume of peat in the growth medium, results in a slight reduction of several indicators, including GWP. However, the reduction achieved by this practice has a limited relevance on the overall impact of our functional units. This can be explained by the small amount of peat replaced, the relative importance of growing media components in the assessed categories, and finally because of the impacts related to compost production process. When considering also nutrient release from compost amendment and subsequent reduction of fertigation needs, a significant reduction for EP category (-19.6%) is observed, which can be explained both by reduction of fertilizer production and decreased leaching. We highlight that the minimum value of EP observed for cyclamen is very similar to that obtained for this scenario. This result is justified by data on cultivation with closed-loop fertigation systems with nutrient solution recirculation. To maximize impact reduction from nutrient production and leaching to surface and groundwater, a combination of fertigation management and use of nutrient-rich amendment in the growth medium could be a useful indication for best management practices.

Table 4 shows the impact results of average production practices and the alternative scenarios for zonal geranium plants. We highlight how the potential for impact reduction is strongly limited by the major burdens linked to heating in all impact categories. Application of IPM programs achieves a moderate reduction of results for HT (-2.4%) category. Use of compost, not considering nutrient supply, achieves a reduction exceeding 1% of impact results only for FWAE (1.08%), TE (1.11%) and HT (1.63%) categories. When considering mineral fertilizing offset, the differences increase, in particular for EP that shows a 14% reduction of final result.

Table 4. Sensitivity analysis for one zonal geranium plant subjected to alternative practices. In relation to garden waste compost addition to the growing medium in option 1, NPK content of compost does not replace fertilizers and in option 2 NPK content replaces part of the mineral fertilizers applied through fertigation. IPM = integrated pest management..

		Compost		
Impact category	**Reference unit**	**Option 1**	**Option 2**	**IPM**
Acidification potential	kg SO_2 eq.	1.74E-03	1.77E-03	1.74E-03
Freshwater aquatic ecotoxicity	kg 1,4-DB eq.	3.45E-02	3.41E-02	3.51E-02
Climate change	kg CO_2 eq.	0.7711	0.7709	0.7719
Terrestrial ecotoxicity	kg 1,4-DB eq.	1.42E-03	1.39E-03	1.42E-03
Eutrophication	kg PO_4^{3-} eq.	4.17E-04	3.59E-04	4.18E-04
Human toxicity	kg 1,4-DB eq.	9.99E-02	9.93E-02	9.91E-02

This value is lower than the observed minimum, highlighting the higher uniformity and technological level adopted for zonal geranium fertigation. Addition of compost to growing media for geranium growth may be increased to 40%, providing a large part of its nutrient requirements, as evidenced by Perner et al. (2007) in growth trials conducted on potted geranium; results showed how rates of compost amendment from 20 to 40% had a supporting effect on overall growth of geranium plants, while they might still require nutrient addition through fertigation for optimal flowering and plant size. The adoption of this practice therefore shows a potential for impact reduction in EP category, if mineral fertilizer inputs are accordingly reduced. The alternative practice we investigated falls among the priorities in pollution prevention listed as Best Agricultural Practices for protected crops in Mediterranean Climates(FAO, 2004), yet their improvement potential differs greatly depending on the set of impact categories and technological level, material and energy requirements of the investigated production system. For low energy-input crops such as cyclamen, the decrease in fertilizer and pesticide use can result in a significant impact reduction for most of the selected categories. The potential benefit resulting from combined application is 32% for HT, 20% for AP and EP, 12.5% for FWAE, and 10% for GWP.

For zonal geranium, we highlight how reduction of energy input is the first priority for soilless heated crops, since best practices for other highly impacting materials (plastic containers and cover) have already been adopted. The reduced amount of fertilizer and plant protection product translates in a relatively irrelevant contribution, except for the EP category.

5. Conclusions

In this study we investigated the environmental aspects of the cultivation of cyclamen and zonal geranium starting from data coming from different greenhouse farms located in Treviso province. Given the fragmented structure of productive chain for floriculture products in this region, the definition of common practices and their characterization should be linked to a variability measure, in order to include the complexity and plurality of structures and management choices in the final results. In the case of cyclamen production, technological level and management choices can greatly affects the values obtained for different environmental indicators, in particular with regard to fertigation management and use of plant protection products. The results of the analysis also highlighted how the efficiency of reduction measures should always be checked with a life cycle study on the production or process to address (e.g. potted ornamental plants). While 'sustainable' choices such as composting and reuse of waste biomass and reduction of chemical treatments have a significant benefit when applied to crops grown in passive greenhouse, energy saving and changes in fuel type should be the main concern when aiming at reducing the impacts for crops requiring active control of growth environment, as in the case of zonal geranium.

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Chapter VI - General conclusions

This research investigated several aspects of sustainability of potted flowering plants. The main difficulties we met were attributable partly to the lack of specific background and literature data, partly to the heterogeneity and complexity of the investigated sector, and partly to the unavailability and lack of specific data and knowledge on practices and materials of ornamental growers. Our first results, obtained exploiting data from single companies and growth trials, highlighted how theoretically eco-friendly alternatives for important components of the production process, such as containers and growth media, must be evaluated from both the agronomic and environmental perspectives to assess whether their application is viable, and can produce significant environmental benefits that would justify increased costs or structural changes in the supply chain. The assessment of plastic and compostable rice hulls containers showed that both type of pots are major contributor to the global warming potential of the studied systems, but in the considered scenarios rice hulls pots had only slightly lower, or even higher, impacts compared to plastic ones. Replacement of 10% expanded perlite by 10% fresh rice hulls can lower the environmental impact of cyclamen pot production without affecting final product quality. Further additions are not desirable as they slightly increase the environmental impact while reducing plant performances. The investigation of a larger sample of nurseries underlined that the variability we observed is a structural component of the Italian floricultural sector, and should be taken into account when assessing the environmental, as well as economic and social aspects. The differences in knowledge and perspectives of individual growers regarding the environmental issues sometimes translated into different choices in the cultivation of potted plants. Since the possibilities of varying the production process are generally limited, we focused our analysis on the potential benefits deriving from practices and structures already used in the investigated sector. For crops with winter heating needs such as poinsettia and zonal geranium, a shift in energy sources from fossil fuels to renewable sources seems to be strongly advisable. In particular, boiler systems powered with wood biomass from sustainable sources could be a preferable choice to diesel-powered burners; heat pumps powered by solar energy have an even greater potential for impact reductions, yet this will require proper sizing of the thermal storage units. However, the reduction of the required thermal energy through low temperature systems and better thermal insulation is equally important, and can radically change the achievable environmental benefit. Other cleaner production practices that fall among the priorities in pollution prevention listed as Best Agricultural Practices for protected crops in Mediterranean climates may result in significant benefits for some important environmental indicators when applied to crops with low energy inputs, as in the case of cyclamen. Some important best practices for highly impacting material, such as plastic containers and greenhouse covers have already been adopted by most of the interviewed growers. A decrease in fertilizer and pesticide use can result in significant impact reductions on human health, freshwater toxicity and eutrophication, and acidification potential, while compost amendment of the growth medium had a significant benefit only when considering the lower use of mineral nutrients, which resulted in a decrease of eutrophication potential. These results need to be properly translated into indicators that are better perceived by consumers and emerging market niches. Reuse or recycling of plastics, air and water pollution, and human health are among the issues where consumer awareness is already strong and can therefore be immediately perceived and appreciated when properly communicated. Growers who have already adopted sustainable practices may wish to use this knowledge to increase the visibility and appeal of their products. Barriers to adopt and communicate these choices are also linked to the lack of knowledge of consumers' behavior and interests when purchasing ornamental products. Diffusion and communication to growers of results and advice from studies on this topic could drive economic and environmental progress in this floriculture sector.