

# LCA Analysis of the Benefits Deriving from Sustainable Production Practices Applied to Cyclamen and Zonal Geranium

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**Abstract:** Italian floriculture is facing structural changes. Possible options to maintain competitiveness of the involved companies include promotion of added values, from local productions to environmental sustainability. To quantify value and benefits of cleaner production processes and choices, a holistic view is necessary, and could be provided by life cycle assessment (LCA) methodology. 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.

**Keywords:** LCIA; plant protection; compost; sustainable greenhouse production

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## 1. 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 over 14,000 companies with a GSP of over 1,125 million € [1]. 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 [2] 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). The GSP value of marketable pot plants decreased slightly (-0.5%) until 2016, then the trend reversed. The nursery production of ornamental, vegetable and orchard plants is stable. Regarding marketing areas, local and regional sales

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are falling (from 34.3% to 29.1% and from 22.6% to 20.2% in five years, respectively) in favor of a slight increasing share of sales to other Italian regions (+3.9% in five years) or EU countries (+4.7% in five years). Indeed, an increased number of companies have obtained the Certificate of Conformity required for sales in EU member countries, 264 (+18%) in 2018. The changes high-lighted by these data are partly related to increased competitiveness from emerging countries [3], and partly to the shift in consumer preferences. Italian companies operating in the northern, high-cost regions are generally small and family-run, and cannot tackle sudden changes in international markets with cost reductions and technological improvements only. 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 [4].

Cleaner production is defined by the United Nations Environmental Program [5] 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. Plastic waste, fertilizer use, peat-based growing media and heating requirements are usually perceived as major contributors to protected crop's impact on environment. Some of the above-mentioned issues have been addressed by researchers, such as integrated or biological crop protection [6–9], use of slow-release fertilizers [10–13], irrigation plans based on crop needs [14], and also cultivation of native low energy demanding species has been considered [15]. Use of alternative containers such as biodegradable pots for the cultivation of ornamental pot plants was evaluated in different studies [16,17]; also peat substitution with composted materials, or other agro-industrial by-products rich in nutrients, has been widely evaluated in several trials on container grown plants, such as shrubs [18], poinsettia [17], geranium [19–21], and other bedding plants [22–24]. Efficient use of energy in greenhouses received great focus [25–27]. Many trials aimed at reducing the energy consumption of greenhouses have focused on ventilation processes and the effects of thermal energy and mass transfer [28–31].

To quantify the potential impacts and assess the efficiency of reduction measures on specific crops and production systems, a life cycle methodology should be used. LCA is a material and energy balance applied to the production of goods or services (ISO 14040 [32]). 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 [33–37]. Most assessments, except for a study on nursery production conducted by Lazzerini et al. [35], 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.

## **2. Materials and Methods**

### *2.1. Goal and scope*

The goal of this research is to characterize the final cultivation phase of two potted flowering plants, cyclamen and zonal geranium, 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

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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 [38]. 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) (GWP), eutrophication potential (EP), fresh water aquatic ecotoxicity (FWAE), human toxicity (HT), and terrestrial ecotoxicity (TE).

## 2.2. Data collection

Data were collected through a survey conducted through questionnaires and interviews with 20 floriculture companies belonging to the Florveneto association, representing ornamental plant growers in Treviso province. The questionnaires were administered in person to the owners, in the company, so that the data collected could be, at least in part, verified. 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.

### 2.2.1. 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 variety and young plant producers found among the surveyed companies.

### 2.3. System description: *Cyclamen*

Cyclamen (*Cyclamen persicum* Mill.) plants are 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

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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 (*Aphis gossypii*, *Aulacortum circumflexum*), vine weevil (*Otiorhynchus sulcatus*) and mites (*Steneotarsonemus pallidus*, *Tetranychus 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), to control inhibited petiole elongation, are applied once or twice by 14 growers.

#### 2.4. System description: Zonal geranium

Zonal geranium (*Pelargonium ×hortorum* Bailey) 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 (*Acyrtosiphon 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 calibrachos, 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. Neonicotinoid 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).

#### 2.5. 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

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for an estimation of mitigating options. For fertilizer use, we estimated nitrate ( $\text{NO}_3^-$ ) 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 ( $\text{PO}_4^{3-}$ ) emissions were calculated according to SALCA-P emission model [39]. Plant protection products applied were modeled as emissions to agricultural soil.

#### *2.6. 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.

#### *2.7. Integrated pest management and biological plant protection*

Monitoring of insects' presence (with chromotropic 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 more applicable [40].

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.

Based on information from four growers using IPM strategies, we assessed the potential impact of less chemical input and use (manufacturing of raw materials and soil emissions).

#### *2.8. 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 [19,41,42]. 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. An analysis from a local composting plant shows the chemical composition and nutrient content of composted garden waste (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. [43], 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.

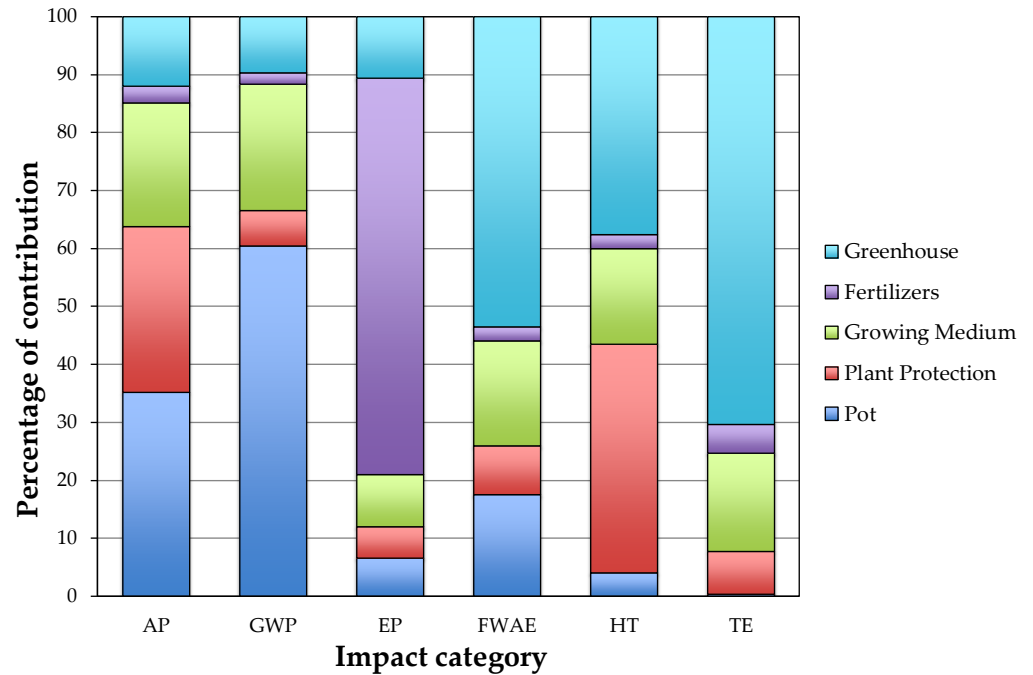
Compost characteristic	Value
Bulk density (kg m <sup>-3</sup> )	404
Water holding capacity (v/v)	64.8
Dry matter (%)	66.5
Organic matter (%)	38.7
pH	8.70
Electrical conductivity (Sd m <sup>-1</sup> )	3.78
NO <sub>3</sub> <sup>-</sup> (mg L <sup>-1</sup> )	108
PO <sub>4</sub> <sup>3-</sup> (mg L <sup>-1</sup> )	40.6
Na <sup>+</sup> (mg L <sup>-1</sup> )	200
NH <sub>4</sub> <sup>+</sup> (mg L <sup>-1</sup> )	19.7
K <sup>+</sup> (mg L <sup>-1</sup> )	603
Mg <sup>2+</sup> (mg L <sup>-1</sup> )	22.8
Ca <sup>2+</sup> (mg L <sup>-1</sup> )	115

### 3. Results and Discussion

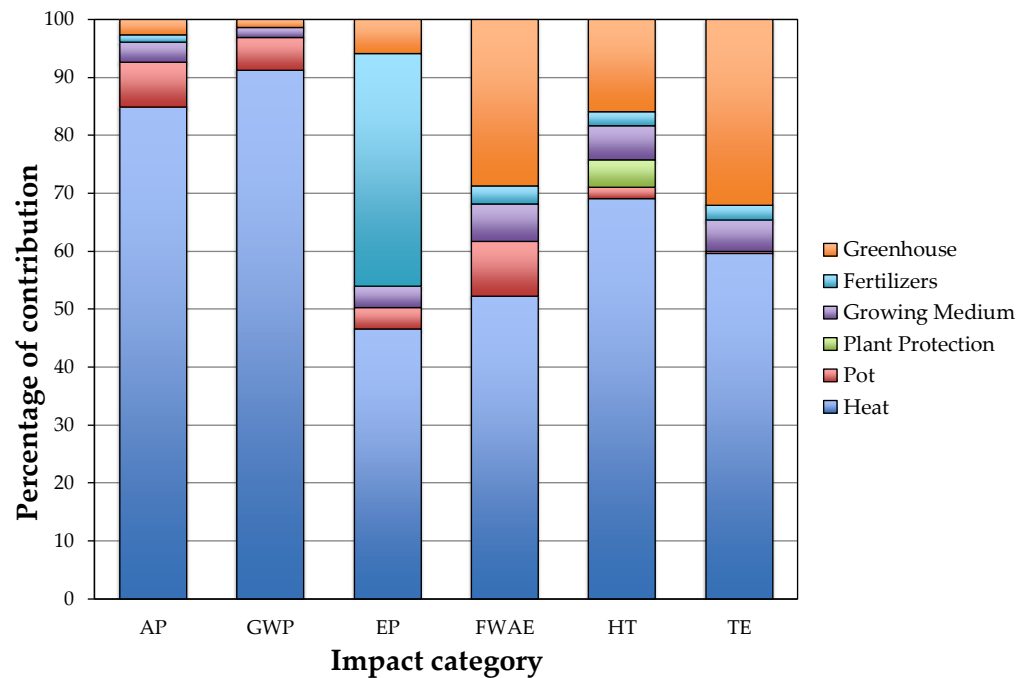
The considered inputs were grouped in six main categories, which include production, use and end-of-life phases: greenhouse structures (GH), fertigation (Fert), protection products (PP), containers (Pot), growing media (GM) and heating (H). Looking at absolute values (Table 2) for the assessed impact 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 (Figure 1 and Figure 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).

Impact category	Reference unit	Cyclamen		Zonal geranium	
		mean	St.dev. (%)	mean	St.dev. (%)
Acidification potential (AP)	kg SO <sub>2</sub> eq.	0.00036	11.63	0.00175	1.28
Global warming potential (GWP)	kg CO <sub>2</sub> eq.	0.07459	3.32	0.77210	1.29
Eutrophication potential (EP)	kg PO <sub>4</sub> <sup>3-</sup> eq.	0.00027	23.01	0.00042	11.02
Fresh water aquatic ecotoxicity (FWAE)	kg 1,4-DB eq.	0.01934	4.35	0.03490	3.48
Human toxicity (HT)	kg 1,4-DB eq.	0.04410	15.60	0.10200	1.03
Terrestrial ecotoxicity (TE)	kg 1,4-DB eq.	0.00066	4.63	0.00144	0.79



**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) (GWP), eutrophication potential (EP), fresh water aquatic ecotoxicity (FWAE), human toxicity (HT), and terrestrial ecotoxicity (TE).



**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) (GWP), eutrophication potential (EP), fresh water aquatic ecotoxicity (FWAE), human toxicity (HT), and terrestrial ecotoxicity (TE).

Relative contributions in the impact categories is depicted graphically in Figure 1 and Figure 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

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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.

### 3.1. *Cyclamen* (Figure 1)

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 (18%), 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) [34,35], while few studies conducted complete LCIA including other impact categories [33,44]. 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 [33]. 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 [44].

### 3.2. *Zonal geranium* (Figure 2)

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, except for HT (4.8%). 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 [36]; the overall impact dramatically increases [45] and is almost entirely attributable to energy demand, as in the case of zonal geranium.

### 3.3. *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.

Impact category	Reference unit	Compost		IPM
		Option 1	Option 2	
Acidification potential (AP)	kg SO <sub>2</sub> eq.	0.00035	0.00034	0.00030
Global warming potential (GWP)	kg CO <sub>2</sub> eq.	0.06980	0.06910	0.07260
Eutrophication potential (EP)	kg PO <sub>4</sub> <sup>3-</sup> eq.	0.00027	0.00022	0.00027
Fresh water aquatic ecotoxicity (FWAE)	kg 1,4-DB eq.	0.01810	0.01780	0.01850
Human toxicity (HT)	kg 1,4-DB eq.	0.04180	0.04100	0.03290
Terrestrial ecotoxicity (TE)	kg 1,4-DB eq.	0.00063	0.00063	0.00064

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 [41] reported lower impact values for different categories, including climate change, acidification potential, eutrophication potential and photochemical ozone formation. In this 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.

**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.

Impact category	Reference unit	Compost		IPM
		Option 1	Option 2	
Acidification potential	kg SO <sub>2</sub> eq.	0.00174	0.00177	0.00174
Freshwater aquatic ecotoxicity	kg 1,4-DB eq.	0.03450	0.03410	0.03510
Climate change	kg CO <sub>2</sub> eq.	0.77110	0.77090	0.77190
Terrestrial ecotoxicity	kg 1,4-DB eq.	0.00142	0.00139	0.00142
Eutrophication	kg PO <sub>4</sub> <sup>3-</sup> eq.	0.00042	0.00036	0.00042
Human toxicity	kg 1,4-DB eq.	0.09990	0.09930	0.09910

When considering mineral fertilizing offset, the differences increase, in particular for EP that shows a 14% reduction of final result. This value is lower than the observed minimum, highlighting the higher uniformity and technological level adopted for zonal geranium fertigation. In a trial on geranium bedding plants [20] compost from selected materials was found to have a supporting effect on growth of geranium plants, providing an increased nutrient budget in the growing media and an increased uptake and nutrient content in plant tissues. The use of peat-free substrate increases production risk and requires expertise, and often alternative substrates cannot be adopted [46], however, the 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. [41] in growth trials conducted on potted geranium. 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 [45], 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.

#### 4. 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 affect 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,

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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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