

# An Environmental Evaluation of the Cut-Flower Supply Chain (*Dendranthema grandiflora*) Through a Life Cycle Assessment

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## Abstract

Colombia is a major flower exporter of a wide variety of species, among which the chrysanthemum plays a major role due to its exporting volume and profitability on the international market. This study examines the major environmental impacts of the chrysanthemum supply chain through a life cycle assessment (LCA). One kg of stems export quality was used as the functional unit (FU). The study examines cut-flowers systems from raw material extraction to final product commercialization for two markets (London and Miami) and analyzes two agroecosystems: one certified system and one uncertified system. The transport phase to London resulted in more significant environmental impacts than the transport phase to Miami, and climate change (GWP100) category was significant in both cities, generating values of 9.10E+00 and 2.51E+00 kg CO<sub>2</sub>-eq\*FU for London and Miami, respectively. Furthermore, when exclusively considering pre-export phases, the uncertified system was found to have a greater impact than the certified system with respect to fertilizer use (certified 1,448E-02 kg\*FU, uncertified 2.23E-01 kg\*FU) and pesticide use (certified 1.24 E-04 kg\*FU, uncertified 2.24E-03 kg\*FU). With respect to the crop management, eutrophication (EP) and acidification (AP) processes imposed the greatest level of environmental impact. Strategies that would significantly reduce the environmental impact of this supply chain are considered, including the use of shipping and a 50% reduction in fertilizer use.

**Keywords:** Environmental analysis, floriculture, chrysanthemum, energy, certification systems, agroecosystem.

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# Evaluación ambiental de cadena de suministro de flores de corte (*Dendranthema grandiflora*) a través de análisis de ciclo de vida

## Resumen

Colombia es uno de los grandes exportadores de flores con una importante variedad de especies, entre las cuales el crisantemo (*Dendranthema grandiflora*) ocupa un destacado lugar por su volumen de exportación y calidad en los mercados internacionales. Esta investigación identificó los impactos ambientales en la cadena de suministro de crisantemos mediante análisis de ciclo de vida –ACV. La unidad funcional fue un kg de tallos con calidad de exportación. El estudio evaluó los sistemas de flores de corte desde la extracción de materia prima hasta la comercialización del producto en dos mercados, Londres y Miami y analizó dos agroecosistemas, uno certificado ambientalmente y otro sin certificar. La fase de transporte a Londres generó mayores impactos frente al transporte a Miami, especialmente en la categoría de cambio climático (GWP100), con valores de  $9,10E+00$  y  $2,51E+00$  kg CO<sub>2</sub>-eq\*UF<sup>-1</sup> para Londres y Miami, respectivamente. Al considerar las fases previas al transporte, el sistema sin certificar generó mayor impacto que el certificado, específicamente por mayor aplicación de fertilizantes (certificado  $1,448E-02$  kg\*UF<sup>-1</sup>, sin certificación  $2,23E-01$  kg\*UF<sup>-1</sup>) y plaguicidas (certificado  $1,24E-04$  kg\*UF<sup>-1</sup>, sin certificación  $2,24E-03$  kg\*UF<sup>-1</sup>). En manejo de cultivo las categorías con mayor carga ambiental fueron eutroficación (EP) y acidificación (AP). En escenarios de mejora se observó que el transporte marítimo y la reducción del 50% en fertilizantes, disminuía los impactos ambientales en esta cadena de suministro.

**Palabras clave:** Análisis ambiental, floricultura, crisantemos, energía, certificación, agroecosistema.

# Avaliação Ambiental De Cadeia De Suprimento De Flores De Corte (*Dendranthema Grandiflora*) Através Da Análise Do Ciclo De Vida

## Resumo

Colômbia é um dos grandes exportadores de flores, com uma importante variedade de espécies, entre as quais o Crisântemo (*Dendranthema grandiflora*) ocupa um lugar destacado por seu volume de exportação e qualidade, nos mercados internacionais. Esta investigação identificou os impactos ambientais na cadeia de suprimento de Crisântemos, mediante análise de ciclo de vida, ACV. A unidade funcional foi 1 Kg de brotos com boa qualidade para exportação. O estudo avaliou os sistemas de flores de corte desde a extração de matéria-prima até a comercialização do produto nos mercados de Londres e Miami, e analisou dois agroecosistemas: um deles certificado ambientalmente e outro não certificado. A fase de transporte a Londres gerou maiores impactos comparando-a com a de transporte a Miami, especialmente na categoria de câmbio climático (GWP100), com valores de  $9,10E+00$  e  $2,51E+00$  Kg CO<sub>2</sub>-eq\*UF<sup>-1</sup> para Londres e Miami, respectivamente. Ao considerar as fases prévias ao transporte, o sistema não-certificado gerou maior impacto que o certificado, especificamente por seu maior uso de fertilizantes (certificado  $1,448E-02$  Kg\*UF<sup>-1</sup>, não-certificado  $2,23E-01$  Kg\*UF<sup>-1</sup>) y defensivos (certificado  $1,24E-04$  Kg\*UF<sup>-1</sup>, não-certificado  $2,24E-03$  Kg\*UF<sup>-1</sup>). Considerando o manejo de cultivo, as categorias com maior carga ambiental foram eutroficação (EP) e acidificação (AP). Nos melhores cenários se observou que o transporte marítimo e a redução de 50% em uso de fertilizantes diminuem os impactos ambientais nesta cadeia de suprimento.

**Palavras-chave:** Análise ambiental, floricultura, Crisântemo, energia, Certificação, agroecosistema.

## 1. Introduction

Floriculture is one of the major productive sectors in Colombia as it plays an important role in the export of non-traditional products. The sector generates income and job diversity in the country's rural sector, and especially in Sabana de Bogotá and eastern Antioquia, which represent the country's two main production areas. However, as this production system is characterized by high demands on natural energy resources and intensive labor use (Parrado and Leiva, 2011), it is necessary to understand its environmental impact and to improve the efficiency of materials and energy use in meeting the requirements of international markets, for which this product is typically marketed and in which retailer and consumer demands are increasing.

The development of production systems such as flower cultivation involves transforming the structure and functioning of the ecosystems involved, these have implications regarding the transfer of matter and energy from the system (Pervanchon et al., 2002) and affect its sustainability. In recent years, there has been a growing awareness of sustainable production schemes and certified systems in agriculture, and numerous scientific studies aimed at improving the environmental performance of these production processes have been conducted. In this context, life cycle assessment (LCA) has been a widely used methodology for understanding and managing production processes (Hospido et al., 2010). With respect to the geographical development of this methodology, the majority of studies that have applied LCA methods to examine agricultural crops have focused on Europe. In research carried out on this region, considerations about the use of chemicals such as fertilizers and pesticides and high fossil fuel consumption for transportation have been common. However, over the last decade, various investigations on developing countries have also been conducted, which have described alternative means of certifying agricultural production, procuring green stamps and obtaining opportunities to enter international markets. Such studies have provided preliminary analyses

of material optimization and energy flows and of strategies for increasing production process efficiency.

From these works, a number of difficulties such as a lack of acceptance by producers due to limited awareness of methodologies, the need for external database use, a lack of reliable data, and gaps in data dissemination by governmental and private entities have been widely observed (Ntiamoah and Afrane, 2008); these factors remain as challenges to the methodology's full realization. In this respect, Latin America has made significant efforts to apply LCA methods to agricultural crop management through university, consulting firm and scientific development organization initiatives. A number of these works have been conducted in Brazil and have focused on biofuels for various crops associated with the production of ethanol and palm oil (Queiroz et al., 2012) as well as on coffee crops, oranges, cocoa, and various other agricultural products (Mourad et al., 2007). In Chile, studies of various crops with energetic uses such as rapeseed and sunflower (Iriarte et al., 2010) have been conducted, and similar studies have been executed in Peru and Argentina (Panichelli, 2006).

This particular methodology has not been relevant in the context of the Colombian agricultural sector as it has not been used as a tool for environmental analysis or for addressing national policies in this sector apart from being implemented in private sector consulting work. However, a number of palm oil studies are distinct and stand apart from other studies (Yáñez et al., 2009). This include studies on greenhouse-grown tomatoes and cut flowers (Medina et al., 2006; Parrado and Bojacá, 2011 and Bojacá et al., 2014) and unpublished and thesis-level works on crops such as sugarcane, castor oil and cut flowers, in which fertilizer, pesticide, and transportation-related emissions are highlighted as having major environmental impacts. These factors are also identified as the main elements that can be better managed improve agricultural processes (Bojacá and Schrevens, 2010).

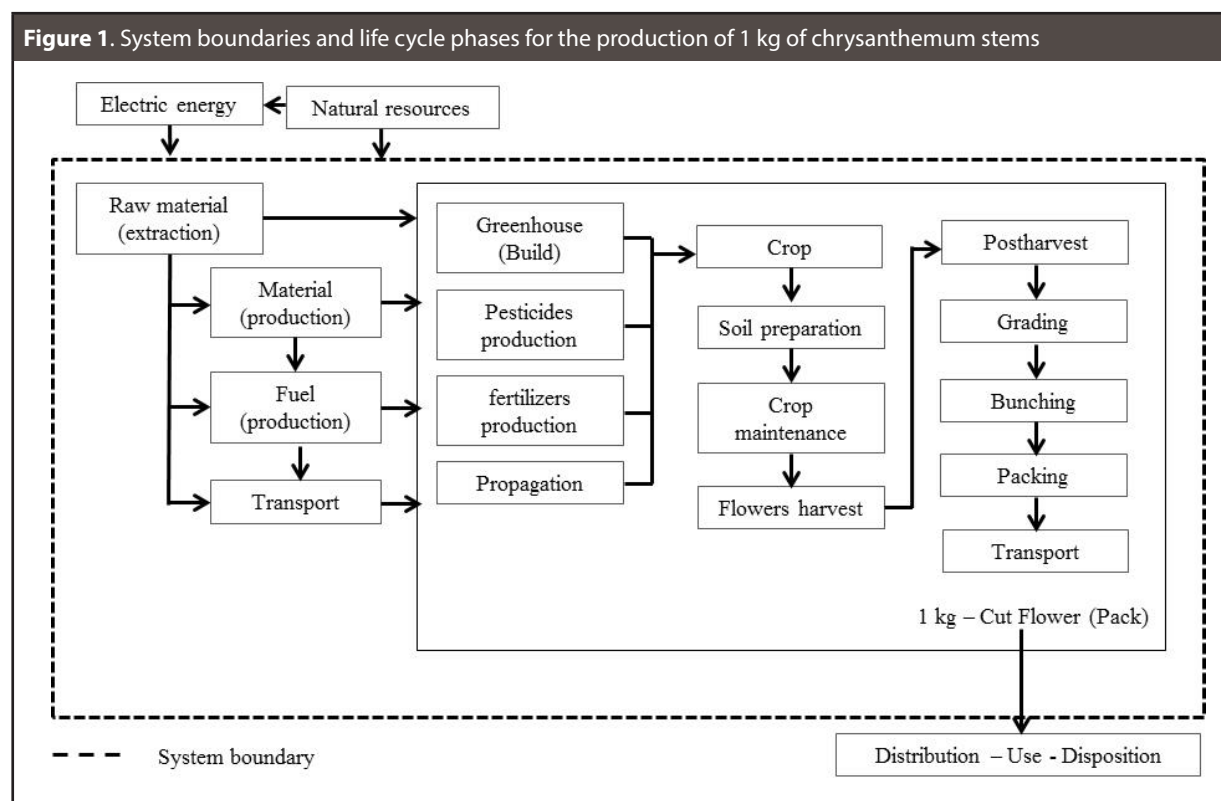
Finally, in addressing research needs in the flower industry and in highlighting the importance of this methodological approach, this study aims to determine the flow of energy and materials in the life cycle chain by interpreting and evaluating the potential environmental impacts of the chrysanthemum supply chain under different production systems, using certified and uncertified crops as points of reference. In addition to the previous objectives mentioned, this study aims to identify critical points of material and energy flow within the chrysanthemum supply chain life cycle as well as ways to improve the production process.

## 2. Materials and methods

The study follows the methodology established by the series of ISO 14040 standards (2006) for life cycle assessment. The analysis is developed over four phases, which each relate to a particular facet of the series.

### 2.1. Study objective and scope

The objective of this study is to illustrate the flow of materials and energy in the chrysanthemum supply chain life cycle and to evaluate and interpret the potential environmental impacts of this life cycle under two production systems: with environmental certification and without environmental certification. Additionally, the study aims to determine critical points of impact for processes and life cycle stages through which major environmental burdens are caused. In the analysis, five phases are considered: greenhouse construction, propagation, crop management, post-harvest and transport. The 1 kg of stems export quality chrysanthemum was taken as the functional unit (FU). The study scope accounts for crop cycle production over a three-month period for production system supply chains at the inter-continental geographic scale. In **Figure 1**, system limitations and chrysanthemum life cycle phases are shown.



## 2.2. Description of production systems

### 2.2.1. Uncertified system

The production process spans a period of three months, which corresponds to the production cycle. The process begins with the propagating stage, in which cuttings from mother plants are removed and then planted in greenhouse plots. This stage involves the use of fertilizers and pesticides to ensure crop development, and this stage thus involves the use of equipment and energy. Once plants have grown and the stems have been obtained, post-harvest tasks are performed. At this stage, stem quality control measures are performed (the American market generally requires 60 cm-long stems while the European market calls for 70 cm-long stems), and stems are arranged into bouquets inside plastic sleeves (six to seven stems per bunch) and then packed into cardboard boxes (25 bouquets per box) for transport. Finally, the boxes are transported in refrigerated trucks to the airport and then sent to various international markets by air cargo.

### 2.2.2. Certified system

This production process involves similar production stages and crop-use and energy-consumption processes as uncertified systems. Rather, the process does not exclude agricultural practices as is done in organic farming systems. However, the certified system (*Florverde*® Certification) is managed under additional socio-environmental management schemes involving labor rights, employee health and safety, the rational use of water, reduced agricultural inputs, integrated pest management, and waste management strategies.

### 2.2.3. Inventory analysis

Life cycle inventory (LCI) analysis is the second phase of LCA. It involves completing an inventory of input/output data for foreground and background systems being studied. Inventory analysis consists

of two main steps: data collection and data analysis. For this study, data collection was conducted for two chrysanthemum production systems, one certified and one uncertified, in the municipality of La Ceja Antioquia (6° 2'23.87" N, 75° 25'27.35" W) for 2012. Within the major system, subsystems corresponding to the phases of establishment and crop management were examined based on daily farm records. The system included raw material extraction; fertilizer, pesticide, steel, timber and plastics production, material transport, energy generation and material disposal. Inventory data for transportation were calculated based on average distances between farms, major seaports, and the José María Córdova International Airport (IATA: MDE, ICAO: SKRG) in Medellín. Additionally, electricity generation records were drawn from the XM Group report. Background data on synthetic fertilizer, raw material, building material, and fuel production were taken from the Ecoinvent database. Similarly, fuel, fertilizer, and pesticide emissions were drawn from this database based on the methods of Hauschild (2000); Heathwaite (2000); Brentrup *et al.*, (2000) and Audsley (1997). The data collected were converted into values that relate to the FU. Data processing and mass and energy balances were performed using Umberto 5.6 software. Emissions and impacts associated with transportation were included for each of these phases with the exception of the transport phase, for which transportation data were measured individually.

### 2.2.4. Impact Analysis

At this stage, the results of the inventory analysis were processed and analyzed in terms environmental and societal impacts. With respect to the ISO 14040 (2006) standards of data classification and characterization.

In the classification phase, inventory data were grouped into the following 10 impact categories: abiotic resource depletion (RD), acidification (AP), eutrophication (EP), climate change (CC), human toxicity (HT), freshwater ecotoxicity (FET),

marine ecotoxicity (MET), terrestrial ecotoxicity (TET), stratospheric ozone depletion (OD) and photochemical oxidant formation (PO). During the characterization phase, classified inventory data were quantified based on a common unit for each impact category. For this task, the mass value obtained from the characterization inventory was multiplied by a factor based on the literature and then calculated using Umberto 5.5 software. To evaluate impact, the CML 2002 method developed by the Center for Environmental Sciences at the University of Leiden was applied, which involves the determination of midpoint impacts (Guinée *et al.*, 2002.).

### 3. Results

In the material flow, water consumption and pesticide and fertilizer use were the main inputs to the production system. For energy flow, total energy consumption is shown, including different energy sources involved in processes associated with the product life cycle. The results are presented with reference to the FU.

#### 3.1. Material and energy flows

Raw material and energy inputs for each system are shown in **Table 1**. Oil is the main contribution for both production systems because this material involves different material and fuel manufacturing processes, the latter representing the greatest proportion of all inputs of this raw material. Additionally, a significant transportation distance difference of 6,078 km (IATA distances) between Miami and London was observed. When adding agricultural inputs, the active ingredients of products used in production were taken into account. Fertilizers constitute the main agricultural inputs, reaching a total of 1.48 E-02 kg\*FU and 2.23 E-01 kg\*FU for certified and uncertified systems, respectively; indicating high consumption of these inputs in the uncertified system, and of nitrogen fertilizers and correctives in particular. Similarly, with respect to pesticide use, the highest inputs

were found in the uncertified system, reaching a total of 2.24 E-03 kg\*FU. In the certified system, these inputs only reach a value of 1.24 E-04 kg\*FU.

#### 3.1.1. Energy consumption

**Table 2** shows different energy consumption levels observed over life cycle phases for each production system. For both systems, the highest energy levels (ranging between 9.29 E-01 and 1.29 E+00 Mj\*FU) were consumed during transport to the final destination. The highest quantity was found for the London destination, corresponding to 62.2 % of total energy for the certified system. For the uncertified system, energy use at this stage fell within the range of 9.29 E-01 and 1.29 E +00 Mj\*FU, representing a maximum of 69.1 % for the non-certified system. Differences between destinations were identified, as transport to London involved higher levels of energy consumption than transportation to Miami.

Among the pre-export phases, the highest levels of consumption were observed in the crop management phase, generating a maximum of energy level of 6.46 E-01 MJ\*FU, which is equivalent to 37% of the total value generated through the certified system for exports to Miami. For the uncertified system, the maximum value was 5.80 E-01 MJ\*FU, which represents 29% of energy consumption involved for the London-export system. On the other hand, the lowest levels of consumption occurred during the greenhouse construction phase, generating values between 1.39 E-02 and 1.43 E-02 MJ\*FU and representing only 0.7% on average for both systems.

In comparing the production systems, the certified system required higher degrees of energy consumption than the uncertified system. These differences were mainly observed in the crop management phase of both systems, while no differences in the remaining analyzed phases were found between the systems. During the crop management phase, the use of fertilizers, pesticides and greenhouse lighting for plant growth were

identified as the most energy-intensive processes, and this is attributable to production process characteristics (or own crop management activities). Material, fertilizer and pesticide manufacturing

processes did not involve significant levels of energy consumption at this stage of the life cycle. In **Figure 2**, energy flow for certified and uncertified systems and export destinations are shown.

**TABLE 1. MATERIALS AND ENERGY INPUTS PER FU IN THE ANALYZED SYSTEMS**

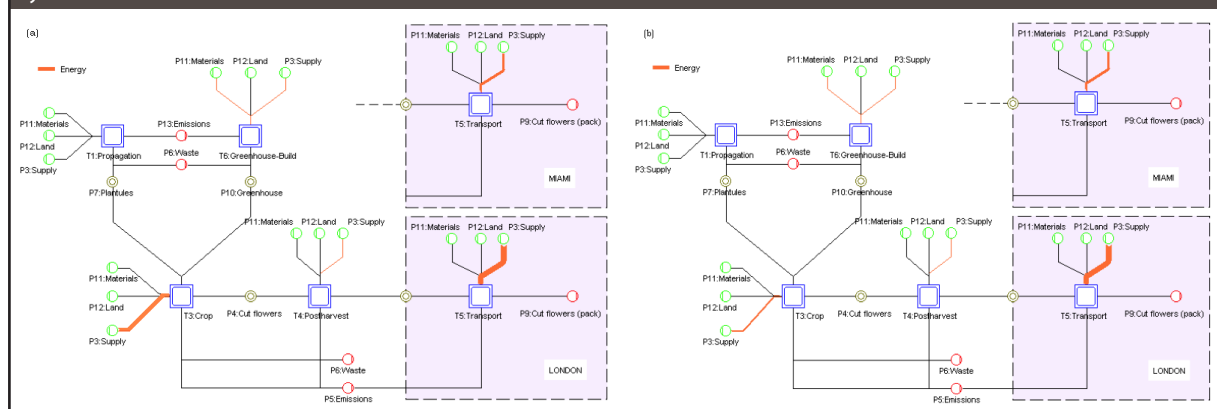
Inputs	Certified	Uncertified	Unit
<i>Energy</i>			
Total energy	1,72E+00* - 2,08E+00**	1,34E+00* - 1,99E+00**	MJ
Chrysanthemum production	6,46E-01	4,85E-02	MJ
<i>Materials</i>			
Oil	7,40E-01* - 2,70E+00**	7,40E-01* - 2,70E+00**	kg
Raw material	9,87E-01	9,80E-01	kg
Substrate	1,26E-01	9,46E-02	kg
Fertilizers	1,48E-02	2,23E-01	kg
N,P,K	9,43E-03	2,22E-01	kg
Fe, B, Mn, S	9,49E-04	3,50E-05	kg
Correctives (Ca, Mg)	4,46E-03	8,31E-04	kg
Pesticides	1,24E-04	2,24E-03	kg
Acaricide	-	5,65E-05	kg
Coadjuvant	6,22E-05	3,21E-04	kg
Fungicide	2,95E-05	1,44E-03	kg
Insecticide	3,21E-05	4,20E-04	kg
Total water	3,05E+03	3,25E+03	kg
Chrysanthemum production	1,58E+01	7,51E+01	kg
<i>Land use</i>			
Land use	2,70E-01	2,01E-01	m <sup>2</sup>

\* Miami \*\* London

**TABLE 2. ENERGY CONSUMPTION BY PHASE FOR CERTIFIED AND UNCERTIFIED SYSTEMS PER FU**

	Certified				Uncertified			
	London	%	Miami	%	London	%	Miami	%
Greenhouse	1.43E-02	0.7	1.43E-02	0.8	1.39E-02	0.7	1.39E-02	1.0
Propagation	5.10E-02	2.5	5.10E-02	3.0	5.20E-02	2.6	5.20E-02	3.9
Crop management	6.46E-01	31.1	6.46E-01	37.7	5.80E-01	29.2	3.01E-01	22.4
Post-harvest	7.44E-02	3.6	7.44E-02	4.3	4.85E-02	2.4	4.85E-02	3.6
Transport	1.29E+00	62.2	9.29E-01	54.2	1.29E+00	65.0	9.29E-01	69.1
Total	2.08E+00		1.72E+00		1.99E+00		1.34E+00	

**Figure 2.** Sankey diagram of energy flows per FU for transport to London and Miami: (a) Certified system (b) Uncertified system



**TABLE 3.** ENVIRONMENTAL BURDENS FOR THE IMPACT CATEGORIES ANALYZED BY SYSTEM AND TRANSPORT DESTINATION FU

Impact Category	Certified		Uncertified		Unit
	London	Miami	London	Miami	
AP	3.55E-02	9.99E-03	4.27E-02	1.72E-02	kg SO <sub>2</sub> -eq
OD	1.00E-06	2.72E-07	1.04E-06	3.13E-07	kg CFC-11-eq
AD	5.92E-02	1.65E-02	5.95E-02	1.68E-02	kg Sb-eq
CC(GWP100a)	9.06E+00	2.48E+00	9.10E+00	2.51E+00	kg CO <sub>2</sub> -eq
FET	2.42E-01	8.67E-02	2.33E-01	7.77E-02	kg 1.4 DB-eq
MET	1.63E+00	5.20E-01	1.60E+00	4.84E-01	kg 1.4 DB-eq
TET	9.53E-04	2.93E-04	1.24E-03	5.75E-04	kg 1.4 DB-eq
EP	7.06E-03	2.17E-03	1.31E-02	8.16E-03	kg PO <sub>4</sub> -eq
PO	1.47E-03	4.08E-04	1.49E-03	4.26E-04	kg C <sub>2</sub> H <sub>4</sub> -eq
HT	7.03E+00	1.92E+00	7.04E+00	1.92E+00	kg 1.4 DB-eq

### 3.4. Impact assessment

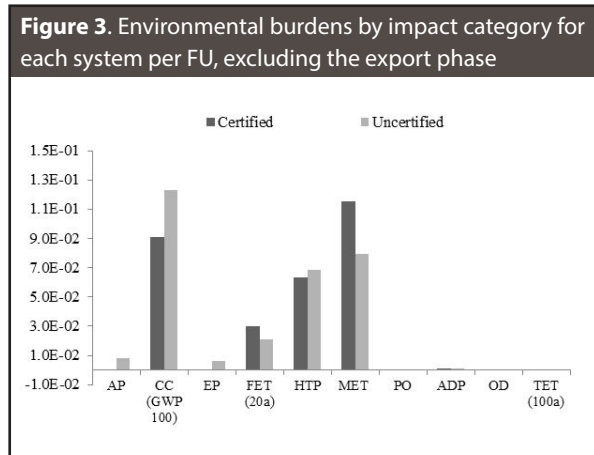
Table 3 shows the characterization and environmental impact results by impact category for the examined systems and corresponding export destinations. The most significant impacts were related to the CC (GWP 100a) category. Major differences were observed between the two export destinations, with London showing a maximum value of 9.10E+00 kgCO<sub>2</sub>-eq\*FU and Miami producing a value of only 2.51E+00 kgCO<sub>2</sub>-eq\*FU. The second most significant impact category was HT. The highest value for this category was 7.03E+00 kg1,4 DB-eq\*FU for the system involving transportation to London,

while for the system that transports to Miami this value was 1.92E+00 kg1.4 DB-eq\*FU. The third high-impact category was ME, which generated maximum values of 1.63E+00 kg 1.4DB-eq\*FU for the system terminating in London and 4.84E-01 kg1.4DB-eq\*FU<sup>-1</sup> for the system terminating in Miami.

When only considering productive phases for certified and uncertified systems and excluding transport to the final destination, the CC (GWP 100a) ME, HT and FE categories, imposed greater environmental burdens for both of the studied systems (Figure 3). For CC (GWP 100a) HT, AP and EP the most significant environmental burdens occurred



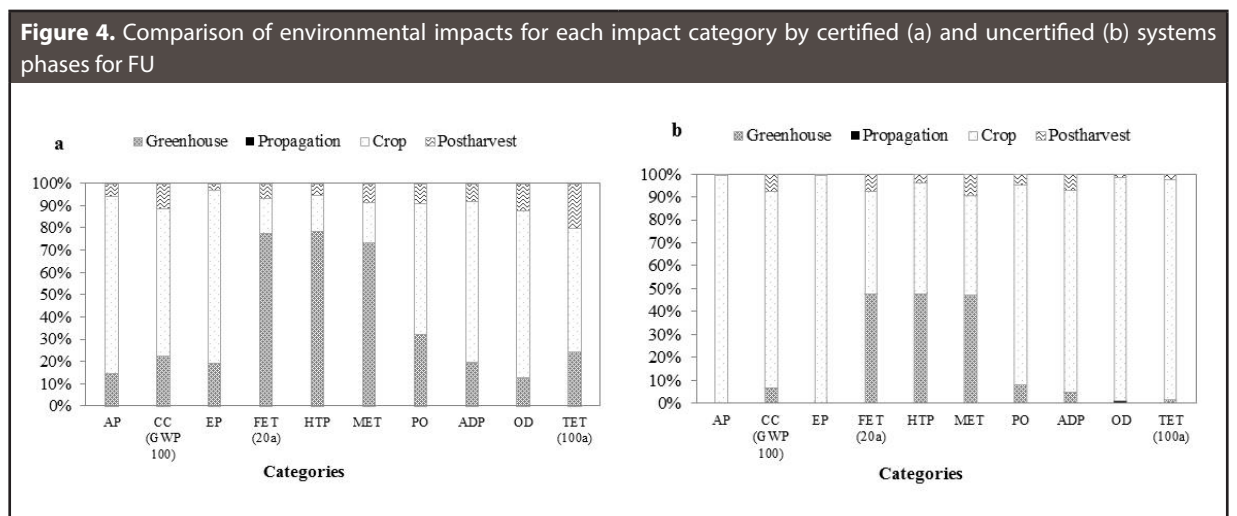
in the uncertified system. On the other hand, for the FET and MET the most significant environmental burdens occurred in the certified system. In contrast, the remaining categories generated significantly difference results between the systems. In the case of EP, a greater value of  $6.0E-03 \text{ kg}^{-1} \text{ PO}_4\text{-eq*FU}$  was generated in the uncertified system than in the certified system, accounting for a percentage contrast of 88.4%. A similar result was found for the AP category, in which a  $7.2E-03 \text{ kg SO}_2\text{-eq}$  difference was found between the two systems, accounting for 82.8%. Other categories for which the uncertified system generated greater impact contributions included: OD, TET and PO, generating percentage differences of 72.8, 72.3 and 30.5%, respectively.



### 3.5. Impact assessment of life-cycle phases

**Figure 4** lists potential chrysanthemum productive cycle environmental burden contributions of the systems for the examined categories. For certified system (**Figure 4a**), the results show that for most of these categories, the crop management phase generates the majority of the impact. Exceptions are found in the MET, HT and FET categories, in which the greenhouse phase has the greatest environmental impact. For uncertified system (**Figure 4b**), among the phases occurring prior to delivery to the final marketing destination, the crop management phase contributed most to the same categories of high impact found for the certified system: AP, CC (GP100a), EP, PO, AD, OD and TET. For this system, the AP category had the most significant environmental impact during the crop management phase, accounting for 80.0% of the generated contributions. This pattern during the crop management phase was also found for EP (77.6%), OD (75.0%), and AD (72.1%) categories.

For the uncertified system, EP category has the greatest impact during the crop management phase (99.3%) followed by AP (98.9%), OD (97.71%) and TET (96.5%) categories. Moreover, during the greenhouse construction phase, the greatest impacts occurred in FET (47.5%) and MET (46.9%).



## 4. Discussion

### 4.1. Materials and energy flows

The highest level of energy consumption occurred in the scenarios involving transportation to London. This occurred as a consequence of the 8,400 km flight involved in the transport route to London compared to the 2,322 km route to Miami (IATA distances). These differences are reflected in kerosene, materials and energy consumption levels found in the transport life-cycle results generated through the analysis. Murty (2000) argues that systems involving air transport consume higher levels of energy than those driven by land transport due to the types of fuel and high levels of consumption required for air operation. Nevertheless, air transport requirements during the export phase are too essential for producers to omit in the interest of improving energy-use efficiency. The distance to the final export destination influences energy consumption levels for productive systems involving products to be sold in other countries. On this issue, Michael (2011) reported on the effects of distance to final export destinations for waxflower crop production in Australia. In this study, differences in energy consumption were documented depending on the export destination, with the furthest destination (Netherlands) requiring the highest levels of energy consumption and export to Japan requiring the least.

For the production stage of the chrysanthemum, excluding the transportation phase, larger quantities of energy were consumed in the certified system. This result is attributable to the lighting method used during the crop management stage and to the type of machinery used for fertilizer and pesticide application. Based on these results, efforts to improve such systems should involve evaluating the efficiency of these activities, and especially because the certified system examined in this study values efficient energy use to a greater degree than uncertified. On this issue, Vringer and Blok (2000) analyzed the effects of energy consumption on 37 flower farms in the Netherlands (including chrysanthemum farms) and found a

proportional relationship between management and energy consumption. A number of their results showed that energy consumption required for the production of free exposure crops account for only a quarter of the required energy to produce greenhouse crops. Likewise, the authors observe fluctuations in energy use throughout the year due to varying seasonal lighting requirements. However, as there is no seasonal variability in the tropics, energy use for lighting may be managed more efficiently. Although the results are not comparable due to system and methodological calculation approach limitations, the authors argue that high levels of energy consumption for flower crop production under Dutch conditions differ from those required for tropical systems due to heating and machinery requirements.

With respect to chrysanthemum production, a consumption level of 12.5 MJ per stem was estimated, and a maximum values for the alstroemeria and gerbera varieties were found to be 15 MJ and 13.5 MJ, respectively. Similar results were observed by Williams (2007) when comparing rose cultivation in the Netherlands and Kenya, in which higher degrees of energy were consumed in the productive system in the Netherlands (45.5 MJ per stem) than in Kenya (4.4 MJ), the determined FU was 12,000 flower stems. The author argued that energy consumption differences are attributable to crop heating and lighting requirements.

With respect to the use of inputs such as fertilizers and pesticides, the uncertified system generated the highest values, illustrating inefficiencies and areas for improvement that can be remedied through certification, which involves reducing these inputs for the production of crops. Rather, nitrogen fertilizers account for major environmental impacts on agricultural crops, and especially during the crop management stage (Iriarte *et al.*, 2010). Similar processes are evident for other crops such as corn and soybeans in the United States (Landis *et al.*, 2007), sunflowers and rapeseeds in Chile (Iriarte *et al.*, 2010); tomatoes in Colombia (Parrado and Bojacá, 2009) and rice in Italy (Blengini and Busto, 2009).

#### 4.2. Impact interpretation

The category that had the greatest impact on the chrysanthemum supply chain life cycle (under the limits studied) was CC (GWP 100). The environmental impact of this category is attributable specifically to the means of transport used during each phase from the materials input site to the crop production site, in which ship transport distances greater than 10,000 km were included in the case of fertilizers and pesticides as well as truck transportation from seaports and material factories located in Colombia and air transportation for chrysanthemum export. The CC category affects different points in the chrysanthemum supply chain from production to transport, and improvements must transcend limits of the productive system. Another important factor involved in the generation of environmental impacts of this category are emissions derived from the application of agricultural inputs (mainly fertilizers), which enter certified and uncertified systems as nitrates, ammonia and urea. Air emissions from the use of such fertilizers account for  $N_2O$  1.25 % of applied nitrogen levels according to Bentrup *et al.*, (2000) and Weidema *et al.*, (2000);  $NO_x$  levels account for 10% of total  $N_2O$  emissions, and  $NH_3$  levels account for 2% of applied fertilizer use according to Audsley (1997). As for pre-field uses, the IPCC (2006) notes that major atmospheric emissions through urea manufacturing are composed primarily of  $NH_3$  and urea powder, which both arise from granulation processes. Emission levels can range between 0.5 and 1 kg of  $NH_3$  ton of urea and 0.5 and 1.5 kg of powdered urea ton. During this process, atmospheric  $CO_2$  is considered fixed, and levels are estimated using this method in impact analyses of fertilizer use.

This category most significantly impacted environmental processes during the transport phase to final destinations. This impact is dependent on the distance traveled, the amount of fuel used, the volume of product transported and differences in emission levels generated through air transport compared to sea and land transport, according Murty (2000) observations. At the same time, high

levels of fuel consumption led to increased raw material and energy use and emissions during different stages of the life cycle and throughout the cycle more generally. The results for the climate change category were proportionally similar to those obtained in a study on rose and carnation crops examined under similar geographic conditions and agricultural practices in Colombia. In this study, Parrado and Leiva (2011) considered the same export destinations (London and Miami) and observed a major difference in environmental impacts caused by differences in locations and life cycle phases. Rather, transport to London resulted more climate change impacts compared to values found for the transportation to Miami, generating maximum values of 12.44 and 6.44 kg  $CO_2$ -eq for 1 kg of export quality rose stems, respectively. In addition, the air transport phase generated a high incidence of environment impact for the rose and carnation systems. Similarly, Michael (2011) reported the effect of final marketing destination distance for waxflower crops in Australia. In this case, the author observed quantities of 13.6 kg  $CO_2$ -eq for export to the Netherlands (the determined FU was determined as 10 stems of flowers), and this value was lower when Japan was the final destination, which generated a value of 7.1 kg  $CO_2$ -eq. The author again attributes these differences to energy consumption through air transport.

Conversely, Williams (2011) conducted a study on greenhouse rose crops in two countries (Kenya and the Netherlands), using the life cycle approach to analyze the climate change category. The results showed that production in Kenya generated 0.18 kg  $CO_2$ -eq per stem of roses, while in the Netherlands the environmental burden amounted to 2.91 kg  $CO_2$ -eq. A reference analysis of reports from other studies on contributions to this impact category shows that chrysanthemum production examined in this study generates between 0.08 and 0.31 kg  $CO_2$ -eq, which is similar to the trend observed for rose production in Kenya and lower than production in the Netherlands. These results are also lower than

findings reported by Parrado and Leiva (2011) for rose production in Colombia, in which the values for transport to London ranged between 0.17 and 0.48 kg CO<sub>2</sub>-eq and between 0.06 and 0.16 kg CO<sub>2</sub>-eq for Miami. This trend was also found for the two highest-impact categories following climate change, which in this study were HT and MET.

Furthermore, when only considering the pre-export phase, contributions to this environmental category occur during the crop management phase, thus demonstrating the need to reduce loads through improved agricultural practices, and especially in uncertified systems, in which this phase accounts for 86.1% of CO<sub>2</sub>-eq emissions, thus having a greater impact than the greenhouse construction, propagation and postharvest phases. In this case, climate change impacts were caused to a greater extent by manufacturers and through the use of fertilizers, followed by manufacturing, pesticide use, and transportation required at each phase. These results are similar to those observed by Iriarte *et al.* (2010) in relation to rapeseed and sunflower production in Chile, where the authors reported a high correlation between manufacturing processes and fertilizer use and impacts associated with climate change, representing between 83% and 93% of production equivalent to CO<sub>2</sub> despite the fact that this study did not contemplate final product transport.

For the uncertified system, regardless of the export stage, the greatest environmental impacts caused by the EP category are related to nitrate and phosphate leaching from fertilizer application as argued by Wang *et al.*, (2010) based on observations of rice crops in China. For this category, the highest values in the uncertified system were caused by an intensified use of nitrogen fertilizers, because in this system, 2.08 E-01 kg more fertilizer / kg of stems was applied than was applied in the certified system. This characteristic becomes evident when comparing pre-export phases, because the main contributions to environmental burdens occur during the crop management phase in the two systems as a result of fertilizer application. This represents the most

significant impact activity during the crop, pesticide application and manufacture phases as well as during farm input transport. In contrast, Bentrup *et al.*, (2001) analyzed the environmental impact of the sugar beet life cycle with an emphasis on different forms of nitrogen fertilization and found that the environmental impact of this system is higher when urea is used; mainly in areas such as acidification and eutrophication by NH<sub>3</sub> emissions. The lowest degrees of environmental impact were observed in fertilization systems that include calcium ammonium nitrate, which is made evident by lower emissions of NH<sub>3</sub> and NO<sub>3</sub> generated due to increased uptake by plants.

Similarly, environmental impacts from AP were higher in the uncertified system as a result of more intense fertilizer and pesticide use in this system compared to the certified system, with the crop management phase representing the greatest contributor to this category. In turn, this phase reached a maximum representativeness of 98.4 % for this category in relation to the other categories analyzed for the uncertified system. These results coincide with observation by Sahle and Potting (2013) in their examinations of Ethiopian rose cultivation through consideration of pre-export phases prior to final product export. In this case, the results show that the crop management phase imposed the most significant environmental burden on the AP category, generating a contribution of 90%. This contribution was higher than those of other phases analyzed in the life cycle, and this is mainly attributed to the use of fertilizers. Additionally, the study showed that impacts associated with the EP are related by more than 50% to the application of fertilizers, and this result coincides with observations on chrysanthemum production described in the present study.

The OD category was vastly superior in the uncertified system. Among the system phases, crop management imposed the greatest environmental impact, accounting for a maximum representation of 97.7 % in the system. In this case, environmental

burdens are related to the manufacture and use of pesticides, and the application rate was much higher in the uncertified system. Ntiamoah and Afrane (2008) observed similar representativeness of this category during the crop management stage (96%) for the cocoa supply chain in Ghana and argued that this resulted from the use of pesticides and from the release of CFCs during production. This study analyzed environmental impacts caused through the production of 1 kg of processed cocoa beans using a life-cycle approach that examined three phases: growing, processing and truck transportation. Although the crops and conditions examined in this study differ from those investigated in the present study, the authors highlight these causes as the main contributing factors to acidification environmental loads in crops.

Other categories that showed significant differences between systems were TET and PO, which were 60% higher in the uncertified system than certified system. This difference is attributed to the use and manufacture of pesticides and fertilizers, and especially during the manufacturing stage. This practice generates toxic substances and releases of heavy metals into the environment. These results are consistent with those reported by Baranowska *et al.*, (2005) in studies on the distribution of heavy metals and pesticides in food chains in Poland. For this reason, the crop phase showed the highest levels of environmental burden for this category, reaching a maximum rate of 96.5 % for the uncertified system.

## 5. Sensitivity analysis

Once the impacted categories with greater environmental effects and critical phases were identified, a sensitivity analysis was performed to analyze possible ways to limit chrysanthemum life cycle environmental impacts. Because air transport and flight distance were the main factors related to environmental impacts, and especially in relation to CC (GWP100a), an additional scenario that concerns

shipping as a means of exporting to final destinations was analyzed. This analysis was conducted to determine the relevance of transportation as a means of improving this process. Moreover, without considering the export stage, it was found that the crop management phase imposed the main environmental burden for the systems analyzed as a result of fertilizer and pesticide application in this phase of the system, and especially for the EP and AP. Therefore, a scenario in which the application of these inputs is reduced by 50% is analyzed as a means of reducing environmental impacts caused during this stage, both in certified and uncertified systems.

When the mode of transportation during export was changed, the environmental burden of the CC (GWP100) decreased; London, from  $9.10 \text{ E} +00 \text{ kg CO}_2\text{-eq*FU}$  with air transport to  $1.42 \text{ E}-01 \text{ kg CO}_2\text{-eq*FU}$  with shipping, representing a 98.4% decrease in emissions caused by the chrysanthemum life cycle. For Miami, these values were  $2.51 \text{ E} +00$  and  $1.07 \text{ E}-01 \text{ kg CO}_2\text{-eq*FU}$  for air and sea transport, respectively, representing a 95.7% decrease.

Therefore, shipping can be considered as a means of improving the chrysanthemum supply chain from an environmental perspective, under the limitations and scope specified in this study. As for the 50% decrease in the application of nitrogen fertilizers and pesticides, the former figures account for reductions of environmental burdens of the EP and AP categories. For the certified system, implementing this scenario reduced the impact of the EP from  $3.06 \text{ E}-04$  to  $8.9 \text{ E}-05 \text{ kg PO}_4\text{-eq*FU}$ , representing a decrease of 70.9 % for this impact. For this AP category, a  $5.94 \text{ E}-04$  to  $3.92 \text{ E}-04 \text{ SO}_2\text{-eq kg*FU}$  reduction occurred, accounting for a decrease of 34.1%. Meanwhile, for the uncertified system, the impact for EP category was reduced from  $6.34 \text{ E}-03$  to  $1.27 \text{ E}-03 \text{ kg PO}_4\text{-eq* FU}$  (79.8%) and from  $7.88 \text{ E}-03$  to  $4.13 \text{ E}-03 \text{ kg SO}_2\text{-eq*FU}$  (48.6%) for the AP category. This suggests that a decrease in the application of agricultural inputs by 50% can

effectively reduce environmental effects of the crop management phase for the analyzed systems.

## 6. Conclusions and recommendations

Energy use levels were higher in the certified system due to lighting systems used to extend the photoperiod and due to machinery used for applying agricultural inputs. This result showed that appropriate energy consumption monitoring is not performed in these systems, even when energy efficiency certification is regarded as a certification parameter.

Because flowers must be transported to be sold, the export destination was the determining factor that shaped observed differences in environmental loads analyzed in this study, and mainly in the category of climate change. A 6,078 km difference in the flight distance between Miami and London resulted in higher levels of energy and materials consumption during the export process to London from fuel use for transportation and manufacturing processes and for in raw material extraction associated with the life cycle of this transport mode. For this reason, the category with the greatest environmental impact on the supply chain was CC (GWP100a).

The sensitivity analysis of two scenarios of reduced impact was conducted to explore alternatives as a starting point for possible improvements to the process, despite the fact applications of these alternatives were not referred to in the objectives of this study. The first component of the analysis examined shipping possibilities for final product exporting, which caused over 95 % reductions of climate change impacts for the two export destinations. However, it is recommended that such measures be analyzed in reference to other factors involved in the production process such as cold-chain, ground transportation to nearby ports and roads while maintaining quality and meeting delivery times.

Furthermore, scenarios of fertilizer and pesticide reductions of 50 % were analyzed, which for the two systems considered resulted in an over 70% decrease in environmental loads from EP and of approximately 40 % from AP categories. This approach can improve the environmental profile of the chrysanthemum supply chain, although applications of this scenario must be based on other technical criteria that analyze species physiologies and production system productivity.

It is recommended that the life-cycle assessment method be applied to evaluate environmental certifications, because apart from being useful for analyzing environmental loads in production systems, it enables one to evaluate the efficiency of such systems to identify critical points for improvement in materials and energy management. It is also necessary to conduct research to generate databases regarding product and service life cycle and emission levels for the Colombian territory. The lack of geographical data similar to those presented in this study was one of the major difficulties encountered in the application of the life-cycle assessment methodology over the course of this research.

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