17th International Conference on Environmental Science and Technology

Athens, Greece, 1 to 4 September 2021

Environmental LCA and Carbon Footprint of Cauliflower as Produced in Southeast Spain

RASINES L.[1,2], SAN MIGUEL G.[3], MOLINA-GARCÍA A.[4], ARTÉS-HERNÁNDEZ F.[1,2], HONTORIA E.[5] and AGUAYO E.[1,2]

[1]Postharvest and Refrigeration Group. Universidad Politécnica de Cartagena (UPCT), 30202 Cartagena, Spain.
[2]Food Quality and Health Group, Institute of Plant Biotechnology (UPCT), Campus Muralla del Mar, 30202 Cartagena, Spain.
[3]School of Industrial Engineering (ETSII), Grupo de Agroenergética, Universidad Politécnica de Madrid, UPM, Spain.
[4]Electrical Engineering Department, UPCT.
[5]Department of Business Economics, UPCT.

*corresponding author:
e-mail: encarna.aguayo@upct.es

Abstract Southern Spain has an optimal climate for growing fruits and vegetables. Over 39,534 ha are currently dedicated to the production of cauliflower and broccoli in Spain, 33% of which correspond to the Region of Murcia. This type of intensive agriculture causes environmental impacts which must be quantified and minimized as much as possible. This study details the Life Cycle Assessment (LCA) of cauliflower production with a cradle-to-farm-gate approach using precise and updated primary data from local producers. Foreground inventory data was collected for the nursery and on-field stages, including energy use, consumption, application and diffusion of fertilizers and pesticides, machinery and transport to the packaging center. Ecoinvent v3.6 datasets were adapted to the characteristics of the system for background inventory and the EF 3.0 method was used for evaluation. The carbon footprint of 1 kg of cauliflower was estimated at 91.2 g CO_2eq. Impact values for the same functional unit in other categories were as follows: Photochemical ozone formation 3.33E-04 kg NMVOC eq., Acidification 3.41E-04 mol H+ eq., Freshwater eutrophication 2.27E-05 kg P eq. The mitigation practices in cauliflower production should focus on energy use during irrigation and reduced use of pesticides.

Keywords: Sustainable agriculture, cauliflower, vegetables, carbon footprint, pesticides.

1. Introduction

Food production contributes to over 24% of all global anthropogenic greenhouse gas emissions (Clune, 2019). Intensive horticulture has been reported to cause significant damage to the environment, including nutrient losses and a decline in soil fertility and biodiversity (Persiani et al., 2019). These impacts need to be adequately quantified and evaluated to promote the development of policies and practices aimed at promoting sustainable development. Life Cycle Assessment (LCA) has been used for over 50 years to assess the environmental performance of goods and services, including food and agriculture products, and farming activities (Perrin et al., 2014).

Cauliflower and broccoli farming in Europe covers 120,410 ha and generates 2,159,000 t of produce, 32% of which originates in Spain (FAOSTAT, 2019). In 2020, the Region of Murcia (southeast Spain) produced 23% of all the vegetables and 18% of the fruit exported by Spain (FEPEX, 2021). In this region, about 40% of the agricultural fields are irrigated and 66% of the irrigated land is devoted to vegetables and fruit (Martín-Górriz et al., 2020). More specifically, 13,750 hectares in the Region of Murcia are dedicated to growing cauliflower and broccoli, representing 33% of the Spanish production.

The environmental performance of cauliflower has been studied by several authors. Martínez-Blanco et al. (2011) investigated the effects of three fertilizing strategies using LCA, reporting negative global warming and eutrophication emissions due to CO_2 sequestration in the cultivation stage and PO_4^{-3} eq reductions due to the composting of organic residues. Similarly, Perrin et al. (2014) reported greenhouse gas emissions between – 900 and 200 g CO_2 eq. per kilogram of fresh cauliflower. However, recent publications have questioned the consideration of short-cycle CO_2 uptakes, such as those occurring in agricultural processes, in the evaluation of climate change (L Zampori and Pant, 2019). Heuts et al. (2016) studied the LCA of cauliflower and leek rotation systems comparing two nitrogen application strategies. The results showed that fertirrigation reduced impacts on acidification, eutrophication and human toxicity compared to conventional application systems. However, fertirrigation increased both global warming potential and cumulative energy demand (CED) due to the electricity used in water pumping operations and embodied impacts from pipeline manufacturing.

2. Materials and methods

2.1. Goal and scope definition

The main aim of this study is to update and refine upon information regarding the environmental performance of intensive cauliflower production under open farming conditions. Secondary objectives include: i) describing the contribution of key life-cycle stages and processes to priority categories and, ii) providing alternatives to improve the environmental performance of the food product.

The structure of the analysis is based on ISO 14040-14044 (ECS, 2006) following the guidelines of Product Category Rule (PCR) UN CPC 012 for arable and vegetable crops (Environdec, 2020). The functional unit (FU) was defined as 1 kg of fresh cauliflower.

2.2. System description and boundaries

A cradle-to-farm-gate approach has been used, considering the processes described in Figure 1. As proposed in PCR UN CPC 012, the system has been structured into three phases:

- Upstream: Extraction of materials for the construction of the greenhouse, machinery, irrigation system; the chemical compounds necessary for producing pesticides and fertilizers; and the activities in the nursery to produce the seedlings.

- Core: material and energy inputs for cauliflower production in greenhouse and on-field activities, such as water use, electricity and diesel consumption for water management and for the activities associated with the cultivation and harvesting. Application of pesticides and fertilizers and their diffusion into the environment.

- Downstream: end of life of products and materials.

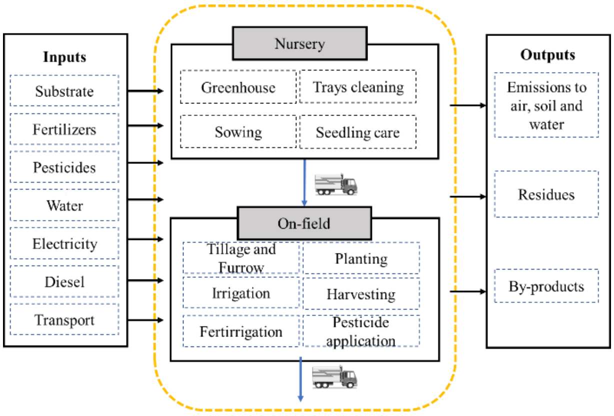

Figure 1. LCA of open-field cauliflower production

2.3 Assumptions and limitations

The main assumptions made to model the system were:

- Foreground life cycle inventory data was collected from a local producer and applied to cauliflower cultivation in Murcia from Oct 2019 to May 2020.
- The electricity was modelled considering the electric mix in Spain in 2020 as follows: 22% nuclear, 22% wind, 18% combined cycle, 12% hydraulic, 11% cogeneration, 8% solar, 2% carbon, 2% fuel and gas, and 3% other renewable energy sources.
- The lifetime of the irrigation system was 15 years.
- The transport volume for raw materials was estimated assuming an average distance of 50 km and considering the use of mid-range Euro 5 trucks.

2.4 Life cycle inventory

Table *1* shows the LCI data for the cauliflower system per unit of hectare cultivated. The cauliflower seeds are initially planted on 700 x 460 mm polystyrene (PS) trays (each containing 294 cells and a lifespan of four years) using a mechanical sowing machine. The seedlings were fertigated using different nitrogen fertilizers (N-P_2O_5-K_2O: 13-14-13; 20-20-20; 12-61-0; and 0-52-34). The agrochemicals (insecticides, fungicides and herbicides) used were applied twice a year considering the active principles and doses reported by Martín-Gorriz et al. (2020) for broccoli. Twenty days after sowing, the seedling trays were transported 30 km by road to the field, in a 3.5-ton lorry Euro 5.

On-field, the cultivable area (350 ha) was plowed and furrowed by tractors prior to manual planting, followed by the installation of the drip irrigation system. An energy intensity for water use of 0.28 kWh/m^3 was considered for water intake and distribution to the field (Hardy and Garrido, 2010). Energy for drip irrigation was obtained from Maraseni et al. (2012) who reported 0.034 kWh/m^3/ha.

Table 1. Life cycle inventory (LCI) of the cauliflower system

	Inputs per ha	Units
Nursery		
Greenhouse	70.86	m^2
Trays (PS)	1.008	kg
Substrate	5.986	kg
Fertilizers	225	kg
Pesticides	10	kg
Water	2.457	m^3
Electricity	429	kwh
Diesel	452	L
On-field		
Plant density	10.501	plants/ha
	23.070	kg/ha
Machinery	121	h
Fertilizer	689	kg
Pesticides	111	kg
Water	3600	m^3
Electricity	1130	kWh
Diesel	100	L

The fertilizer units (N-P_2O_5-K_2O) for the cultivation stage were 275-100-312.5 (Pato Folgoso et al., 2006). Types and doses for pesticide treatments were obtained from MAPA (2020). In fertilizer and pesticide emissions, production, application and emission to the environment were considered. To estimate diffusion of nitrogen-based fertilizers to the environment NH_3 and NO emissions factor were taken from IPCC, 2019 guides, whilst N_2O direct and indirect emissions factors were obtained in Zampori and Pant (2019), which includes emission from agricultural land and emissions associated with nitrogen volatilization. Pesticide emissions were calculated according to Product Category Rules of arable and vegetable crops CPC 012, modeled thus: 90% emitted to the soil, 9% emitted to air, and 1% emitted to water.

The harvesting was manual, workers' transport (vehicles) to the field was by road, and the consumption of a forklift and transporting the cauliflowers to the warehouse was also considered.

2.4 Life cycle assessment software and impact categories

The system was modelled with SimaPro v9.1.1 using the EF 3.0 impact assessment method and Ecoinvent v3.6 databases, which were adapted to the features of the system when required (e.g., electricity mix in Spain). The impact categories evaluated were: climate change (including fossil fuel, biogenic and land use change emissions), ozone depletion, photochemical ozone formation, acidification, freshwater eutrophication and ecotoxicity and mineral fossil and resource depletion.

3. Results and discussion

The results showed that the production of 1 kg of cauliflower generated 91.20 g CO_2 eq., 99.4% of which corresponded to fossil fuel emissions (Table 2). The main contributor to climate change was irrigation (73%) due to the electricity consumed to pump the water to the fields. This supports the findings published by Heuts et al. (2016) related to the significance of irrigation activities in the climate change emissions of cultivation systems. The harvesting phase contributed 9% (Figure 2), while the pesticides (including production, application, and diffusion) accounted for 6% of the total.

Table 2. Characterized impacts of the cauliflower system

Impact category	Unit	Total
Climate change		
- Fossil	kg CO2eq	9.12E-02
- Biogenic	kg CO2eq	1.85E-04
- Land use change	kg CO2eq	3.38E-04
TOTAL	kg CO2eq	9.17E-02
Ozone depletion	kg CFC-11 eq	4.78E-08
Photochemical ozone formation	kg NMVOC eq	3.33E-04
Acidification	mol H+ eq	3.41E-04
Freshwater eutrophication	kg P eq	2.27E-05
Freshwater ecotoxicity	CTUe	2.98E+01
Mineral, fossil, and ren resource depletion	kg Sb eq	2.44E-06

In contrast, ozone layer depletion was dominated by pesticides (mainly fabrication), which contributed to 80% of the total impact generated by the cauliflower system in this category (4.78E-08 kg CFC-11 eq). These results are in line with those reported by Martínez-Blanco et al. (2011) for the same product.

Fertilizer diffusion was the main contributor to photochemical ozone formation (36%) followed by irrigation (27%) and field work (13%). In acidification potential, irrigation reached 48% followed by harvesting with 13%, and field work (tillage, furrow, and transplanting the seedling to the field) with 10% of the contribution. Irrigation was also the main contributor to freshwater eutrophication with 53%. Pesticide production contributed to 19% of the impact on freshwater ecotoxicity. Furthermore, pesticide diffusion was the main contributor to freshwater ecotoxicity (94%).

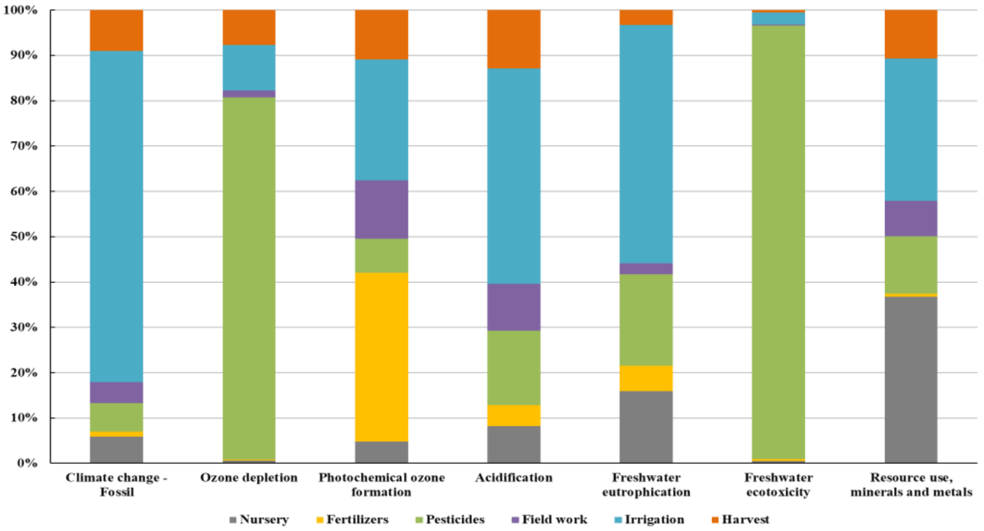

Figure 2. Contribution of different life cycle stages to the characterized impacts in selected categories

The contribution of the nursery stage and the irrigation activities to mineral, fossil fuel, and resource depletion impact categories represented 31% and 37%, respectively. In the nursery phase, this was due to the construction of greenhouse structures, whilst in the irrigation phase this was mainly attributable to electricity consumption and, to a lesser extent, fabrication of the irrigation system.

4. Conclusions

- The life cycle carbon footprint of 1 kg of cauliflower has been estimated at 91.2 gCO_2 eq.

- Most of this carbon footprint (74%) was caused by the electricity consumed for irrigation, an activity that also dominated environmental damage in other categories such as acidification and freshwater eutrophication.

- The fabrication of pesticides was responsible for most (80%) of the damage in the category of ozone layer depletion, whilst their diffusion into the air, water and soil generated most (94%) of the damage in freshwater ecotoxicity.

- Recommendations for environmental improvement should focus on two areas related to electricity use: firstly, the transition to a more renewable mix; and secondly, improved water management which would reduce water requirements and energy supplies.

- Organic farming could be established to improve the environmental impacts associated with pesticides. In general, agrochemicals used in organic farms are less hazardous than those used in conventional systems. Another method could be the use of biological alternatives, for instance, pheromones are used in pest control. In general, the pheromones from specific species can help to control some insects and have less toxicity in comparison with conventional pesticides.

Acknowledgments

This research was funded by the Fondo Europeo de Desarrollo Regional/Ministerio de Ciencia e Innovación-Agencia Estatal de Investigación (FEDER/MICINN-AEI), project RTI2018-099139-B-C21 (Karp0-LIFE). Laura Rasines acknowledges financial support from the Spanish Ministerio de Ciencia e Innovación through the “Ayudas para contratos predoctorales para la formación de doctores 2019” Program [PRE2019-090573].

References

Clune, S., 2019. Calculating GHG impacts of meals and menus using streamlined LCA data, Environmental Nutrition. Elsevier Inc.

European Committee for Standardization, 2006. Environmental management. Life cycle assessment. Principles and framework. (ISO 14040:2006). Bruxelles.

FAOSTAT, 2019. http://www.fao.org/faostat/en/#data/QC/visualize (accessed 3.22.21).

FEPEX, n.d. Exportación/Importación Española de Frutas y Hortalizas - Datos del sector - FEPEX. URL https://www.fepex.es/datos-del-sector/exportacion-importacion-española-frutas-hortalizas (accessed 4.11.21).

Hardy, L., Garrido, A., 2010. Análisis y evaluación de las relaciones entre el agua y la energía en España.

IPCC, 2019. N2O Emissions From Managed Soils, and CO2 Emissions From Lime and Urea Application. 2019 Refinement to 2006 IPCC Guidel. Natl. Greenh. Gas Invent. 1–48.

Maraseni, T.N., Mushtaq, S., Reardon-Smith, K., 2012. Integrated analysis for a carbon- and water-constrained future: An assessment of drip irrigation in a lettuce production system in eastern Australia. J. Environ. Manage. **111**, 220–226.

Martin-Gorriz, B., Gallego-Elvira, B., Martínez-Alvarez, V., Maestre-Valero, J.F., 2020. Life cycle assessment of fruit and vegetable production in the Region of Murcia (south-east Spain) and evaluation of impact mitigation practices. J. Clean. Prod. 265, 121656.

Martínez-Blanco, J., Antón, A., Rieradevall, J., Castellari, M., Muñoz, P., 2011. Comparing nutritional value and yield as functional units in the environmental assessment of horticultural production with organic or mineral fertilization : the case of Mediterranean cauliflower production. Int. J. Life Cycle Assess. **16**, 12–26.

Ministerio de Agricultura Pesca y Alimentación, n.d. Registro de Productos Fitosanitarios. https://www.mapa.gob.es/es/agricultura/temas/sanidad-vegetal/productos-itosanitarios/registro/productos/conregnom.asp (accessed 3.22.21).

Perrin, A., Basset-Mens, C., Gabrielle, B., 2014. Life cycle assessment of vegetable products: A review focusing on cropping systems diversity and the estimation of field emissions. Int. J. Life Cycle Assess. **19**, 1247–1263.

Persiani, A., Diacono, M., Monteforte, A., Montemurro, F., 2019. Agronomic performance, energy analysis, and carbon balance comparing different fertilization strategies in horticulture under Mediterranean conditions. Environ. Sci. Pollut. Res. 26, 19250–19260.

Soria Alfosno, A., Pato Folgoso, A., Rodríguez, L.F.C., Noguera García, M., Vicente Consea, F.E., 2006. Fertirrigación en la zona vulnerable del campo de cartagena 1–40.

Zampori, L, Pant, R., 2019. Suggestions for updating the Product Environmental Footprint (PEF) method.