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The environmental impact of fresh tomatoes consumed in cities: A comparative LCA of long-distance transportation and local production

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ABSTRACT

Eight scenarios of fresh tomato supply to urban citizens were analysed using a Life Cycle Analysis (LCA) approach. Two of the scenarios corresponded to unheated greenhouses and a long distance transportation to the final consumer; four scenarios corresponded to zero-miles agriculture in a rural environment, including heated greenhouses, unheated greenhouses and open-field production; another two scenarios corresponded to Urban Agriculture (UA). The objective was to compare the environmental impacts of the production and transportation of tomatoes to the final consumer. Zero-miles production in heated greenhouses had the highest environmental impact (e.g. the Global Warming Potential GWP was 0.33 kg CO_2 eq per kg of tomato), to such an extent that production in unheated greenhouses far away was comparatively better (GWP was 0.21 kg CO_2 eq). Conversely, zero-miles production in the open-field was, environmentally, the best option with a GWP of 0.12 kg CO_2 eq. Interestingly, the distance travelled by the product was less important than the efficiency of the transport. Other important environmental burdens were inefficient irrigation, chemical disinfection of the soil and the technological appliances used for micro-agriculture. As a consequence, the best zero-miles agriculture scenario was not the one where tomatoes were grown closest to the consumer's table, but the one that used the most efficient and less contaminating agronomic management and transport strategy. Thus, UA was not environmentally superior to zero-miles agriculture carried out in rural areas; conversely, rural horticulture helps to stabilize the population in regions suffering from depopulation.

1. Introduction

Food production is the main contributor to environmental impacts (Campbell et al., 2017). Thus, as the human population is in continuous growth, there is an increasing concern worldwide to reduce the environmental impacts of agriculture, and increasing consumer awareness of the environmental footprint of foods (Parajuli et al., 2021). Moreover, the population is concentrated in cities, and this tendency is expected to increase in the following years (United Nations, 2019). In this context, new models of agriculture are being developed to provide cities with fresh foods at the lowest environmental impact, and urban agriculture (UA) (Peña and Rovira-Val, 2020) and zero-kilometres agriculture (Zasada, 2011) are emerging as an outstanding option.

UA is considered an alternative to reduce the environmental impacts associated with providing food to cities, mainly due to the reduction of food transportation impacts (Specht et al., 2014). However, the difference between rural agriculture and UA is more complex than simply the location. Urban farming enterprises need to adjust to urban conditions by stepping into appropriate business models (Pölling et al., 2017). Moreover, there is still a lack of technological know-how to provide UA with circular economy strategies, specifically of nutrient recirculation which would be the best strategy to improve the environmental performance of UA (Rufí-Salís et al., 2021), because the reuse of local resources has been very low up to now and is limited to water and composted organic residues at best (Thomaier et al., 2015). Even if UA undeniably provides food for city inhabitants, it is currently more a leisure, educational and therapeutic activity than a professional one (Sakura, 2016).

Zero-kilometres agriculture, also known as zero-miles agriculture or proximity agriculture, refers to the production of food that is consumed less than 100 km from the production area. It corresponds to peri-urban agriculture (Zasada, 2011). Peri-urban farms benefit from the proximity of the city and they exploit the potential of the advantageous urban consumer and avoid many of the disadvantages caused by the city

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environment in UA (Pölling et al., 2016).

In this context, the aim of this paper was to analyse the environmental impact of different agriculture systems to provide a fresh vegetable to urban consumers, including the traditional supply model involving transportation from the main producing centres, and the new models of UA and zero-kilometres supply chains. Tomato was selected as the model fresh vegetable, because it is the most produced vegetable crop worldwide, with 181 million t in 2019 (FAO, 2021). Europe produces more than 6 million t of fresh tomato (data from 2019) and Spain contributes almost 30%, being the leading European country in fresh tomato production, with more than twice the production of the second European producer, the Netherlands (European Commission, 2020). The tomatoes consumed in Europe are produced under two different models which differ in the winter production in greenhouses (Tello, 1997). The first model corresponds to the Mediterranean basin where, due to the mild climatic conditions, the greenhouses do not need heating and lighting, resulting in lower energy consumption and fewer input requirements compared to the second model used in colder regions where heating and lighting are necessary for winter production (Torrellas et al., 2012). In Spain almost 99% of the tomatoes for export are produced in the Mediterranean basin (ICEX, 2021). West Almería is the leading Spanish Mediterranean region in the production of tomatoes during winter; they are mainly exported to Europe (including the United Kingdom) which receives more than 97% of the vegetables exported from Almería (García Torrente et al., 2021).

The objective of this work was to assess the environmental impacts of the production and transportation of fresh tomatoes to the table of a consumer located in a medium-sized European city in a region suffering from depopulation. In order to achieve the objective, we used the Life Cycle Analysis (LCA) approach. LCA is considered the most comprehensive tool for assessing the environmental impact of agricultural production (Goglio et al., 2015). Moreover, LCA has proved to be useful for appraising the differences between the environmental effects of different production systems (Dekamin et al., 2018). Eight scenarios were compared, of which two corresponded to tomatoes produced in unheated and unlighted greenhouses located in Almería (Spain) and transported almost 900 km to the consumer's table; one of them was in a conventional system, and the second in an organic one. Four scenarios corresponded to zero-miles professional agriculture: i) greenhouse production during spring-summer in unheated greenhouses, ii) greenhouse production during late winter-spring in heated greenhouses, iii) open-field summer production in a conventional system, iv) open-field summer production in an organic system. Finally, two scenarios corresponded to leisure UA in organic systems including, respectively, urban allotments and micro-agriculture in elevated beds on balconies. As a whole, the work includes all the different options available to date for the supply of fresh tomatoes to a city. The work provides entrepreneurs and policy makers with useful information about the environmental impact of the different agricultural systems in order to make decision for optimizing value chains in a world that is increasingly urban.

2. Materials and Methods

2.1. The LCA approach

The LCA approach followed the ISO 14044 guidelines (ISO, 2006a). The first step was to define the goal and scope, the second was life cycle inventory (LCI) (ISO, 2006b), the third consisted of the life cycle impact assessment (LCIA) and the last was life cycle interpretation.

2.2. LCA goal and scope definition

The general goal of the LCA was to evaluate the environmental impact of fresh tomato consumption in a medium-sized European city. The scope was to analyse in terms of Global Warming Potential (GWP), Cumulative Energy Demand (CED) (total and excluding biomass) and other environmental impact categories (Abiotic depletion, Ozone layer depletion. Photochemical oxidation, Acidification and Eutrophication), the fresh tomato production and transportation based on a cradle to consumers' gate (farm to fork) assessment. The LCA compared long-distance production, zero-miles rural agriculture and UA. UA was leisure agriculture, whilst long-distance and zero-miles agriculture were professional.

2.3. Selection of the model city

León (Spain) was selected as the model city for this work. It is the capital city of the homonymous province in north-western interior Spain. It has around 203,000 inhabitants (year 2019). According to Köppen–Geiger climate classification (Köppen and Geiger, 1936), the main climate is warm temperate with a precipitation type summer dry and temperature type warm summer. Due to the climatic conditions, it is not economically feasible to produce zero-miles tomatoes during the winter months in unheated greenhouses, and thus during the winter season (December–March) the tomatoes for local consumption must be transported from other regions, whereas in November and March local production in heated greenhouses is possible.

2.4. Description of the functional unit

The functional unit was 1 kg of tomato put on the consumer's table. However, the use of an additional functional unit based on production surface is usually recommended in the LCA of agricultural products (Abeliotis et al., 2013) because it improves the interpretation of the environmental results obtained (van der Werf et al., 2007). Thus, we used as a second functional unit 1 cropped m^2, with the same approach that for 1 kg of product, that is including the transportation of the product to the consumer's table.

2.5. Scenarios for the LCA

Eight scenarios were considered that were grouped into three categories.

2.5.1. Professional long-distance scenarios

In these scenarios, tomatoes are produced in unheated greenhouses located in Almería (Spain), which is the European region with highest tomato production. Almería is located almost 900 km from León. The production season is winter, from September to May.

Scenario 1 is in a conventional system: Professional, Almería, Greenhouse, Conventional system (P_A_G_C).

Scenario 2 is in an organic system: Professional, Almería, Greenhouse, Organic system (P_A_G_O).

2.5.2. Professional zero-miles scenarios in rural areas (zero-miles rural agriculture)

The tomatoes are produced in rural areas, located less than 100 km from León city. Two scenarios correspond to greenhouse production, both in conventional systems, and two correspond to open-field production.

Scenario 3 is in a heated and artificially illuminated greenhouse in a conventional system: Professional, León, Greenhouse, High Technology (P_L_G_Ht). The production season is from March to November, both inclusive. We considered two options regarding the system to heat the greenhouses, the first one with a mix of the available energy sources and the second cogeneration using the residual heat of an electricity power plant powered with biogas. The second is the real situation of the farm used for data registration.

Scenario 4 is in an unheated greenhouse without artificial illumination in a conventional system: Professional, León, Greenhouse, Low Technology (P_L_G_Lt). The production season is from April to October, both inclusive.

Scenario 5 is open-field production in a conventional system: Professional, León, Open-field, Conventional (P_L_OF_C). The production season is from June to October.

Scenario 6 is open-field production in an organic system: Professional, León, Open-field, Organic (P_L_OF_O). The production season is from June to October.

2.5.3. Leisure UA in León city

There are plenty of UA initiatives in the city of León, some of them with private funding and others with public funding, but the same happens as in the rest of Europe: the primary purpose of UA is leisure, educational or occupational therapy and not commercial, and it is conducted exclusively in organic systems.

Scenario 7 is open-field production in urban lots (each unit 72 m^2) that are managed and funded by León City Council with the purpose of occupational therapy and entertainment for retired persons: Leisure, León, Open-field, Organic (L_L_OF_O).

Scenario 8 is micro-agriculture in raised beds with artificial substrate located on balconies. The purpose is leisure, and it is privately funded by the owner: Leisure, León, Micro-Agriculture, Organic (L_L_MA_O). We considered two options, depending on the technology used for irrigation, automatic solar-powered or completely manual irrigation.

2.6. System boundaries

All the systems of fresh tomato production, packaging on the farm and transportation to the consumer's table were covered by the system boundaries (Fig. 1). No post-harvesting physical or chemical treatments were considered because tomatoes are harvested, packaged as explained below and dispatched to the final destination. On the one hand, the structures were considered (Table 1), including the greenhouse structure, the plastic cover and the auxiliary equipment for heating and ventilation of the greenhouse in scenarios 1 to 4 and the raised bed in scenario 8 (L_L_MA_O). The irrigation system and the support system for plants that are needed in all the scenarios were also included (Table 1), as well as the substrate where necessary (Table 1). On the other hand, the agricultural activities, packaging and transportation result in pollutant emissions to the soil, water and air, and they have been considered (Table 2 and Appendix A Tables A1 and A2). The following steps were included in the agricultural activities: soil occupation, production and transplant of seedlings, preparation of soil or substrate and soil disinfection where applicable, weed control where applicable, fertilization, irrigation and phytosanitary control. For fertilizers and phytosanitary products, the processes incorporated the extraction of raw materials, the manufacturing process, electricity consumption, fuel production and transportation to the farm gate. The application process of fertilizers and phytosanitary products was also included (Table 2). The harvesting, packaging and transport of tomatoes to the consumer's table were considered. In scenarios 1 to 6 the tomatoes are transported to a local supermarket in León city centre, which consumers access on foot and thus no burdens were assigned to the buying process. Conversely, in scenario 7 (L_L_OF_O) the amateur farmer's trips in their own car to pick up the tomatoes and to transport them home were considered; in scenario 8 (L_L_MA_O), located at the consumer's home, no transport was needed.

2.7. LCI data collection and system model

Table 1 shows the inventory of inputs corresponding to the structures, auxiliary equipment, irrigation system, support system for plants and substrate where needed, and Table 2 and Appendix A (Tables A1 and A2) show the inventory of inputs for the agricultural production, packaging and transportation. Tomato variety was a round tomato genotype, for all the scenarios except for scenario 8 in which it was a cherry tomato genotype (black cherry). The expected yield is also included in Table 2. The lifespan for the elements that last more than one season is shown in Table 3. Data for the LCI were obtained from commercial farms, except for scenario 8 for which they were obtained from a research experiment managed by the authors that lasted from 2017 to 2021. Data from scenarios 1 and 2 were provided by the "Estación Experimental Cajamar", a private R&D&i institution located at Paraje las Palmerillas, El Ejido, Almería (Spain). The data are average values of 5 years (2016–2020) and they represent the most common agronomic practices in the region named West Almería. The data from scenarios 3 and 4 were gathered during the years 2019–2021 from the greenhouses belonging to a private company located at Vidanes (León). The data from scenario 5 were obtained from a farmer located in the town of Fresno de la Vega (León) during the years 2018–2020 and the data from scenario 6 (average data for 2018–2021) come from the field-record book of an organic farmer located at Matalobos del Páramo (León). The data from scenario 7 were provided by the person in charge of the leisure urban allotments belonging to León City Council. The inventory data for the LCA were taken from the Ecoinvent database v. 3.6 (Wernet et al., 2016) using the system model Allocation at the Point of Substitution (APOS) and unit processes which are fully transparent and include uncertainty data. The APOS system model follows the attributional approach in which burdens are attributed proportionally to specific processes. The phytosanitary products were taken from the

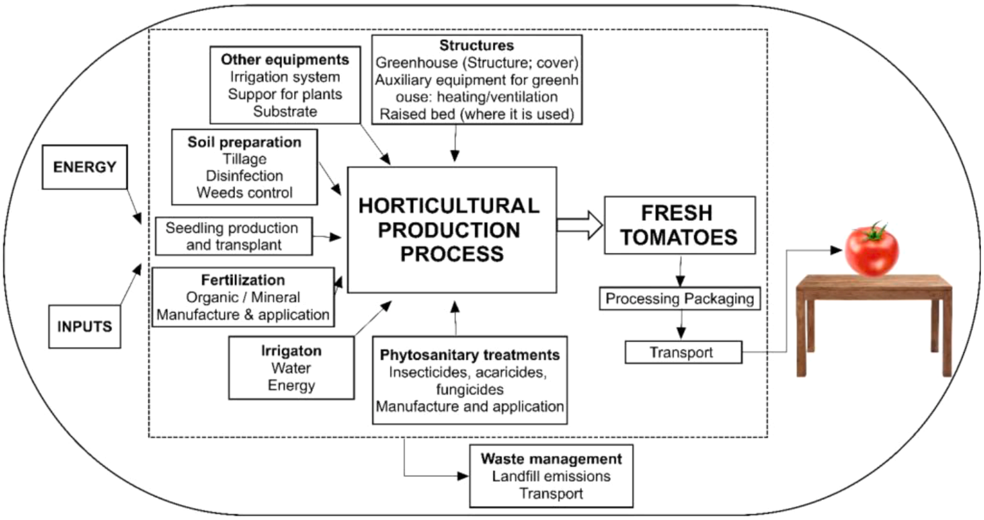

Fig. 1. System boundaries for the LCA corresponding to the fresh tomato value chain.

Table 1
LCI: inventory of structures (greenhouse and raised bed) with auxiliary equipment, irrigation system, support system for plants and substrate, where needed, for the production of fresh tomatoes in the main scenarios considered.

Element			Scenario for fresh tomato production[1]							
			P_A_G_C	P_A_G_O	P_L_G_Ht	P_L_G_Lt	P_L_OF_C	P_L_OF_O	L_L_OF_O	L_L_MA_O
Structures	Greenhouse	Description	Plastic tunnel	Plastic tunnel	Greenhouse plastic walls and roofs	Greenhouse plastic walls and roofs	-	-	-	-
		Structure	Galvanized steel	Galvanized steel	Galvanized steel,	Galvanized steel,	-	-	-	-
		Cover	EVA (ethylene vinyl acetate) copolymer sheet	EVA (ethylene vinyl acetate) copolymer sheet	Double EVA (ethylene vinyl acetate) copolymer sheet	Double EVA (ethylene vinyl acetate) copolymer sheet	-	-	-	-
	Auxiliary equipment for greenhouse	Greenhouse heating system	No heating	No heating	Two alternatives were considered, conventional power and cogeneration	No heating	-	-	-	-
		Greenhouse ventilation system	Passive (manually opened)	Passive (manually opened)	Passive (manually opened)	Passive (manually opened)	-	-	-	-
	Raised bed	-	-	-	-	-	-	-	Raised bed made of treated wood (0.017 m^3 per each m^{-2} of raised bed)	
Irrigation system			Fertigation system made of a network of polyethylene pipes including pumps, metal parts and drippers	Fertigation system made of a network of polyethylene pipes including pumps, metal parts and drippers	Fertigation system made of a network of polyethylene pipes including pumps, metal parts and drippers	Fertigation system made of a network of polyethylene pipes including pumps, metal parts and drippers	Fertigation system made of a network of polyethylene pipes including pumps, metal parts and drippers	Fertigation system made of a network of polyethylene pipes including pumps, metal parts and drippers	Hose for manual irrigation	Two alternatives were considered, manual irrigation and solar powered automatic irrigation including solar panel, micro-pump, polyethylene microtubes and drippers
Support system for plants			Agricultural raffia made of polypropylene 4.7 g m^{-2}	Agricultural raffia made of polypropylene 4.2 g m^{-2}	Agricultural raffia made of polypropylene 4.5 g m^{-2}	Agricultural raffia made of polypropylene 4.5 g m^{-2}	Sawnwood, softwood, air dried, planed 4.41 l m^{-2}	Sawnwood, softwood, air dried, planed 4.41 l m^{-2}	Sawnwood, softwood, air dried, planed 2.59 l m^{-2}	Made of steel covered with PVC 400 g steel m^{-2} and 100 g PVC m^{-2}
Substrate			Sand at a rate of 155 kg m^{-2}	Sand at a rate of 155 kg m^{-2}	Perlite at a rate of 1,89 kg m^{-2}	-	-	-	-	Coconut husk (60%) + compost from biobased materials (30%) + expanded pertlite (10%)

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[1] P_A_G_C: Professional, Almería, Greenhouse, Conventional system; P_A_G_O: Professional, Almeria, Greenhouse, Organic system; P_L_G_Ht: Professional, León, Greenhouse, High Technology; P_L_G_Lt: Professional, León, Greenhouse, Low Technology; P_L_OF_C: Professional, León, Open-field, Conventional; P_L_OF_O: Professional, León, Open-field, Organic; L_L_OF_O: Leisure, León, Open-field, Organic; L_L_MA_O: Leisure, León, Micro-Agriculture, Organic

Table 2
LCI: inventory of inputs for agricultural activities, packaging and transportation to the consumer's table corresponding to the fresh tomato value chain in the main scenarios considered.

Activity		Scenario for fresh tomato production[1]							
		P_A_G_C	P_A_G_O	P_L_G_Ht	P_L_G_Lt	P_L_OF_C	P_L_OF_O	L_L_OF_O	L_L_MA_O
Agronomic practices		Sand mulch	Sand mulch	Hydroponic on perlite	On soil	On soil	On soil	On soil	On raised bed with substratum
Seedlings production and transplant by hand		In unheated greenhouse (1.33 plants m^{-2})	In unheated greenhouse (1.6 plants m^{-2})	In unheated greenhouse (1.8 plants m^{-2})	In unheated greenhouse (1.8 plants m^{-2})	In unheated greenhouse (1.5 plants m^{-2})	In unheated greenhouse (3 plants m^{-2})	In unheated greenhouse (5.5 plants m^{-2})	In heated greenhouse (5.5 plants m^{-2})
Soil preparation		Ploughing, with small plough	Ploughing, with small plough	Grown in substrate (perlite) 1.89 kg m^{2}	Tillage, cultivating, chiselling	Ploughing, with 4 soc plough	Tillage, chiselling	By hand	By hand
		Harrowing with small tractor	Harrowing with small tractor		Harrowing with small tractor	Harrowing, with small tractor	Harrowing, with small tractor (crossed)		
		Harrowing with rototiller			Harrowing with rototiller	Soil preparation, with rotary tiller			
Soil disinfection		Solarization (no environmental burdens assigned) + metam-Na 30 g m^{-2} (yearly)	Bio-solarization (no environmental burdens assigned to solarization, whilst the organic matter addition is included in organic fertilization)	Not necessary	Not necessary	Not necessary	Not necessary	Not necessary	Not necessary
Weeds control		Pre-transplant herbicide applied with knapsack sprayer Pendimethalin 99 mg m^{-2} +Triazinylsulfonylurea herbicides, 39 mg m^{-2}	By hand	Not applicable because it is grown in substrate (perlite)	Polytehylene mulch 400 gauge in the line to avoid weeds growth (90 mg m^{-2})	Mechanical control with harrow (one pass)	Paper mulch in the line to avoid weeds growth (72 g m^{-2})	By hand	By hand
		Mechanical control				By hand			
Organic fertilization		Manure from cattle mechanically distributed (3 kg m^{-2})	Manure from cattle mechanically distributed (1.8 kg m^{-2})	Aminoacids at a dose of 75 mg m^{-2}	Compost, from green waste, biowaste, sludge, manure and slurry (600 g m^{-2})	Humic and Fulvic Acids by fertirrigation (equivalent to 6.5 ml m^{-2})	Green residues and straw shredded and mechanically broadcasted (1.2 kg m^{-2})	Manure, from cattle, stocked, broadcasted by hand (3.0 kg m^{-2} from cow and 1.5 kg m^{-2} from sheep)	Commercial solid product based on guano (260 g m^{-2})
			Green residues and straw, shredded and mechanically buried (1.5 kg m^{-2})				Compost, of biowaste and green waste mechanically broadcasted (1.5 kg m^{-2})	Green manure (vetch *Vicia sativa* 66% + *Avena sativa* 34%) buried by hand	Commercial liquid product based in molasses from sugar beet: 480 ml m^{-2} (620 g m^{-2}) in total. It is provided weekly
			Poultry manure, dried pelleted mechanically broadcasted (0.274 kg m^{-2})				Green manure (vetch) mechanically buried	Compost, of green waste made *in situ* broadcasted by hand (2.1 kg m^{-2})	
Mineral fertilization		N: 43.4 g m^{-2}	K (in authorised form for organic agriculture): 18.3 g m^{-2}	N: 77 g m^{-2}	N: 34 g m^{-2}	N: 30 g m^{-2}	-	-	-
		P: 8.5 g m^{-2}		P: 78 g m^{-2}	P: 14 g m^{-2}	P: 10 g m^{-2}	-	-	-
		K: 59.5 g m^{-2}		K: 346 g m^{-2}	K: 38 g m^{-2}	K: 40 g m^{-2}	-	-	-
		Ca: 32.0 g m^{-2}		Ca: 134 g m^{-2}	Ca: 27 g m^{-2}	Ca: 10.0 g m^{-2}	-	-	-
		Mg: 15 g m^{-2}		Mg: 69 g m^{-2}	Mg: 70 g m^{-2}	Mg: 5 g m^{-2}	-	-	-
		Microelements		Microelements	Microelements	Microelements	-		-
Irrigation		Drip irrigation 600 l m^{-2}	Drip irrigation 450 l m^{-2}	Drip irrigation 600 l m^{-2}	Drip irrigation 600 l m^{-2}	Drip irrigation 950 l m^{-2}	Drip irrigation 1,100 l m^{-2}	Manually with a hose using tap water 750 l m^{-2}	750 l m^{-2} of which 20 % is tap water and 80% is collected rain water
Phytosanitary treatments	No. of applications[2]	11 applications	12 applications	9 applications	8 applications + several in spots against mites[3]	5 applications	10 applications	10 applications	6 applications
	Distribution								

(continued on next page)

Table 2 (*continued*)

Activity	Scenario for fresh tomato production[1]							
	P_A_G_C	P_A_G_O	P_L_G_Ht	P_L_G_Lt	P_L_OF_C	P_L_OF_O	L_L_OF_O	L_L_MA_O
	Fixed distribution system operated by a central pump (7 treatments) and treatments with knapsack sprayer (4 treatments)	With knapsack sprayer (11 treatmens)	Fixed distribution system operated by a central pump (9 treatments)	Fixed distribution system operated by a central pump (8 treatments) and with knapsack sprayer against mites in spots, (equivalent to 1.2 surface units)	Distribution with atomiser on demand (8 treatments in average)	With knapsack sprayer (8 treatments)	With knapsack sprayer (8 treatmens)	With small handheld sprayer 1 litre in capacity
Harvesting (by hand) and packaging in the farm[4]	In carton board boxes 10 kg of tomato in capacity, palletised in wood pallets 800 kg in capacity, tied up with polyporpylene straps					In carton board boxes 10 kg of tomato in capacity,	Not necessary, recycled boxes	Not necessary
Transport	Lorry 32 t EURO6 * 881 km + lorry 3.5-7.5 t EURO6 * 2 km		Lorry 3.5-7.5 t EURO6 * 60 km + lorry 3.5-7.5 t EURO6 * 2 km		60% is transported in lorry 3.5-7.5 t and 40% in light commercial vehicle Distance is 32 km	Light commercial vehicle every two weeks. Distance is 40 km	4 trips by particular car to carry the harvest (the trips are shared by other 2 products[5]). Average distance 10 km each round trip	Not necessary
Expected yield (kg m^{-2})	16	14	16	16	15	12	11	11

[1] P_A_G_C: Professional, Almería, Greenhouse, Conventional system; P_A_G_O: Professional, Almeria, Greenhouse, Organic system; P_L_G_Ht: Professional, León, Greenhouse, High Technology; P_L_G_Lt: Professional, León, Greenhouse, Low Technology; P_L_OF_C: Professional, León, Open-field, Conventional; P_L_OF_O: Professional, León, Open-field, Organic; L_L_OF_O: Leisure, León, Open-field, Organic; L_L_MA_O: Leisure, León, Micro-Agriculture, Organic

[2] The details about the products and doses delivered in each application are in Appendix A – Table S1

[3] Equivalent to 1,2 times in all the surface

[4] The details about the products used for packaging are in Appendix A – Table A2

[5] The environmental burdens were also shared with the other products

Table 3
Lifespan of the structures (greenhouse and raised bed), auxiliary equipment, irrigation system, support system for plants and substrate, where needed.

Element		Scenarios in which it is used[1]	Lifespan value
Structure	Greenhouse structure and auxiliary equipment	All the scenarios with a greenhouse (heating only P_L_G_HT)	25 years
	Greenhouse cover (EVA)	All the scenarios with a greenhouse	4 years
	Raised bed made of treated wood	L_L_MA_O	10 years
Irrigation system	Drip irrigation system	All the scenarios with professional irrigation system	Plastic materials 5 years and metal parts 10 years
	Solar panel for solar powered irrigation	L_L_MA_O	25 years
Support system por plants	Made of wood	P_L_OF_C, P_L_OF_O, L_L_OF_O	3 years (P_L_OF_C, P_L_OF_O) and 8 years (L_L_OF_O)
	Made of steel covered with PVC	L_L_MA_O	10 years
Substrates	Substrate (Coconut husk 60% + compost 30% + expanded perlite 10%)	L_L_MA_O	8 years
	Sand	P_A_G_C and P_A_G_O	15 years
	Perlite	P_L_G_Ht	3 years
Transport	Euro pallet made of wood	The scenarios in which tomato is transported (all except for UA)	3 years

[1] P_A_G_C: Professional, Almería, Greenhouse, Conventional system; P_A_G_O: Professional, Almeria, Greenhouse, Organic system; P_L_G_Ht: Professional, León, Greenhouse, High Technology; P_L_G_Lt: Professional, León, Greenhouse, Low Technology; P_L_OF_C: Professional, León, Open-field, Conventional; P_L_OF_O: Professional, León, Open-field, Organic; L_L_OF_O: Leisure, León, Open-field, Organic; L_L_MA_O: Leisure, León, Micro-Agriculture, Organic

Agri-footprint database, which provides more accurate information about specific product families (Durlinger et al., 2014). In the LCI calculation, the emissions from field activities were implemented as indicated by Nemecek et al. (2014): Ammonia (NH3) from mineral fertilizers application and manure spreading, and Nitrogen oxides (NO_x, NO, NO_2) as described inEEA (2016); Nitrous oxide (N_2O), and CO_2 biogenic and fossil as described in Eggleston et al. (2006); NO_3 leaching as in the SQCB-NO_3 model (Faist Emmenegger et al., 2009); PO_4 leaching to water as in the SALCA-P model (Prasuhn, 2006). SimaPro v.9.1 software (PRé Sustainability, 2020) was used to define the processes as from the information in Tables 1 and 2, and Tables A1 and A2 (from Appendix A); following, the product stages were defined for each of the 8 scenarios, prior to LCIA analysis.

2.8. LCIA

The LCIA was performed also using SimaPro v.9.1, excluding, in all cases, infrastructure processes and long-term emissions. The method used has been CML-IA, that was proposed by Centre of Environmental Science of Leiden University (CML-Department of Industrial Ecology, 2016); it was defined for the midpoint approach, using the baseline version. CML-IA is the globally oriented LCIA methodology that has been most widely used in the scientific literature for the LCA applied in production of fresh tomato (Torres Pineda et al., 2021), and for this reason it has been selected for this work; moreover, from the 11 indicators included in CML-IA methodology, the six more frequently reported in the mentioned work (Torres Pineda et al., 2021) were selected: abiotic depletion, GWP with a lifetime of 100 years, ozone layer depletion, phytochemical oxidation, acidification and eutrophication. Moreover, the CED was also calculated based on the lower heating values of fuels, which were developed for Ecoinvent version 1.01 and subsequently expanded (Frischknecht et al., 2007; Weidema et al., 2013).

3. Results

Table 4 and Appendix B Fig. B1 show the LCIA of the value chain for the production, packaging and transportation of fresh tomatoes to the consumer's table for the eight scenarios, plus two others derived respectively from P_L_G_Ht and L_L_MA_O: P_L_G_Ht_cogen, in which the energy needed for heating is produced by a cogeneration plant, and no burdens were assigned to the functioning of the heating system; and L_L_MA_O_irr._man, in which the solar-powered automatized micro-irrigation system was replaced by manual irrigation. The data shown consist of six baseline categories from the CML-IA method plus the CED for two different assumptions, the first considering all the energy categories and the second excluding the categories based on biomass, that penalizes the organic horticulture scenarios because they use a large amount of biomass for organic fertilization. The impacts were allocated to 1 m^2 of horticultural soil and to 1 kg of tomatoes, the latter being used in the Discussion (section 4).

The contribution to the midpoint impact categories of the inventory elements included in the production, packaging and transportation processes depends on the category analysed and can be observed in Fig. 2 allocated to 1 kg of tomato and in Appendix B Fig. B2 allocated to 1 m^2 of greenhouse.

3.1. Total environmental impact of different scenarios for several impact categories

A relevant result was that the highest environmental impact for most of the impact categories analysed was produced by the scenario of zero-miles agriculture in a heated greenhouse in which the energy for heating is produced by conventional sources (P_L_G_Ht_heated) (Table 4 and Appendix B Fig. B1). This was due to the environmental burden of the climate system, which was included in the 'greenhouse + climate' section in the contribution analysis (Fig. 2). When the heating system power was replaced by that from a cogeneration plant, the total impact was reduced by between 30% and 60% depending on the impact category (Table 4). It is also noteworthy that for the category abiotic depletion, the scenarios with greenhouses produced a much higher environmental impact than the open-field scenarios (more than 40 times higher on average) (Table 4 and Appendix B Fig. B1) due to the high burdens of the greenhouse and auxiliary equipment, as can be observed in the contribution analysis (Fig. 2). Moreover, the scenarios in organic systems showed unexpectedly high environmental burdens, specifically for some categories such as GWP, ozone layer depletion, eutrophication and especially for CED when all the energy categories were included. This is because the organic fertilizer produced a high environmental impact (Fig. 2); moreover, the organic substratum used in the scenario of micro-agriculture in raised beds (L_L_MA_O) accounted for the highest environmental burden in the category eutrophication (Fig. 2), making the total impact of this scenario high (Table 4 and Appendix B Fig. B1). In this work, the burdens of the organic fertilizers or organic substratum have been allocated to crop production, but as the biomass used as raw material is commonly residues, some authors allocate the environmental burdens to the processes that generate the residues (see Discussion in section 4).

The scenarios in greenhouses produced a higher average yield than those in the open-field (Table 2). As a consequence, some open-field scenarios that performed better than the greenhouse ones when the LCIA was allocated to 1 m^2 showed the opposite results when the LCIA was allocated to 1 kg of tomatoes (Table 4 and Appendix B Fig. B1).

Appendix B Fig. B3 shows, for each month of the year, the possibility of supplying fresh tomatoes to the city of León, using a colour scale to

Table 4
LCIA: comparison between environmental impacts per cropped m^2 and per kg of tomatoes produced, packaged and transported to the consumer's table in the main scenarios considered. CML-IA methodology baseline version..

Impact category	Unit	Allocation	Scenario for fresh tomato production[1]								
			P_A_G_C	P_A_G_O	P_L_G_Ht heated	P_L_G_Ht cogen	P_L_G_Lt	P_L_OF_C	P_L_OF_O	L_L_OF_O	L_L_MA_O irr. autom.	L_L_MA_O irr. man.
Abiotic depletion	kg Sb eq	surface (m^2)	8.03E-04	6.79E-04	1.46E-03	7.52E-04	6.97E-04	3.19E-05	2.39E-05	7.15E-07	1.08E-05	1.08E-05
		kg of product	5.02E-05	4.85E-05	9.15E-05	4.70E-05	4.65E-05	2.66E-06	2.18E-06	6.50E-08	9.80E-07	9.80E-07
Global warming (GWP100a)	kg CO2 eq	surface (m^2)	3.29E+00	2.49E+00	5.24E+00	3.03E+00	2.79E+00	1.44E+00	2.56E+00	3.13E+00	2.36E+00	1.53E+00
		kg of product	2.06E-01	1.78E-01	3.27E-01	1.90E-01	1.86E-01	1.20E-01	2.32E-01	2.85E-01	2.15E-01	1.39E-01
Ozone layer depletion (ODP)	kg CFC-11 eq	surface (m^2)	3.70E-07	2.73E-07	3.44E-07	2.22E-07	2.14E-07	1.45E-07	3.11E-07	3.05E-07	1.23E-07	1.21E-07
		kg of product	2.31E-08	1.95E-08	2.15E-08	1.39E-08	1.43E-08	1.21E-08	2.83E-08	2.77E-08	1.12E-08	1.10E-08
Photochemical oxidation	kg C2H4 eq	surface (m^2)	8.09E-04	6.44E-04	1.63E-03	7.40E-04	7.59E-04	3.82E-04	5.93E-04	2.58E-04	8.88E-04	3.72E-04
		kg of product	5.05E-05	4.60E-05	1.02E-04	4.62E-05	5.06E-05	3.18E-05	5.39E-05	2.35E-05	8.07E-05	3.39E-05
Acidification	kg SO2 eq	surface (m^2)	1.44E-02	1.14E-02	2.70E-02	1.53E-02	1.20E-02	6.37E-03	1.01E-02	7.93E-03	1.59E-02	9.67E-03
		kg of product	8.97E-04	8.15E-04	1.69E-03	9.55E-04	8.02E-04	5.31E-04	9.20E-04	7.21E-04	1.44E-03	8.79E-04
Eutrophication	kg PO43- eq	surface (m^2)	3.47E-03	2.38E-03	5.37E-03	3.72E-03	2.81E-03	1.51E-03	3.74E-03	3.74E-03	5.55E-03	5.31E-03
		kg of product	2.17E-04	1.70E-04	3.36E-04	2.32E-04	1.87E-04	1.26E-04	3.40E-04	3.40E-04	5.05E-04	4.83E-04
Energy demand (total)	MJ	surface (m^2)	5.45E+01	6.86E+01	7.93E+01	4.65E+01	7.30E+01	5.52E+01	1.26E+02	1.50E+02	7.27E+01	4.88E+01
		kg of product	3.41E+00	4.90E+00	4.95E+00	2.90E+00	4.87E+00	4.60E+00	1.15E+01	1.36E+01	6.61E+00	4.44E+00
Energy demand (excluding biomass)	MJ	surface (m^2)	4.76E+01	3.81E+01	7.08E+01	3.86E+01	4.20E+01	1.90E+01	3.47E+01	3.05E+01	4.08E+01	1.69E+01
		kg of product	2.97E+00	2.72E+00	4.43E+00	2.42E+00	2.80E+00	1.58E+00	3.16E+00	2.77E+00	3.71E+00	1.54E+00

[1] P_A_G_C: Professional, Almería, Greenhouse, Conventional system; P_A_G_O: Professional, Almeria, Greenhouse, Organic system; P_L_G_Ht: Professional, León, Greenhouse, High Technology; P_L_G_Lt: Professional, León, Greenhouse, Low Technology; P_L_OF_C: Professional, León, Open-field, Conventional; P_L_OF_O: Professional, León, Open-field, Organic; L_L_OF_O: Leisure, León, Open-field, Organic; L_L_MA_O: Leisure, León, Micro-Agriculture, Organic

show the environmental impact of each scenario (impact values taken from LCIA Table 4).

3.2. *Contribution of LCI elements to environmental impact (Fig. 2)*

The greenhouse and climate system (Table 1) accounted for the highest environmental impacts in several scenarios, for all the impact categories; interestingly, not only in the heated greenhouses powered with conventional energy sources but also in other unheated greenhouses (Fig. 2).

Transportation accounted for the highest environmental impacts on ozone layer depletion in most of the scenarios except for P_L_G_Ht because the impact of the heating system was greater, P_L_OF_O because the impact of the organic fertilizer was greater and the micro-agriculture scenarios in which there was no transportation. Transportation was the highest environmental burden for the indicator GWP in the scenarios with longer transport distances, P_A_G_C and P_A_G_O, and for the indicator CED in the scenario P_A_G_C (Fig. 2). However, intriguingly, in other scenarios with shorter distances but with inefficient transport systems using light commercial vehicles (P_L_OF_O) or private cars (L_L_OF_O), transportation accounted for the highest environmental burdens. Mineral fertilization produced the highest impacts for several scenarios in conventional systems for GWP, eutrophication and acidification (Fig. 2).

4. Discussion

In this work we have used the LCA approach to compare the environmental sustainability of zero-miles agriculture, UA and supply chains in which the product travels a long distance, from Almería (Spain) where there is a very high level of agronomic specialization for vegetable production. This work is necessary because there is an increasing interest worldwide about supply chains in which foods travel a short distance (Loiseau et al., 2020; Palau-Saumell et al., 2021), and a reliable comparison of the environmental burdens associated with the different supply chains is needed. In this work, the inventory and system limits were based on homogeneous criteria for all the scenarios, that is essential in order to make a reliable comparison using the LCA methodology. The existing literature about LCA for fresh tomato production is very heterogeneous in the detail of the inventory and scope of the studies (Torres Pineda et al., 2021) and thus a reliable comparison based on literature metadata is not possible. In this work, we have gathered data from commercial farms over several years, to obtain a sound LCI based on normal values and discarding atypical ones.

The environmental impacts of fresh tomato production and transportation have been estimated using the LCA approach in several works in the scientific literature. The impact values vary depending on the production system, the agronomic practices, the LCI and the system limits considered. For the most popular indicator, GWP, and using 1 kg of fresh tomato as the functional unit, the values obtained in our work ranged from 0.120 kg CO_2 eq for zero-miles agriculture in the open-field, on soil and in a conventional system (P_L_OF_C) to 0.327 kg CO_2 eq for zero-miles agriculture in a hydroponic system in heated greenhouses using conventional power sources. Sanyé-Mengual et al. (2015) calculated the GWP of UA in rooftop gardens for fruit and vegetable production using soil as a substrate; the values obtained ranged from 0.068 to 0.194 kg CO_2 eq, the lowest values corresponding to tomatoes. In contrast, Maaoui et al. (2020) estimated the GWP of 1 kg of fresh tomato produced in a soilless geothermal greenhouse in Tunisia as 0.954 kg CO_2 eq, and Parajuli et al. (2021) obtained an average value of 0.740 kg CO_2 eq per kg of fresh tomato in a large-scale assessment in the United States. Torrellas et al. (2012), for the same production system of fresh tomatoes as ours, consisting of multi-tunnel greenhouses located in West Almería (Spain), obtained a GWP of 0.250 kg CO_2 eq per kg of tomato, that is 20% higher than the value obtained in our work (0.206 kg CO_2 eq). The differences are mainly due to optimization of the technology as a

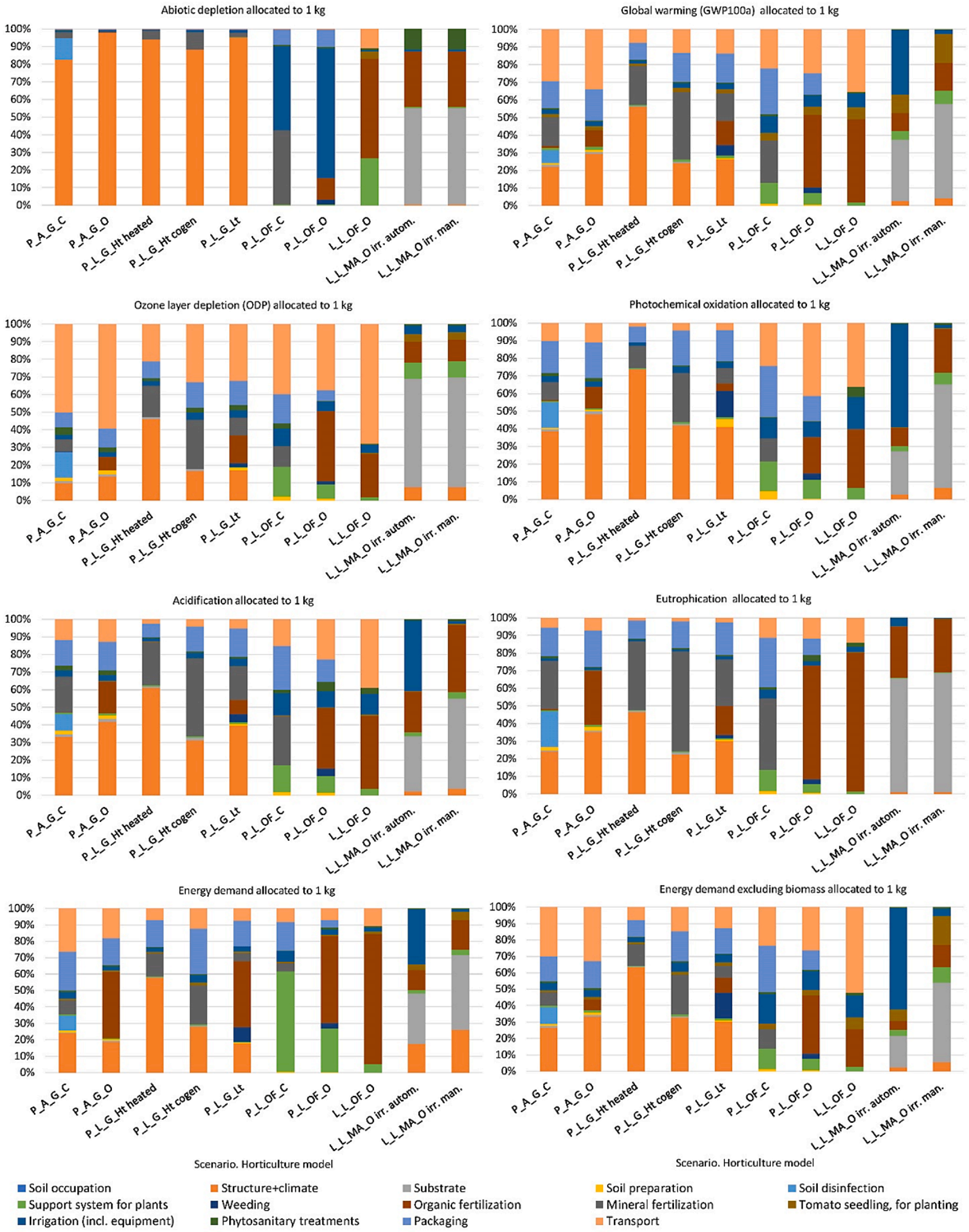

Fig. 2. Contribution to the midpoint impact categories of the inventory elements included in the value chain for fresh tomatoes, allocated to 1 kg of tomatoes put on the consumer's table.

consequence of the intense R&D&i work carried out in Almería during the time elapsed between the two works. Technological improvements have optimized mineral fertilization and the use of phytosanitary products, resulting in a significant reduction of the doses applied with a negligible reduction in the final yield.

4.1. Climatic constraints hamper the expansion of zero-miles agriculture

In many European regions, including the interior central and northern Spain, climatic constraints prevent the local production of tomatoes in the open-field for several months of the year. During this period, the alternatives for availability of fresh tomatoes are production in heated greenhouses, long-term post-harvest conservation or purchase from productive regions. In the case of León, local open-field production is from June to October, whilst in unheated greenhouses the production lasts from April to October, and in heated ones from March to November. Thus, the unavailability of locally produced tomatoes during winter months hampers the shift to local/regional supply that it is considered as a key aspect in reducing the environmental impacts of agriculture (Marklein et al., 2020). During the months of March and November in León city, there coexist the possibility of buying tomatoes from Almería (P_A_G_C or P_A_G_O) and from zero-miles production in heated greenhouses (P_L_G_Ht). Our work has demonstrated that purchasing fresh tomatoes from unheated Almerían greenhouses is, regardless of whether a conventional or organic system is used, a better option environmentally than zero-miles production in heated greenhouses using conventional power sources, for all the indicators except for ozone layer depletion. This result is in agreement with those of other authors who also demonstrated that the production of tomatoes in heated greenhouses in high-yield systems has higher environmental burdens than unheated options (Maaoui et al., 2020), mostly in terms of climate change (Goldstein et al., 2016) and energy demand per kilogram of tomatoes (Pérez Neira et al., 2018). Nonetheless, when the heating system was powered from the residual heat of a cogeneration plant, and for the part of the year when climatic conditions allow production in unheated greenhouses, we observed a dramatic improvement of the environmental performance of the zero-miles option, although organic tomatoes from Almería were still environmentally better in terms of GWP, photochemical oxidation and eutrophication.

In summary, in León city, the local production of tomatoes in heated systems is environmentally worse than transportation from a long distance, unless a cogeneration system is used. As a consequence, with the technology used today, there are no environmental reasons for shifting to local/regional production if it is necessary to heat the greenhouses. Our result agree with those results obtained by other authors that indicate that importing tomatoes from southern regions is environmentally better than local production in heated infrastructures in northern regions (Pérez Neira et al., 2018; Webb et al., 2013). Notwithstanding that, as expected, the distance travelled has a marked influence on the environmental burden. If the travel distance is 2,500 km, equivalent to the distance from Almería to the countries in Central Europe, the average increase for the seven impact categories considered in this work would be 34% (ranging from less than 1% to 108%). However, purchasing tomatoes from an Almerían organic system is still better than purchasing tomatoes produced locally in a heated greenhouse (except for ozone layer depletion, that is strongly affected by transportation). (Appendix A Table A3). For a distance of 4,000 km, equivalent to the journey from Almería to Eastern Europe, the average increase was 66% (ranging from less than 1% to 208%), but only two indicators (GWP and CED) improved in the local scenario using heated greenhouses (Appendix A Table A3). This is due to the high weighting of transportation in GWP and CED (Fig. 2). According to some authors, the environmental footprint of transporting vegetables from Almería could even be improved by changing the modal distribution of transport (Coley et al., 2009) because, from Almería, the product is transported mainly by truck, which is less efficient than other transport systems such as shipping (Pérez Neira et al., 2016).

The technological optimization of vegetable production in Almería is so great that in the months when local production in unheated greenhouses is possible, April and May, long-distance tomato production in organic systems (P_A_G_O) continues to be environmentally better, for three (GWP, photochemical oxidation and eutrophication) out of the seven impact categories.

4.2. *Environmental performance of zero-miles scenarios*

Of the zero-miles options analysed, the open-field scenarios were environmentally better than the greenhouse ones, for all the indicators; moreover, all the local open-field scenarios were better than the long-distance ones, that consisted of unheated greenhouses. However, the difference between the environmental burdens of the best zero-miles scenario and the best long-distance scenario was only around 30% (average of the analysed impact categories), lower than expected; the reason is that open-field horticulture produces lower yields and is less efficient than Almería's greenhouses in the use of inputs, specifically water and mineral fertilizers. That confirms the previous observation of Ntinas et al. (2017), e.g. that inefficient irrigation burdens the abiotic depletion indicator for the professional local open-field scenarios (P_L_OF_C, P_L_OF_O).

In many regions worldwide, professional UA is a common activity (Hietala et al., 2021; Pölling et al., 2016). Conversely, in Spain, professional agriculture activity is mostly practised in rural areas, whilst UA is commonly a leisure option, although with other functions such as educational, therapy and providing one's own source of food in the case of impoverished persons (Seguí et al., 2017). Thus, in this work, to assess the environmental performance of zero-miles scenarios, we had to compare leisure UA in organic systems with professional organic or conventional farming in rural areas, because this is the real situation. The zero-miles scenario that performed best varied depending on the impact category but, interestingly, for three indicators it was a leisure UA scenario (abiotic depletion, ozone layer depletion and photochemical oxidation) and for the other three it was a professional scenario in a rural environment (GWP, acidification and eutrophication); for CED, a professional and a leisure scenario produced almost the same lowest impact. Thus, this result seems to confirm that UA could help to reduce the environmental impact of agricultural products (Langemeyer et al., 2021) but, intriguingly, the different UA scenarios produced dramatically different environmental impacts and thus, in order to effectively reduce the impacts, the UA model must be well selected and needs optimization considering environmental issues. For example, the UA allotment scenario (L_L_OF_O) was the best for abiotic depletion and photochemical oxidation but performed badly for ozone layer depletion and GWP. The reason is that transport has an important weighting in those impact categories, and the product is carried home from the allotment by private car during harvesting time; even if the trip is not long, this journey is very inefficient and produces a high environmental burden. Loiseau et al. (2020) also measured a high environmental impact for transportation to the home when the consumer goes to the farm to purchase apples. Otherwise, the option of micro-agriculture on balconies using a raised bed (L_L_MA_O) was the worst scenario for the indicator eutrophication, due to the high impact originating from the organic substrate used for cultivation; for the same reason, it was quite bad for the indicator acidification. Moreover, the technology used for the automatic irrigation of L_L_MA_O penalized GWP, CED, photochemical oxidation and acidification, even though it is based on solar technology, but the manufacturing process severely impacts those categories because the use of this equipment for such an small surface is inefficient. Replacement of this technology with manual irrigation improves these impacts.

When comparing zero-miles rural agriculture with UA, other aspects not included in the LCA must be considered. The typical pattern of depopulated regions consists of a densely built-up urban core of small-medium size that it is surrounded by a very sparsely populated rural area with small villages which suffer continuous population decrease and are at risk of disappearing (Castillo-Rivero et al., 2021). This is the case in León province where this work was done. In some areas of southern Europe, rural depopulation is a major problem (Llorent-Bedmar et al., 2021), central Spain being the paradigm of this problem (van Herwijnen et al., 2018). Even if agricultural activity has failed in fixing the population in rural areas because families encourage their children to emigrate (Llorent-Bedmar et al., 2021), the opportunity for the future generation of farmers to live and work in the urban core would worsen rural depopulation and ageing of the rural population. The differences in the environmental performance of the different zero-miles scenarios analysed, including UA, are linked more to agronomic practices than to the transport distance, providing efficient methods are used for transport. In this work, for a hypothetical increase of the transportation distance from 32 to 100 km, the environmental burden of P_L_OF_C increased by between less than 1% and 22%, or even decreased by up to 14% depending on the indicator (data not shown) because for a distance of 100 km, the logistics change and all the produce is transported in a lorry instead of part of it being carried in a light commercial vehicle. Moreover, in densely built-up urban cores, is difficult to recover land for horticulture (Barriuso and Urbano, 2021), because it will compete with recreational use and the shadow cast by tall buildings is a serious limitation (Getter et al., 2009).

Thus, in the present situation, zero-miles rural agriculture would be preferable to UA in the region analysed or in another with similar characteristics. Nowadays, there is still a lack of technological approaches to provide strategies for nutrient recirculation in UA, which would be the best way to improve its environmental performance (Rufí-Salís et al., 2021) because the reuse of local resources is very limited so far (Thomaier et al., 2015).

4.3. Organic and conventional scenarios

The organic fertilizers needed for open-field production in the organic systems, both professional (P_L_OF_O) and leisure (L_L_OF_O), increased their burden for GWP, ozone layer depletion, eutrophication and CED to such an extent that, for these indicators, the environmental burden of the organic systems was higher than that of the conventional one (P_L_OF_C). The assignment of burdens to organic fertilizers is controversial (Michiels et al., 2021) because, in general, the impacts of such products are not accounted for within agricultural and horticultural LCAs, embracing the fact that the raw materials are residues (e.g. Goossens et al., 2017). However, when organic fertilizer is allocated to the horticultural activity, which is the most adequate approach (Michiels et al., 2021), the contribution of the production and usage of organic manure accounts for an important share of the overall environmental impacts (Zhu et al., 2018), as we have observed in this work. Interestingly, unlike in the open-field scenarios, in the greenhouse scenarios, the organic one (P_A_G_O) performed better environmentally than the conventional one (P_A_G_C). This was due to the environmental impacts of other practices followed in the greenhouses and not in the open-field that burden the conventional system, e.g. soil disinfection, weeding system, etc. Moreover, the type of organic fertilizer also has a direct effect on the magnitude of the burden.

4.4. Limitations and future research

One limitation of the present work is that a globally oriented LCIA methodologies as the CML-IA does not considers social and specific environmental impacts that the intensification of agricultural production in West Almería has caused in the region, e.g. social integration and unregulated housing settlements, water aquifer depletion and salinization, inadequate waste management, etc. (Castro et al., 2019). Other regions with similar productive models and limited water resources, e.g. some regions in Northern Africa, have suffered similar problems due to the concentration of greenhouses to produce vegetables off-season for northern countries (Payen et al., 2015). Considering this, local/regional production in heated systems could have other advantages over long-distance production not included in the LCA analysis, as long as future technological improvements reduce the impacts produced by the heating system. Thus, possible future research would be, in the one hand, a deeper analysis of the impact on specific elements, as monthly and annual water scarcity footprint, and a social life cycle analysis in West Almeria region and other regions with high concentration of unheated greenhouses in arid regions. In the other hand, research is needed to improve the efficiency of heated greenhouses; the main aspects to be improved are the use of more efficient heating infrastructures (Hassanien et al., 2016) such as the cogeneration used in the scenario P_L_G_Ht_cogen in this work that drastically reduced the environmental impacts, or other net-zero energy technologies such as solar power (Gorjian et al., 2021). Moreover, in order to make heated greenhouses environmentally more competitive, a significant yield increase and a restrained use of inputs must be achieved (Ntinas et al., 2017) and thus constant technological improvement is necessary.

5. Conclusions

In conclusion, zero-miles scenarios in the open-field are the best option environmentally to provide fresh tomatoes to urban citizens, whilst zero-miles production of tomatoes in greenhouses heated with conventional energy sources is the most environmentally costly option. For the part of the year during which there is availability of tomatoes produced locally in unheated greenhouses, production in Almería in an organic system continues to be better environmentally than local production. It is concluded that in cold regions, climatic constraints preclude the expansion of zero-miles agriculture. Apart from the dramatic influence of the greenhouse heating system, another important finding is that the distance travelled by the tomatoes is not the most important environmental burden: other factors may have a greater effect, namely, the efficiency of the transportation system, or other agronomic practices such as irrigation efficiency or the use of LCI elements that produce a high impact, e.g. the technological appliances used for micro-agriculture, the use of organic substrates, some types of organic fertilizers, etc. Even if in some cases UA is environmentally better than zero-miles agriculture carried out in rural areas, rural agriculture has an important role in stabilizing the population in depopulated regions. Improvement of the environmental performance of zero-miles horticulture depends more on logistics and agronomic practices than on the distance to the consumer's table. The improvement of UA will depend on the development and improvement of technologies for nutrient recirculation.

If the organic inputs, substrate or fertilizer, are allocated to the tomato production process, they produce important impacts. Thus, what makes organic horticulture environmentally better than conventional horticulture is not the replacement of mineral fertilization by organic but the replacement of other high-impact practices typical of conventional horticulture (e.g. soil disinfection, weed control, some phytosanitary treatments) by other environmentally friendly ones. However, in low-input open-field agriculture, the conventional option could even be environmentally better than the organic one due to the relevance of organic fertilization in the absence of other impacting agronomic practices.

CRediT authorship contribution statement

Beatriz Urbano: Investigation, Writing – review & editing, Validation. **Marcia Barquero:** Investigation, Formal analysis. **Fernando González-Andrés:** Conceptualization, Formal analysis, Writing – original draft, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.scienta.2022.111126.

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