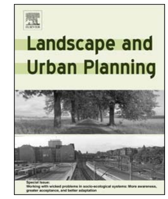
Landscape and Urban Planning 172 (2018) 60–68

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan



Life-cycle energy assessment and carbon footprint of peri-urban horticulture. A comparative case study of local food systems in Spain

David Pérez-Neira[a,*], Anibal Grollmus-Venegas[b]

[a] Department of Applied Economy, University of Leon, Spain
[b] Environmental Engineer, University of Concepcion, Chile

ARTICLE INFO

Keywords:
Sustainability
Agrifood system
Local food
Peri-urban horticulture
Organic farming
Community-supported agriculture

ABSTRACT

In a context of oil depletion and urban population growth, the development of peri-urban agriculture is of special socio-environmental and economic interest in the articulation of local food systems. The quantification and analysis of the environmental impact of peri-urban agriculture is a fundamental element for the design of policies aimed at agrifood and urban sustainability. Based on primary data, the life-cycle assessment of the energy and carbon footprint of peri-urban horticulture in Seville (Andalusia, Spain) was carried out from a cradle-to-consumption approach. Three cases were analyzed taking into consideration their differences in terms of farm management and local supply chain: two conventional farms that sell their output through a local distribution system, and a community-supported agricultural initiative that sells its organic vegetables directly to the consumers. The cumulative energy demand for the production, transport and distribution of 1 kg of fresh vegetables to the consumer in those three cases was estimated at between 2.22 and 5.13 MJ kg^{-1} with a carbon footprint of between 0.117 and 0.271 kg CO_2-eq kg^{-1}. Organic farming consumed approximately 42.5% less non-renewable energy per kilogram than conventional methods, whereas direct distribution reduces greenhouse gas emissions between 63.8 and 91.3% than local supply chains. The results of this work show how the combination of low-input production systems in the peri-urban area of Seville and local supply chains is an economically viable and low energy-impact option for the production and supply of fresh vegetables in the city, especially when the output is organic and the distribution direct.

1. Introduction

The intensification of agriculture (Pimentel & Pimentel, 2008), added to industrialization and the insertion of agricultural goods into global distribution chains, has increased the energy dependence of food production (O'Rourke, 2014). In a context characterized by oil depletion (Murray & King, 2012), the increase in the dependence of food on non-renewable energy has reopened the debate on food insecurity (Arizpe, Giampietro, & Ramos-Martin, 2011). Guaranteeing sufficient food production for a growing population ever more concentrated in the cities (UN, 2012) is among the most significant future challenges (Freibauer et al., 2011). In this sense, the development of urban agriculture is especially interesting, given the possibilities of producing proximity food, improving the resilience of food and energy systems through the diversification of supply (Hodgson, Campbell, & Bailkey, 2011), and increasing the degree of food self-sufficiency in cities, communities or neighborhoods while meeting the demands of a diversity of cultural and geographical environments (Bellwood-Howard, Shakyab, Korbeogoc, & Schlesinger, 2018; Block, Chávez, Allen, & Ramirez, 2012; Saha & Eckelman, 2017). In addition, the reinforcement of urban and peri-urban agriculture may generate important socio-economic (income, employment, food diversity, leisure time, etc.) and environmental (carbon sequestration, reuse of waste, etc.) benefits (Pearson, Pearson, & Pearson, 2010; Specht et al., 2014), and produce a range of non-food and non-market goods related to ecosystemic services with a positive impact on the urban setting (Langemeyer, Camps-Calvet, Calvet-Mira, Barthel, & Gómez-Baggethun, 2018).

One of the most important debates around "local food" has focused on analyzing to what extent the delocalization of production can reduce energy consumption and greenhouse gas (GHG) emissions. Using the concept of "food miles", some authors have argued that a decrease in the distance travelled by food constitutes a fundamental factor of agrifood sustainability (Morgan, Marsden, & Murdoch, 2006; Paxton, 1994). However, others have criticized the reductionism of this concept and have underlined the role of other factors and agrifood phases (e.g., packing, storage, vehicle efficiency, refrigeration, infrastructure, etc.) in the supply chain rendering the analysis more complex (Almeida et al., 2014; Coley, Howard, & Winter, 2009; Mundler & Rumpus, 2012). From the fields of

* Corresponding author. Present address: Department of Applied Economy and Statistics, Leon University, Campus de Vegazana s/n, CP 24071 León, Spain.
E-mail addresses: dpern@unileon.es, dapeneira@uvigo.es (D. Pérez-Neira), anibal.grollmus@gmail.com (A. Grollmus-Venegas).

https://doi.org/10.1016/j.landurbplan.2018.01.001
Received 18 April 2016; Received in revised form 23 December 2017; Accepted 2 January 2018

political economics and geography, Born and Purcell (2006) have argued that environmental (and/or social) outcomes are not inherent to scale, but are produced, or not, within a specific context and according to the particular actors and interrelationships of the given food system. Therefore, the potential of local food and peri-urban agriculture for reducing the system's environmental impact needs to be assessed from a broad perspective, taking into consideration their whole life cycle and incorporating other socioeconomic factors in relation to their contexts (Edwards-Jones et al., 2008).

Based on life-cycle assessment (LCA), many studies have quantified the environmental impact of food (Roy et al., 2009). For instance, Milà i Canals, Burnip, and Cowell (2006) evaluated apples for a case study in New Zealand and Pérez-Neira (2016) did the same with export cocoa in Ecuador, whereas other works like those by Carlsson-Kanyama, Ekstrom, and Shanahan (2003) or Notarnicola, Tassielli, Renzulli, Castellani, and Sala (2017) analyzed a large number of foods associated to Swedish and European diets. In relation to the debate on local food, some studies have reported that local production can be energetically more efficient than non-local production (Jones, 2002; Stadig, 1997) while other researches have presented contradictory results depending on the context and products analyzed (Saunders, Barber, & Taylor, 2006; Webb, Williams, Hope, Evans, & Moorhouse, 2013). For fresh vegetables, Wallgren (2006) obtained a much lower transport-related energy use in local food systems in Sweden, though she underlined the fact that the analyzed products are restricted to two or three summer months. Stoessel, Juraske, Pfister, and Hellweg (2012) concluded that sourcing vegetables locally is a good strategy in relation to GHG emissions insofar as the vegetables are not cultivated in heated greenhouses within the same territory (Sweden).

With regard to urban agriculture and local food, it is important to consider some precedents. Lee, Lee, and Lee (2015) estimated the expected GHG reduction effect in the case of a revitalization of urban agriculture in the city of Seoul. Kulak, Gravesb, and Chatterton (2013) quantified the potential savings associated with food production in urban community farms in the United Kingdom. Sanyé-Mengual, Cerón-Palma, Oliver-Sol, Montero, and Rieradevalla (2013) showed how producing tomatoes in roof-top greenhouses in Barcelona leads to lower energy dependence and reduces other LCA impact categories in contrast with the current linear system in Spain. He et al. (2016) used a LCA to quantify the environmental advantages of producing organic tomatoes in greenhouses as compared to conventional practices in the city of Beijing (China). Within this analytical framework, it is essential to continue researching on the role of urban agriculture, as well as to make diversity visible, especially in relation to food production management and distribution systems.

Since the 1990s, different community-supported peri-urban agriculture initiatives have emerged in Spain that are committed to organic farming and the construction of alternative agrifood systems (Simón-Fernández, Copena-Rodríguez, & Rodriguez, 2010). The most extended community-supported agriculture (CSA) model is that of food cooperatives, which bring together consumers and farmers within the sphere of alternative and solidarity economy (ECSARG, 2016). According to the European Community-Supported Agriculture Research Group (ibid.), there are 75 CSA initiatives in Spain feeding around 7000 persons. Vegetables are the most common type of food available (96%), followed by bread (67%) and fruit (52%). Urban planning in Seville (Andalusia, Spain) has ignored urban and peri-urban agriculture (Dimuro-Peter, Soler-Montiel, & Jerez, 2013), but, in spite of it, agriculture is still alive in the city and, in the last decades, new CSA initiatives and citizen projects linked to agroecology and food sovereignty have emerged (Dimuro-Peter et al., 2013). CSA initiatives are focused on the organic production of seasonal fruits and vegetables distributed through alternative consumption networks that avoid intermediaries. Following Hardmana et al. (2018), this type of initiative may be considered to lie at the more informal end of the urban food growing movement and green activism.

Consequently, the main objective of this work is to analyze the energy metabolism and carbon footprint of peri-urban agriculture in the city of Seville taking into consideration the differences between production models and supply chains. For this purpose, LCA methodology (cradle-to-consumption approach) has been applied to three cases: two conventional farms that distribute their products through the local supply chain (wholesaler-retailer-store) and one CSA initiative that grows organic vegetables and sells them directly to the consumer through alternative distribution networks. As an additional secondary objective, this work analyses the economic profitability of peri-urban farms. The results presented in this paper, in addition to being a novelty in Andalusia and Spain, provide scientific information that, within the limits of the study and in accordance with the methodology applied, can contribute to the design of agricultural policies and practices aimed at agrifood sustainability.

2. Materials and methods

2.1. LCA, system boundaries and functional unit

The methodology used in this work is the life-cycle assessment (LCA) focused on the energy metabolism and carbon footprint. The LCA of peri-urban horticulture in Seville has been divided into 5 phases. Phase 0 calculated the energy costs associated with the agricultural inputs and capital used on the farms. Phase 1 quantified the energy consumption required to produce vegetables. In phases 2 and 3, the energy use associated with wholesale, packing, and retail storage was also quantified. The energy cost associated with the sale of vegetables was measured in phase 4. Phase 5 considered the energy consumption of transporting the products from the farm to the consumer (Fig. 1). The cradle-to-consumption analysis has been divided into two LCA stages: (a) the cradle-to-farm gate approach, including phases 0 and 1 (functional unit: hectares and kilograms) and (b) the farm gate-to-consumption approach, encompassing phases 2, 3, 4 and 5 (functional unit: kilograms).

2.2. Case studies and elaboration of an inventory

The cases were selected with the intention of obtaining a non-statistical representation of conventional and organic horticulture, as well as of the local commercial strategies of *peri*-urban horticulture in Seville (Andalusia, Spain) (Fig. 2). The farms under study represented approximately 1.25% of the cultivated area in *peri*-urban Seville (OPS, 2006) and were situated in the following locations: Farm 1: 37°25′51.3″N 5°57′47.5″W; Farm 2: 37°25′54.3″N 5°57′44.4″W, and Farm 3: 37°25′44.9″N 5°57′30.5″W. The information required to make the environmental and economic estimates was gathered through face-to-face questionnaires during 2012. The data set used in the analysis was collected and organized in the inventory summarized in Tables 1a, 1b and 1c.

The first two cases analyzed (C1 and C2) correspond to two small family farms (F1 and F2) that cultivate conventional vegetables and commercialize their products through a wholesaler. The products reach the consumers through local distribution chains (retailer-store) in Seville and the surrounding areas (Table 1c). The third case (C3) is that of a community-supported agriculture (CSA) initiative that comprises a small organic family farm (F3) and a group of consumers. The farm grows a medium to high diversity of seasonal vegetables that are directly sold to consumers in the city. The consumers are organized into "consumer groups" and undertake to purchase (pre-payment) a weekly basket of vegetables and to actively participate in the logistics of distribution.

The two methods of distribution used by the CSA initiative were analyzed (ECSARG, 2016). In the first one, distribution is organized autonomously by each consumer group (1 group = 1 delivery). Someone from each group collects the baskets at the farm and takes

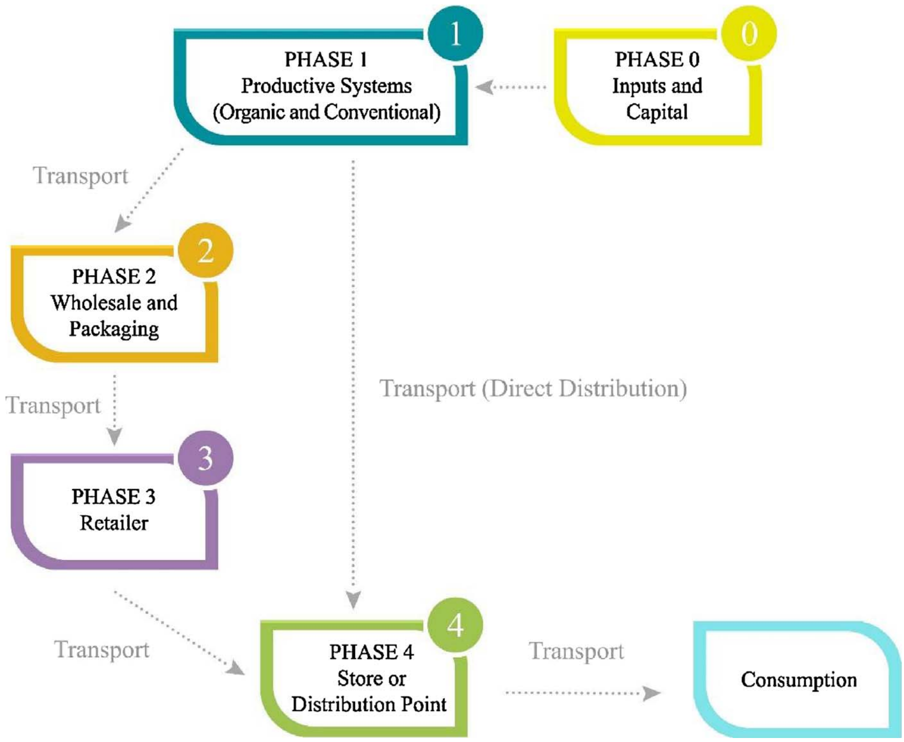


Fig. 1. System boundaries of the peri-urban horticulture agrifood system in Seville.

them by car to a distribution point in the city. In the second method, all the consumer groups jointly participate in the distribution. One single van collects the baskets and takes them to different distribution points in the city (maximum 1 point per group). In both methods, the distribution points are easily accessible, close to the consumers' homes and previously agreed upon by the consumer groups. The families reach them by foot, by bicycle or, to a lesser extent, by car (Table 1c).

2.3. Indicators of energy sustainability and carbon footprint

The energy output was estimated as a function of the gross energy content of the farms' commercialized output (Eq. (1)), according to the nutritional study by Moreiras, Carbajal, Cabrera, and Cuadrado (2005). The cumulative energy demand (CED) was estimated by adding up the "inputs" for production management, packaging and commercial

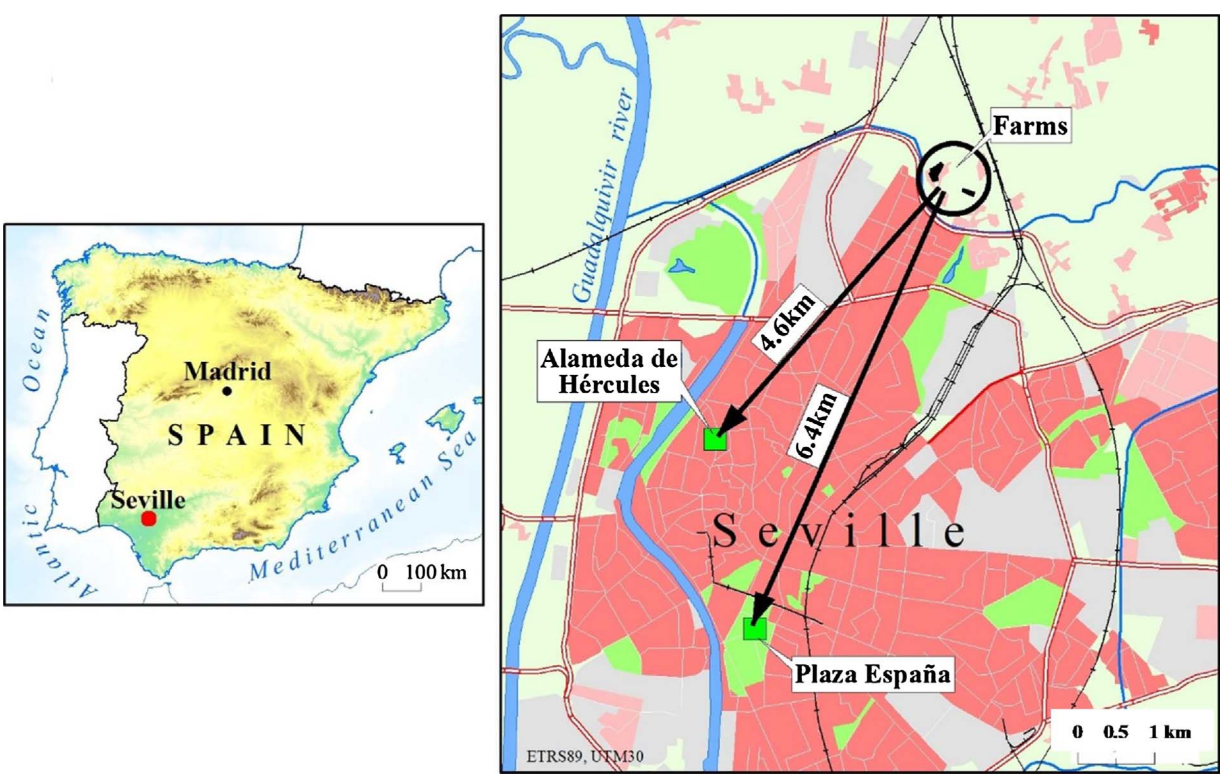


Fig. 2. Geographical location of the farms in peri-urban Seville (Andalusia, Spain).

Table 1a
Description of the cases and inventory of the commercialized products (fresh vegetables).

Cases	Type of farming	Area (ha)	Supply Chain	Sales ($t\,ha^{-1}$)	Main produce
C1	Farm 1: Conventional; Open field	1.65	Local supply chain: Wholesaler-retailer-store	35.95	Chard; tomato; broccoli; green onion; turnip; squash; leek and other produce (43.7; 20.2; 10.1; 7.6; 4.6; 3.4; 3.4 and 4%, respectively)
C2	Farm 2 Conventional; Open field	0.95		44.54	Chard; parsley and mint; onion; turnip; radish and other produce (45.3; 24.9; 12.1; 8.0; 4.8; and 3.8%, respectively)
C3	Farm 3 Organic; Open field	0.85	Direct distribution without intermediaries	35.75	Squash; chard; leak; green pepper; tomato; cabbage; cauliflower; zucchini; broccoli; eggplant; spinach; onion and other produce (12.0; 8.1; 7.2; 7.0; 6.7; 6.5; 6.5; 5.9; 4.8; 4.2; 3.6; 3.6 and 23.8%, respectively)

distribution as a function of the previously defined system boundaries (Eq. (2)).

Energy output = Σ Sales$_{(i)}$ (kg ha^{-1}) x $\alpha_{(i)}$ (MJ kg^{-1}) (1)

Where, (i): crop *i* (tomato, broccoli, etc.); $\alpha_{(i)}$: output energy coefficient of crop *i*. Energy output (MJ kg^{-1}) = Energy output (MJ ha^{-1}) x Sales^{-1} (kg ha^{-1})

Cumulative energy demand (CED) = **Σ** Input$_{(j)}$ (unit f.u.$^{-1}$) x ß$_{(j)}$ (MJ unit^{-1}) (2)

Where, (j): input *j* (diesel, manure, work, kg per km, etc.); f.u. = functional unit (ha or kg); and ß$_{(j)}$: energy coefficient reflecting the energy consumed by input *j*. Where kg per km are the results of multiplying the transported output weight (kg) times the distance travelled (km) as specified in Table 1c.

The coefficients selected (ß$_{(j)}$) to measure the inputs are key factors in energy analyses because they significantly influence the results obtained, but they are not always well defined. Aguilera et al. (2015) designed a coherent database that included the direct and/or indirect energy of the main agricultural inputs at the maximum disaggregation level available. Pérez-Neira, Soler-Montiel, and Simón-Fernández (2013) provided coefficients for organic crops fertilization and protection, labor, oil and electricity in Andalusia, while Delgado-Cabeza et al. (2015) did it for transport in the same region. Carlsson-Kanyama and Faist (2000) provided coefficients capturing the direct energy consumption by kilogram and day for the wholesale, retail and sale phases. The coefficients used for the farm inputs and the supply chain are standardized in Tables 1b and 1c. The energy analysis was based on synthetic indicators and performed with the aid of the following equations:

Energy Return of Investment (EROI) = Energy output (MJ f.u.$^{-1}$) × CED^{-1} (MJ f.u.$^{-1}$) (3)

Net Energy = Energy output (MJ f.u.$^{-1}$) − CED (MJ f.u.$^{-1}$) (4)

Where, f.u. = functional unit (ha or kg)

The CED, EROI and NE indicators were also calculated on the basis of non-renewable energy (NR CED, NR EROI, and NR NE). In order to estimate these indicators, the CED is also classified into renewable and non-renewable forms (Pirdashti, Pirdashti, Mohammadi, Baigi, & Movagharnejad, 2015). Renewable energy includes labor, biomass (manure) and the proportional share of renewable energy (mainly wind, hydraulic and solar) used in the production of agrarian inputs, on the farm and in the supply chain (adapted from Aguilera et al., 2015 and IDAE, 2012). The carbon footprint was then estimated according to non-renewable energy consumption based on data from the Intergovernmental Panel on Climate Change (IPCC, 2006), and the structure of energy use was defined according to the differentiation of sectors in Spain (IDAE, 2012). Direct nitrous oxide emissions were estimated by applying the regional emission factor (EF: 0.47%) obtained by Cayuela et al. (2017) for furrow-irrigated Mediterranean crops like those produced in the three farms analyzed.

Table 1b
Inventory and energy coefficients of the inputs, capital and agricultural machinery used in Farms 1, 2 and 3.

Particulars			Farm 1 (Conv.)	Farm 2 (Conv.)	Farm 3 (Org.)	Energy Coefficients	
A. Inputs	Comments	Unit	per ha	per ha	per ha	MJ unit^{-1}	Ref.
1. Seeds and seedlings							
Seeds	Bought in the market	$	1429	1330	643	4.48	Adapted [1]
Seedlings	Bought in the market	$	1595	1484	717	0.37	
2. Fertilization							
Manure	Cow manure	kg	4800	5000	16,000	1.43	[1]
Urea	Concentration 46%	kg	800	800	–	64.40	[2]
N	Synthetic N	kg	75	276	–	64.40	
P	Synthetic P	kg	75	–	–	13.20	
K	Synthetic K	kg	75	–	–	9.50	
3. Crop protection							
Insecticides and herbicides	Active material	kg	11.6	5.88	–	447.0	[2]
Organic products	F3 (20% BT and 80% sulfur)	kg	–	–	25.1	43.12	[1]
4. Diesel	Irrigation and machinery	l	210.0	253.0	270.7	47.94	[2]
5. Lubricants (oil)	Machinery	l	12.12	10.00	6.70	67.25	[1]
6 Electricity	Flood irrigation	Kw-h	2248	2120	2143	12.27	[1]
7. Labor	Non-remunerated family workforce	h	2618	5472	5952	0.58	[1]
B. Capital and Machinery							
1. Motor irrigation	Water pump; 12 year amortization	kg	26.1	26.1	26.1	64.29	[2]
2. Materials	PVC; 15 year amortization	kg	20.5	20.5	20.5	60.01	[2]
3. Power tiller	< 50 HP	h	58	–	560	9.01	[1]
4. Small machinery	50–80 HP	h	480	480	–	15.03	[1]
5. Rented machinery	90 HP	h	47	34	–	29.10	[1]

Where: Conv. = conventional; Org. = Organic; [1] Pérez-Neira et al. (2013); [2] Aguilera et al. (2015). On energy coefficients see section 2.3.

Table 1c
Inventory and energy coefficients of the local supply chains.

Particulars	Comments and assumptions	Unit	Per kg	Energy Coefficient	
		Per kg	Min.–Max.	MJ $unit^{-1}$	Ref.
C. Local supply chain (C1 and C2)					
1. Wholesaler	Days at wholesaler	days	1	0.02	Adapted [1]
2. Retailer/store	Days at retailer/store until sold	days	3	0.03	
3. Packaging	Plastic	kg	0.03	58.5	[2]
4. Loss of product	Along the supply chain	%	0–5	–	Adapted [3]
5. Transport:					
Farm – Wholesaler	Pickup truck (maximum load)	km	7	3.82×10^{-3}	[4]
Wholesaler – Retailer	Seville city or its surroundings; Large truck	km	15–150	1.87×10^{-3}	
Retailer – Store	Pickup truck (maximum load)	km	3–7	3.82×10^{-3}	
Store – Consumer	1 basket (approx. 6–7 kg). Min.: 25% by car. Max.: 75% by car. The rest: by foot.	km	1–2	133.8×10^{-3}	Adapted [4]
D. Direct distribution (C3)					
1. Method of distribution					
a. By consumption groups	15 Deliveries; 45 kg per delivery and car. Return trip (farm-distribution point)	km	14	19.1×10^{-3}	Adapted [4]
b. Joint distribution	One single delivery: farm-different distribution points. Van (medium load)	km	20	5.88×10^{-3}	[4]
2. Distribution point – Home	1 basket (approx. 6–7 kg). Min.: 25% by car. Max.: 75% by car. The rest: by foot	km	1–2	133.8×10^{-3}	Adapted [4]

Where, [1] Carlsson-Kanyama & Faist (200); [2] Aguilera et al. (2015); [3] Sanyé-Mengual et al. (2013); [4] Delgado-Cabeza et al. (2015). On energy coefficients, see section 2.3.

2.4. Economic analysis

The economic analysis focused on the production phase on the farm. Cost structure, gross margin, net margin, business benefits and benefit-cost ratio (B/C) were the indicators analyzed. In order to calculate the business benefits, an opportunity cost of 42.24 € day^{-1} was defined (7–8 h per day) based on the mean wages paid for vegetable farming in Spain (MAGRAMA, 2013).

2.5. Limits of the study

The present study makes a cautious estimation of the environmental impact of the life cycle of vegetable production in peri-urban Seville. The products' life cycle was not fully incorporated to the analysis: consumption expenses within the home, waste collection and management, and the role of restaurants within the supply chain were not included. Indirect energy and the infrastructure associated to the wholesaler, retailer and transport phase were also not considered within the CED. On the output side, the energy and economic contribution of family self-consumption and other forms of non-monetarized exchange were not taken into account. The role of "reuse" in feeding small livestock (hens and other animals) was not considered either. Even though LCA is an internationally recognized tool, its definition and calculation may differ from one study to another (system boundaries, inputs, cases, converters, etc.). The differences in the methodological definition of apparently similar studies make it necessary to interpret their results with analytical caution (see Plevin & Delucchi, 2014). Given the differences in the output composition of the analyzed farms, the comparative results of the current work must also be interpreted taking into account this methodological limitation.

3. Results

3.1. Energy metabolism and carbon footprint of peri-urban horticulture in Seville

3.1.1. Cradle-to-farm gate approach

The energy cost of cultivating 1 ha of vegetables in *peri*-urban Seville was estimated at 93,260, 99,368 and 73,811 MJ, with a carbon footprint of 4133, 4436 and 2453 kg CO_2-eq ha^{-1} for F1, F2 and F3 (Table 2). Fertilization, energy (diesel + electricity) and machinery (+ lubricants) were the most significant inputs in the three farms and represented between 85.3 and 89.6% of the CED (Fig. 3). Farm 2 was the most productive farm (65,981 MJ ha^{-1}), followed by F3 and F1 (43,028 and 42,340 MJ ha^{-1}). The energy efficiency of the farms (EROI) was estimated at 0.45:1, 0.66:1 and 0.57:1 for F1, F2 and F3. As much as 77.0, 77.5 and 51.9% of the CED was non-renewable energy, which entailed a NR CED of, respectively, 2.00, 1.73 and 1.07 MJ kg^{-1}. Farm 3 had the highest energy efficiency, followed by F2 and F1, with a NR EROI of, respectively, 1.11:1, 0.86:1 and 0.59:1.

Table 2
Energy and carbon footprint indicators of peri-urban horticulture in Seville: cradle-to-farm gate approach.

(A) On the farm				
Indicators	Unit	Farm 1 (Conv.)	Farm 2 (Conv.)	Farm 3 (Org.)
Energy output	MJ ha^{-1}	42,340	65,981	43,028
	MJ kg^{-1}	1.18	1.48	1.20
CED	MJ ha^{-1}	93,260	99,368	73,811
	MJ kg^{-1}	2.59	2.23	2.06
NR CED	MJ ha^{-1}	71,791	77,035	38,330
	MJ kg^{-1}	2.00	1.73	1.07
Carbon footprint	kg CO_2-eq ha^{-1}	4133	4436	2453
	kg CO_2-eq kg^{-1}	0.143	0.129	0.106
EROI	–	0.45	0.66	0.57
NR EROI	–	0.59	0.86	1.11
NR Net energy	MJ ha^{-1}	−29,452	−11,055	4698

Where, Conv. = Conventional; Org. = Organic.

3.1.2. Farm gate-to-consumption approach

The CED of the supply chain of vegetables in C1 and C2 was estimated at 1.95 and 2.38 MJ kg^{-1} (Table 3). Packaging, followed by transport, was the most relevant energy consumption of the local supply chain (between 90.1 and 73.6%). For C3, the CED of direct distribution was 0.15 and 0.47 MJ kg^{-1} for joint distribution and distribution by consumer groups. The use of low-efficiency vehicles (private car) and the increase in the number of trips in the case of distribution by consumer groups multiplied by 3.1 the energy consumption of joint distribution, made with a single van.

3.1.3. Cradle-to-consumption approach

The CED of the agrifood system of peri-urban horticulture in Seville was estimated at between 2.22 and 5.13 MJ kg^{-1} (Table 4). Production on the farm was the most energy-demanding phase (between 47.0 and 93.2% of the CED), followed by packaging for C1 and C2 (between 34.2 and 41.8%) and transport for C3 (between 6.8 and 18.5%). The NR CED amounted to between 55.2 and 76.4% of the energy use of the agrifood

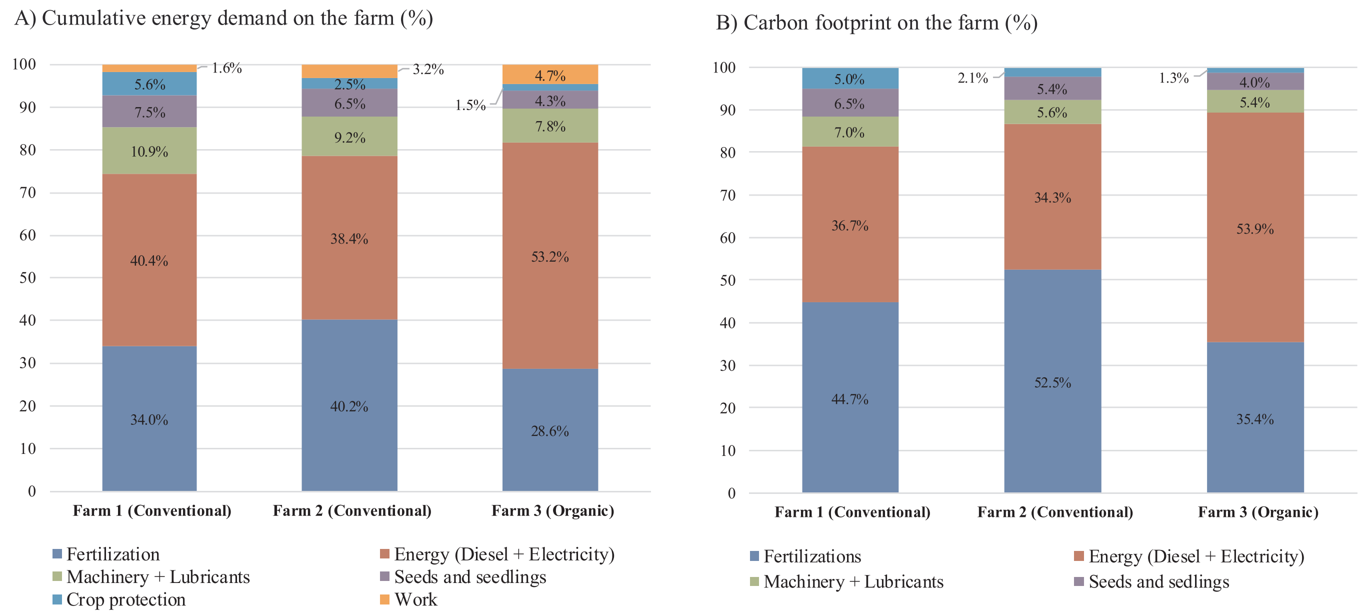


Fig. 3. Cumulative energy demand (A) and carbon footprint (B) of peri-urban horticulture in Seville: cradle-to-farm gate approach.

system in all three cases. The NR EROI was estimated at between 0.30:1 and 0.97:1. The production and direct distribution – especially through joint distribution – of organic vegetables was the most efficient agrifood system analyzed.

3.2. Economic results

The cost of production of 1 ha of vegetables in peri-urban Seville was estimated at 13,174, 11,699 and 9591 euros for F1, F2 and F3 (Table 5). The use and renting of machinery was the main cost of production for the three farms, representing between 59.5 and 73.9% of the total. It was followed by, in order of importance, seed purchases, fertilization and crop protection, which amounted to 34.3, 34.7 and 18.9% of the total cost of production at F1, F2 and F3. The remaining expenses (diesel + electricity) were less important from a monetary point of view (between 4.8 and 7.2%). Income was estimated at 24,486, 27,749 and 42,383 € ha^{-1} for F1, F2 and F3. In terms of profitability, F3 obtained higher gross and net margins (39,849 and 32,793 € ha^{-1}) than F1 (19,293 and 11,312 € ha^{-1}) and F2 (22,972 and 16,050 € ha^{-1}). Economic efficiency (Net Benefit/Cost) was estimated at 1.86:1, 2.37:1 and 4.42:1 for F1, F2 and F3. Business benefits, calculated by subtracting the cost of opportunity of family labor from the net margin, were −2328, −12,584 and 15,440 € ha^{-1} for F1, F2 and F3.

4. Analysis and discussion

4.1. Energy, carbon footprint and organic farming

The impact of vegetable production is closely related to the management, degree of intensification and technologies used as a function

Table 4
Energy and carbon footprint indicators of the *peri*-urban horticulture agrifood system in Seville: cradle-to-consumption approach.

(C) Agrifood system		Conventional farming and local supply chain		Organic farming and direct distribution
Indicators	Unit	C1	C2	C3
CED	MJ kg^{-1}	4.56–5.13	4.20–4.75	2.22–2.53
NR CED	MJ kg^{-1}	3.37–3.91	3.10–3.63	1.22–1.54
Carbon footprint	kg CO_2-eq kg^{-1}	0.239–0.271	0.225–0.257	0.117–0.141
EROI	–	0.26–0.23	0.35–0.31	0.54–0.47
NR EROI	–	0.35–0.30	0.48–0.41	0.97–0.77

Table 5
Economic indicators of *peri*-urban horticulture in Seville (on the farm).

On the farm Indicators	Unit	Farm 1 (Conv.)	Farm 2 (Conv.)	Farm 3 (Org.)
Income	€ ha^{-1}	24,486	27,749	42,383
Total Cost	€ ha^{-1}	13,174	11,699	9591
Gross Margin	€ ha^{-1}	19,293	22,972	39,849
Net Margin	€ ha^{-1}	11,312	16,050	32,793
Labor	h ha^{-1}	2618	5472	5952
Business Benefit	€ ha^{-1}	−2328	−12,584	15,440
Gross B/C	–	4.71	5.81	16.72
Net B/C	–	1.86	2.37	

Where, Conv. = Conventional; Org. = Organic.

Table 3
Cumulative energy demand and carbon footprint of the supply chain of *peri*-urban horticulture in Seville: farm gate-to-consumption approach.

(B) Supply chain	Local supply chain (C1 and C2): Min.–Max.		Direct distribution (C3): Joint distribution – Distribution by groups	
Particulars/unit	MJ kg^{-1}	CO_2-eq kg^{-1}	MJ kg^{-1}	CO_2-eq kg^{-1}
1. Wholesaler, packing, retailer and store	1.85	0.088	–	–
2. Transport (a + b)	0.10–0.53	0.007–0.040	0.15–0.47	0.011–0.035
a. Farm gate to store or distribution point	0.07–0.33	0.005–0.025	0.12–0.27	0.009–0.020
b. Store or distribution point to consumer	0.03–0.20	0.002–0.015	0.03–0.20	0.002–0.015
Total	**1.95–2.38**	**0.096–0.128**	**0.15–0.47**	**0.011–0.035**

Table 6
Carbon footprint of peri-urban horticulture (PUH) in Seville in relation to other production alternatives (farm-to-consumption approach).

Particulars	Distances travelled by large truck to Seville	Farm (CO$_2$-eq emissions per kg)	Transport (CO$_2$-eq emissions per kg)	Supply chain (CO$_2$-eq emissions per kg)	Cumulative CO$_2$-eq emissions per kg	Percentage in relation to PUH in Seville	Ref.
PUH − This study	15–159 km	0.14–0.11	0.01–0.04	0.10	0.12–0.27	100–100	–
Conventional open-field vegetables (Mediterranean region, Spain)	150–450 km	0.22	0.02–0.06[a]	0.10[b]	0.34–0.38	124–322	Adapted [1]
Ecological open-field vegetables (Mediterranean region, Spain)		0.18	0.02–0.06[a]	0.10[b]	0.30–0.34	109–288	
Tomatoes grown in multi-tunnel greenhouses (Andalusia, Spain)	Almeria: 412 km	0.24	0.06[a]	0.10[b]	0.39	145–335	Adapted [2]
Tomatoes grown in roof-top greenhouses (Barcelona, Spain)	0 km	0.25	0.00	0.01	0.26	96–221	[3]
Tomatoes grown in greenhouses (Souss-Massa, Morocco)	By truck: 230–330 km; By boat: 388 km	0.22	0.04–0.05[a]	0.10[b]	0.35–0.37	130–313	Adapted [4]

[a] Estimation made from the distances travelled (see Section 2).
[b] Due to the lack of specific information, the values obtained in this work have been accepted; [1] Aguilera et al. (2013); [2] Torrellas et al. (2012a); [3] Sanyé-Mengual et al. (2013) and Payen, Basset-Mens & Perret (2015).

of time and territory (Torrellas et al., 2012b). The three *peri*-urban farms in Seville follow a low-input production model, characteristic of small-scale family agriculture. The estimated CED (2.06–2.59 MJ kg^{-1}) and carbon footprint (0.106–0.143 kg CO_2-eq kg^{-1}) are relatively low when compared to those of other production activities in the Mediterranean basin. Also in the region of Andalusia, Torrellas et al. (2012a) and Pérez-Neira et al. (2013) estimated a higher energy impact for tomatoes grown in multi-tunnel greenhouses in Almeria (4.00 MJ kg^{-1}) and the ecological vegetable open-field or greenhouse production (5.95 MJ kg^{-1}). Aguilera, Guzmán, and Alonso (2013) also obtained higher GHG emissions for organic and conventional open-field vegetables (0.18 and 0.22 kg CO_2-eq kg^{-1}) in the Mediterranean region.

Despite the fact that all three farms follow a low-input model, the differences in production management are reflected in the results. The organic farm (F3) consumed between 38.0 and 46.3% less non-renewable energy and emitted between 17.8 and 25.9% less CO_2-eq emissions than F2 and F1. In the city of Beijing (China), He et al. (2016) also found improvements in the energy consumption (−31.6%) and carbon footprint (−12.2%) of organic tomatoes grown in greenhouses as compared to conventionally grown tomatoes. These results support those of other studies showing that organic production, with some exceptions, allows an increase in efficiency and a decrease in the use of non-renewable resources (Smith, Williams, & Pearce, 2015; Zentner, Brandt, Nagy, & Frick, 2009) and in GHG emissions (Aguilera et al., 2015; El-Hage & Muller, 2010). The lower NR CED of organic production (F3) resulted in higher efficiencies, 1.87 and 1.29 times the NR EROI of F1 and F2. A limitation was found in the relatively low farm yield, which suggested the need for more applied research on agriculture, especially on organic production.

4.2. Peri-urban agriculture in the debates on local food

There is an ongoing debate about the extent to which local food and the shortening of the supply chain can reduce energy use and carbon footprint. Empirical data show contradictory results in relation to local food (Edwards-Jones et al., 2008; Webb et al., 2013). Supply chains are complex, heterogeneous and depend on a multiplicity of economic and logistics factors (modal share, packing, refrigeration, efficiency of the vehicles, etc.). Therefore, the transport phase is not necessarily the one determining the environmental impact of a product's life cycle (Coley et al., 2009; Wakeland, Cholette, & Venkat, 2011). In the specific case of vegetables, different works have analyzed how local distribution of fresh products allows reducing the impact of the food system, especially in urban agriculture (Kulak et al., 2013). Thus, Wallgren (2006) did not find any significant differences in the levels of energy use in transport to the local farmers' market when compared to conventional food system in Sweden, insofar as airplane flights are excluded, but she did in the case of fresh seasonal fruits and vegetables. Lee et al. (2015) estimated the expected reduction of GHG emissions if urban agriculture were revitalized in Seoul and transportation and food miles were decreased.

The local supply chains analyzed in this work have lower environmental impacts (between 0.011 and 0.128 kg CO_2-eq kg^{-1}) and this is partly due to the short distances travelled by the products (between 15 and 159 km). Pérez-Neira, Simón-Fernández, Copena-Rodríguez, Soler-Montiel, and Delgado-Cabeza (2016) estimated that legumes, fruits and vegetables travel more than 4000 km in the international transportation phase before they get to Spain, leaving a carbon footprint (0.27 kg CO_2-eq kg^{-1}) between 2.1 and 24.1 times that of the supply chains of C1, C2 and C3 together. Other works have proved the environmental relevance of packaging. Sanyé-Mengual et al. (2013) and Theurl, Haberl, Erb, and Lindenthal (2014) estimated the GHG emissions of plastic boxes (0.34 kg CO_2-eq kg^{-1}) and tin-plate cans (0.447 kg CO_2-eq kg^{-1}) and showed they were even higher than those produced on the entire life cycle of the analyzed vegetables. In this sense, packaging and intermodal transport efficiency were key factors to reveal the quantitative difference between C1 and C2, on the one hand, and C3 on the other. Direct joint distribution was the option with the lowest environmental impact because it maximizes physical proximity and avoids the energy costs associated with intermediaries in the product-packaging step thanks to social organization and proximity. The retail to consumption phase is typically outside the system boundaries of most analyses. However, the use of private cars can notably contribute to increase the energy use of local distribution (see also Wallgren, 2006).

4.3. LCA and the agrifood system of peri-urban horticulture in Seville

The carbon footprint of peri-urban horticulture in Seville (farm to consumption) was estimated at between 0.12 and 0.27 kg CO_2-eq kg^{-1}, while other nearby geographical and economic alternatives having Seville as the final destination of their output have a larger carbon footprint (Table 6). Thus, for instance, producing conventional open-field vegetables in the Mediterranean region translates into an increment in carbon footprint of between 24 and 222%, depending on the analyzed model. Those differences are similar to the ones obtained for tomatoes grown under plastic in Almeria (Spain) or Morocco, the origin of 15% of Spanish horticultural imports (MITC, 2017). Organic management reduces CO_2-eq emissions inside the farm (Aguilera et al., 2013), and, depending on the local supply chain, could be comparable to peri-urban horticulture in Seville (Table 6).

Among the three peri-urban horticulture experiences in Seville, the CSA initiative (C3) turned out to be the most efficient one in relation to energy use and carbon footprint. In fact, Sanyé-Mengual et al. (2013)

obtained higher CO_2-eq emissions for tomatoes grown in greenhouses inside the city. Undoubtedly, the use of greenhouses in the Mediterranean region allows advancing the production and consuming horticultural products out of season, thus diversifying the diet. However, the lack of seasonality in consumption and the diets are two decisive factors determining the environmental impact of food systems (see Benis & Ferrão, 2017; Stoessel et al., 2012; Theurl et al., 2014). At international level, Clune, Crossin, and Verghese (2017) estimated, from a meta-analysis (122 LCAs; 633 values), a higher average carbon footprint (0.47 ± 0.39 kg CO_2-eq) than the one obtained in this study for the open-field vegetables.

4.4. Economic profitability and linking consumers to food production

Economic profitability is a crucial aspect of sustainability in urban and peri-urban agriculture (van Veenhuizen & Danso, 2007). Economic analyses show how farms are monetarily viable. F3 had better economic results thanks to a combination of cost reduction and income optimization that allowed an increase in profitability, which is 2.9 and 2.0 times higher than that of F1 and F2. The commitments undertaken by consumers (monthly fees, advance payments, involvement in the distribution), generated through bottom-up governance mechanisms (see Fox-Kämper et al., 2018), largely explain why F3 obtained a better income per hectare than F1 and F2 (42,383 against 24,486 and 27,749 € ha^{-1}). F3 was also the most labor-intensive farm (5.95 against 5.47 and 2.91 thousand h ha^{-1}), which, according to Roset (1999) or Weidmann, Kilcher, and Garibay (2011), means more employment per unit of area.

5. Conclusions

This study presents a first approach to the energy metabolism and carbon footprint of peri-urban horticulture in Seville through the use of a LCA (farm-to-consumption approach). The CED of the production and local distribution of conventional vegetables (C1 and C2) was estimated at between 4.20 and 5.13 MJ kg^{-1}, while it ranged between 2.22 and 2.53 MJ kg^{-1} in the case of the CSA initiative (C3) (organic production and direct distribution). The results show how open-field horticulture in peri-urban Seville follows a low-input production model that leads to high-energy efficiency, especially when compared to similar cases in the Mediterranean region. The organic management of vegetables (F3) yielded a NR CED kg^{-1} that amounts to approximately 42.5% of that of conventional management (F1 and F2). Reduced energy dependence translates into higher efficiency: NR EROI at F3 (1.11:1) was respectively 1.9 and 1.3 times higher than at F2 (0.59:1) and F1 (0.86:1).

In peri-urban horticulture in Seville, packaging and intermodal transport efficiency, not just distance, are fundamental elements determining the environmental impact of the local supply chain. The direct distribution model (farm gate to consumption) is the one with less energy requirements among the three models analyzed (between 0.15 and 2.38 MJ kg^{-1}). Its social organization, articulating organic production and consumption, is a key element to understand the environmental and economic results of the CSA initiative. In that sense, C3 not only reduced the environmental impact but also increased profitability and generated more employment per unit of area. At the same time, the works detects some energy limitations. Low farm yields, oil dependence (mainly due to mechanization), packaging and transport efficiency are central aspects that may be subject to technological improvement and social innovation in the three studied cases.

In summary, the present study provides novel information at the local level (Seville, Andalusia, Spain) on the impact and potential of peri-urban horticulture in terms of energy metabolism and carbon footprint. Quantitative evidence was provided on how peri-urban horticulture may, especially when organic and direct distribution models are implemented, play an important role in the construction of sustainable agrifood alternatives. Finally, it is necessary to underline the importance of continuing research work on energy metabolism in urban agriculture, in constant dialogue with other socioeconomic and environmental perspectives that will enrich and render more complex the debates on agrifood sustainability. These considerations should be taken into account by agents capable of taking action and developing agricultural and urban policies, especially in the present context of oil depletion and competition in peri-urban territories.

Acknowledgements

The authors wish to thank the farmers who participated in this research work, most especially Julian and Mari, for their time, dedication and the enormous know-how they shared. Likewise, we would like to thank the members of the environmental education association "El Enjambre sin Reina" for their support and collaboration.

References

Aguilera, E., Guzmán, G., & Alonso, A. (2013). Greenhouse gas emissions from conventional and organic cropping systems in Spain. I. Herbaceous crops. *Agronomy for Sustainable Development, 35*, 713–724. http://dx.doi.org/10.1007/s13593-014-0267-9.

Aguilera, E., Guzmán, G., Infante-Amate, J., Sotom, D., García-Ruiz, R., Herrera, A., et al. (2015). *Embodied energy in agricultural inputs Incorporating a historical perspective.* DT-SEHA15–17.

Almeida, J., Achten, W. M. J., Verbist, B., Heuts, R. F., Schrevens, E., & Muys, B. (2014). Carbon and water footprints and energy use of greenhouse tomato production in northern Italy. *Journal Industrial Ecology, 18*, 898–908. http://dx.doi.org/10.1111/jiec.12169.

Arizpe, N., Giampietro, M., & Ramos-Martin, J. (2011). Food security and fossil fuel 21 dependence: An international comparison of the use of fossil energy in agriculture (1991–2003). *Critical Reviews in Plant Sciences, 30*, 45–63. http://dx.doi.org/10.1080/07352689.2011.554352.

Bellwood-Howard, I., Shakyab, M., Korbeogoc, G., & Schlesinger, J. (2018). The role of backyard farms in two West African urban landscapes. *Landscape and Urban Planning, 170*, 34–47.

Benis, K., & Ferrão, P. (2017). Potential mitigation of the environmental impacts of food systems through urban and peri-urban agriculture (UPA) – A life cycle assessment approach. *Journal of Cleaner Production, 140*, 784–795. http://dx.doi.org/10.1016/j.jclepro.2016.05.176.

Block, D. R., Chávez, N., Allen, E., & Ramirez, D. (2012). Food sovereignty, urban food access, and food activism: Contemplating the connections through examples from Chicago. *Agriculture and Human Values, 29*(2), 203–215. http://dx.doi.org/10.1007/s10460-011-9336-8.

Born, B., & Purcell, M. (2006). Avoiding the local trap: Scale and food systems in planning research. *Journal of Planning Education and Research, 26*, 195–207. http://dx.doi.org/10.1177/0739456x06291389.

Carlsson-Kanyama, C., & Faist, M. (2000). *Energy use in the food sector. A date survey*Stockholm: Swedish Environmental Protection Agency AFR Report 291.

Carlsson-Kanyama, C., Ekstrom, M., & Shanahan, H. (2003). Food and life cycle energy inputs: Consequences of diet and ways to increase efficiency. *Ecological Economics, 44*(2–3), 293–307. http://dx.doi.org/10.1016/S0921-8009(02)00261-6.

Cayuela, M. L., Aguilera, E., Sanz-Cobena, A., Adams, D. C., Abalos, D., Barton, L., et al. (2017). Direct nitrous oxide emissions in Mediterranean climate cropping systems: Emission factors based on a meta-analysis of available measurement data. *Agriculture, Ecosystems & Environment, 238*, 25–35. http://dx.doi.org/10.1016/j.agee.2016.10.006.

Clune, S., Crossin, E., & Verghese, K. (2017). Systematic review of greenhouse gas emissions for different fresh food categories. *Journal of Cleaner Production, 140*, 766–783. http://dx.doi.org/10.1016/j.jclepro.2016.04.082.

Coley, D., Howard, M., & Winter, M. (2009). Local food, food miles and carbon emissions: A comparison of farm shop and mass distribution approaches. *Food Policy, 34*(2), 150–155. http://dx.doi.org/10.1016/j.foodpol.2008.11.001.

Delgado-Cabeza, M., Márquez-Guerrero, C., Coq-Huelva, D., Pérez-Neira, D., Rodríguez-Morillas, C., Sanz-Alduán, A., et al. (2015). *Las cuentas integradas del transporte en Andalucía (The integrated accounts of transport in Andalusia).* Dirección técnica de la Consejería de Fomento y Vivienda, Junta de Andalucía.

Dimuro-Peter, G., Soler-Montiel, M., & Jerez, E. M. (2013). La agricultura urbana en Sevilla: entre el derecho a la ciudad y la agroecología (Urban agriculture in Seville: Between rights to the city and agroecology). *Hábitat y Sociedad, 6*, 41–60.

ECSARG (European Community Supported Agriculture Research Group) (2016). *Overview of community supported agriculture in europe.* Online: http://groupedebruges.eu/sites/default/files/publications/downloads/overview-of-community-supported-agriculture-in-europe-final.pdf (June 1, 2017).

Edwards-Jones, G., Mila' i Canals, L., Hounsomec, N., Truningerd, M., Koerbera, G., Hounsomee, B., et al. (2008). Testing the assertion that 'local food is best': the challenges of an evidence-based approach. *Trends in Food Science & Technology, 19*, 265–274. http://dx.doi.org/10.1016/j.tifs.2008.01.008.

El-Hage, N. S., & Muller, M. L. (2010). Organic agriculture and climate change. *Renewable Agriculture and Food Systems, 25*(2), 158–169. http://dx.doi.org/10.1017/

S1742170510000116.
Fox-Kämper, R., Wesener, A., Münderlein, D., Sondermann, M., McWilliam, W., & Kirk, N. (2018). Urban community gardens: An evaluation of governance approaches and related enablers and barriers at different development stages. *Landscape and Urban Planning, 170*, 59–68. http://dx.doi.org/10.1016/j.landurbplan.2017.06.023.
Freibauer, A., Mathijs, E., Brunori, G., Damianova, Z., Faroult, E., Gomis, G. (2011). Sustainable food consumption and production in a resource constrained world. European Commission-Standing Committee on Agricultural Research (SCAR). The 3rd SCAR Foresight Exercise. European Commission.
Hardmana, M., Chipungub, L., Magidimishab, H., Larkhamc, P. J., Scottd, A. J., & Armitagea, R. P. (2018). Guerrilla gardening and green activism: Rethinking the informal urban growing movement. *Landscape and Urban Planning, 170*, 6–14. http://dx.doi.org/10.1016/j.landurbplan.2017.08.015.
He, X., Qiao, Y., Liu, Y., Dendler, L., Yin, C., & Martin, F. (2016). Environmental impact assessment of organic and conventional tomato production in urban greenhouses of Beijing city, China. *Journal of Cleaner Production, 134*, 251–258. http://dx.doi.org/10.1016/j.jclepro.2015.12.004.
Hodgson, K., Campbell, M. C., & Bailkey, M. (2011). *Urban agriculture: Growing healthy, sustainable places*American Planning Association Planning Advisory Service Report, No. 563.
IDAE (2012). *Resumen del Plan de Energías Renovables 2011–2020 (Summary of renewable energies plan 2011–2020).* Instituto de Diversificación y Ahorro de Energía Online: http://www.minetad.gob.es/energia/es-ES/Novedades/Documents/Resumen_PER_2011-2020.pdf (January 7, 2016).
IPCC (2006). *IPCC guidelines for national greenhouse gas inventories.* The Intergovernmental Panel on Climate Change (IPCC) Online: http://www.ipcc-nggip.iges.or.jp/public/2006gl/ (October 11, 2015).
Jones, A. (2002). An environmental assessment of food supply chains: A case study on dessert apples. *Environmental Management, 30*(4), 560–576. http://dx.doi.org/10.1007/s00267-002-2383-6.
Kulak, M., Gravesb, A., & Chatterton, J. (2013). Reducing greenhouse gas emissions with urban agriculture: A Life Cycle Assessment perspective. *Landscape and Urban Planning, 111*, 68–78. http://dx.doi.org/10.1016/j.landurbplan.2012.11.007.
Langemeyer, J., Camps-Calvet, M., Calvet-Mira, L., Barthel, S., & Gómez-Baggethun, E. (2018). Stewardship of urban ecosystem services: Understanding the value(s) of urban gardens in Barcelona. *Landscape and Urban Planning, 170*, 79–89. http://dx.doi.org/10.1016/j.landurbplan.2017.09.013.
Lee, G. G., Lee, H. W., & Lee, J. H. (2015). Greenhouse gas emission reduction effect in the transportation sector by urban agriculture in Seoul Korea. *Landscape and Urban Planning, 140*, 1–7. http://dx.doi.org/10.1016/j.landurbplan.2015.03.012.
MAGRAMA (2013). *Publicación de Indicadores de Precios y Salarios Agrarios (Publication of Price and Agrarian Salaries Indicators).* Ministerio de Agricultura, Alimentación y Medio Ambiente (MAGRAMA) de España Online: http://www.mapama.gob.es/es/estadistica/temas/estadisticas-agrarias/indicadores_tcm7-14508.pdf (June 7, 2017).
MITC (2017). *Estadísticas de Comercio Español (Spanish Trade Statistics).* Ministerio de Industria, Turismo y Comercio Online: http://datacomex.comercio.es (June 7, 2017).
Milà i Canals, L., Burnip, G. M., & Cowell, S. J. (2006). Evaluation of the environmental impacts of apple production using Life Cycle Assessment (LCA): Case study in New Zealand. *Agriculture Ecosystems & Environment, 114*, 226–238. http://dx.doi.org/10.1016/j.agee.2005.10.023.
Moreiras, O., Carbajal, A., Cabrera, L., & Cuadrado, C. (2005). *Tablas de composición de alimentos (Tables of Food Composition)* (9th ed.). Madrid: Pirámide.
Morgan, K., Marsden, T., & Murdoch, J. (2006). *Worlds of food. Place, power and provenance in the food chain.* Oxford: Oxford University Press.
Mundler, P., & Rumpus, L. (2012). The energy efficiency of local food systems: A comparison between different modes of distribution. *Food Policy, 37*(6), 609–615. http://dx.doi.org/10.1016/j.foodpol.2012.07.006.
Murray, J., & King, D. (2012). Climate policy: Oil's tipping point has passed. *Nature, 481*(7382), 433–435. http://dx.doi.org/10.1038/481433a.
Notarnicola, B., Tassielli, G., Renzulli, P. A., Castellani, V., & Sala, S. (2017). Environmental impacts of food consumption in Europe. *Journal of Cleaner Production, 140*, 753–765. http://dx.doi.org/10.1016/j.jclepro.2016.06.080.
O'Rourke, D. (2014). The science of sustainable supply chains. *Science, 344*, 1124–1127. http://dx.doi.org/10.1126/science.1248526.
OPS (Oficina del Plan de Sevilla), (2006). Plan General de Ordenación Urbanística. Memoria de información (General Plan of Urbanistic Ordination. Memory of Information). On line: www.sevilla.org [February 2, 2016].
Pérez-Neira, D., Soler-Montiel, M., & Simón-Fernández, X. (2013). Energy analysis of organic agriculture in Andalusia (Spain). *Agroecology and Sustainable Food Systems, 37*, 231–256. http://dx.doi.org/10.1080/10440046.2012.734263.
Pérez-Neira, D., Simón-Fernández, X., Copena-Rodríguez, D., Soler-Montiel, M., & Delgado-Cabeza, M. (2016). Analysis of the transport of imported food in Spain and its contribution to global warming. *Renewable Agriculture and Food Systems, 31*(1), 37–48. http://dx.doi.org/10.1017/S1742170514000428.
Pérez-Neira, D. (2016). Energy sustainability of Ecuadorian cacao export and its contribution to climate change. A case study through product life cycle assessment. *Journal of Cleaner Production, 112*, 2560–2568. http://dx.doi.org/10.1016/j.jclepro.2015.11.003.
Paxton, A. (1994). *The food miles report: The dangers of long distance food transport*London: Safe Alliance.
Payen, S., Basset-Mens, C., & Perret, S. (2015). LCA of local and imported tomato: An energy and water trade-off. *Journal of Cleaner Production, 85*, 139–148. http://dx.doi.org/10.1016/j.jclepro.2014.10.007.
Pearson, J., Pearson, L., & Pearson, C. J. (2010). Sustainable urban agriculture: Stocktake and opportunities. *International Journal of Agricultural Sustainability, 8*(1–2), 7–19. http://dx.doi.org/10.3763/ijas.2009.0468.
Pimentel, D., & Pimentel, M. (2008). *Food, energy, and society* (3rd ed.). Boca Raton: CRC Presshttp://dx.doi.org/10.1201/9781420046687.
Pirdashti, H., Pirdashti, M., Mohammadi, M., Baigi, M. G., & Movagharnejad, M. (2015). Efficient use of energy through organic rice–duck mutualism system. *Agronomy for Sustainable Development, 35*, 1489–1497. http://dx.doi.org/10.1007/s13593-015-0311-4.
Plevin, R. J., & Delucchi, M. (2014). Using attributional life cycle assessment to estimate climate-change mitigation benefits misleads policy makers. *Journal Industrial Ecology, 18*(1), 73–83. http://dx.doi.org/10.1111/jiec.12074.
Roset, P. (1999). The multiple functions and benefits of small farm agriculture in the context of global trade negotiations. Food first – The Institute for Food and Development Policy. *FAO/Netherlands conference on the multifunctional character of agriculture and land*.
Roy, P., Nei, D., Orikasa, T., Xu, Q., Okadome, H., Nkamura, N., et al. (2009). A review of life cycle assessment (LCA) on some food products. *Journal of Food Engineering, 90*, 1–10. http://dx.doi.org/10.1016/j.jfoodeng.2008.06.016.
Saha, M., & Eckelman, M. J. (2017). Growing fresh fruits and vegetables in an urban landscape: A geospatial assessment of ground level and rooftop urban agriculture potential in Boston, USA. *Landscape and Urban Planning, 165*, 130–141. http://dx.doi.org/10.1016/j.landurbplan.2017.04.015.
Sanyé-Mengual, E., Cerón-Palma, I., Oliver-Sol, I., Montero, J. I., & Rieradevalla, J. (2013). Environmental analysis of the logistics of agricultural products from roof top greenhouses in Mediterranean urban areas. *Science Food Agriculture, 93*(1), 100–109. http://dx.doi.org/10.1002/jsfa.5736.
Saunders, C., Barber, A., & Taylor, G. (2006). *Food miles e comparative energy/emissions performance of New Zealand's agriculture industry. AERU research report No. 285*Lincoln, New Zealand: Lincoln University.
Simón-Fernández, X., Copena-Rodríguez, D., & Rodriguez, L. (2010). Construyendo alternativas agroecológicas al sistema agroalimentario global: acción y reacción en el Estado español (Constructing agroecologic alternatives to the global agrifood system: action and reaction in the Spanish State). *Revista de Economía Crítica, 10*, 138–175.
Smith, L., Williams, A., & Pearce, B. (2015). The energy efficiency of organic agriculture: A review. *Renewable Agriculture and Food Systems, 30*(3), 280—301. http://dx.doi.org/10.1017/S1742170513000471.
Specht, K., Siebert, R., Hartmann, I., Freisinger, U. B., Sawicka, M., Werner, A., et al. (2014). Urban agriculture of the future: An overview of sustainability aspects of food production in and on buildings. *Agriculture Human Values, 3*(1), 33–51. http://dx.doi.org/10.1007/s10460-013-9448-4.
Stadig, M. (1997). *Life cycle assessment of apple production e case studies for Sweden, New Zealand and France SIK Report 630, 1997*Gothenburg, Sweden: SIK.
Stoessel, F., Juraske, R., Pfister, E., & Hellweg, S. (2012). Life cycle inventory and carbon and water footprint of fruits and vegetables: Application to a swiss retailer. *Environmental Science & Technology, 46*, 3253–3262. http://dx.doi.org/10.1021/es2030577.
Theurl, M. C., Haberl, T. H., Erb, K. H., & Lindenthal, T. (2014). Contrasted greenhouse gas emissions from local versus long-range tomato production. *Agronomy for Sustainable Development, 34*, 593. http://dx.doi.org/10.1007/s13593-013-0171-8.
Torrellas, M., Antón, A., López, J. C., Baeza, E. J., Pérez Parra, J., Muñoz, P., et al. (2012a). LCA of a tomato crop in a multi-tunnel greenhouse in Almeria. *International Journal of Life Cycle Assessment, 17*, 863–875. http://dx.doi.org/10.1007/s11367-012-0409-8.
Torrellas, M., Antón, A., Ruijsm, M., García, N., Stanghellini, C., & Montero, J. I. (2012b). Environmental and economic assessment of protected crops in four European. *Journal of Cleaner Production, 28*, 45–55. http://dx.doi.org/10.1016/j.jclepro.2011.11.012.
UN (2012). *World urbanization prospects: The 2011 revision.* New York: United Nations Population Division Retrieved March 20, 2014.
van Veenhuizen, R., & Danso, G. (2007). *Profitability and sustainability of urban and peri-urban agriculture.* Rome: FAO.
Wakeland, W., Cholette, S., & Venkat, K. (2011). Food transportation issues and reducing carbon footprint. In J. I. Boye, & J. I. Arcand (Eds.). *Green technologies in food production and processing. 211 food engineering series*http://dx.doi.org/10.1007/978-1-4614-1587-9_9.
Wallgren, C. (2006). Local or global food markets: A comparison of energy use for transport. *Local Environment, 11*(2), 233–251. http://dx.doi.org/10.1080/13549830600558598.
Webb, J., Williams, A. G., Hope, E., Evans, D., & Moorhouse, E. (2013). Do foods imported into the UK have a greater environmental impact than the same foods produced within the UK? *International Journal of Life Cycle Assessment, 18*, 1325–1343. http://dx.doi.org/10.1007/s11367-013-0576-2.
Weidmann, G., Kilcher, L., & Garibay, S. (2011). *The world organic agriculture. Statistics and emerging trends 2011.* International Federation of Organic Agriculture Movements and Research Institute of Organic Agriculture.
Zentner, R.P., Brandt, S.A., Nagy, C.N., Frick, B., (2009). Economics and Energy Use Efficiency of Alternative Cropping Strategies for the Dark Brown Soil Zone of Saskatchewan. Project No. 20070029. Final Report to Saskatchewan Agriculture Development Fund: Saskatchewan, Canada.