LCM of green food production in Mediterranean cities: Environmental benefits associated to the distribution stage of Roof Top Greenhouse (RTG) systems. A case study in the city of Barcelona (Catalonia, Spain).

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Abstract This paper aims to assess new systems to face the environmental impacts of the current supply of agrifood products to cities, which are designed to produce horticultural products in buildings, such as Roof Top Greenhouses (RTG). A Life Cycle Analysis (LCA) was applied to the distribution stage in a case study in the city of Barcelona (Catalonia, Spain). The results show that the main contributor to the environmental impact associated to the distribution stage is the packaging, with 62.3 to 88.4% of the environmental impact, in the different categories, followed by the longest distance transport between the warehouse (Almeria) to the distribution centre (Barcelona) (9.3 - 31.1%). Moreover, RTG scenario shows that a system without transport requirements and with a multi.way packaging option could represent savings of 99% of the environmental impact related to the distribution stage of 1 kg of tomato for a Barcelona's consumer.

1 Introduction

Currently, cities are essentially linear systems, where flows pass through them and with a high dependence on the imports of energy and goods. Cities are still far away from the circular zero-waste metabolism of nature [1]. However, they have a key role in the global environment. To exemplify this, while the worldwide ecological footprint is 1.8 global hectares (gha) this is 5.4 gha for Singapore (2007) [2] or 5.6 gha for London [1].

Moreover, as urban areas concentrate 50.6% of the world population, estimated to be increased to 70% by 2050 [3], and agrifood production areas are not necessarily close to them, the food flow and the current supply of agricultural products to cities as linear systems, with high transport requirements, have recently been pointed as one of the potential issues to be improved in order to reduce the environmental impact associated to urban areas.

On the one hand, the increasing demand of agricultural products also increases several impacts associated to this consumption, such as deforestation for farmland uses, and risks, for example the rising energy prices due to the grown demand for agricultural products as feedstock for biofuel production [4]. On the other hand, the lifestyle changes in food consumption have also increased not only the imported food products but also the intensive food production. Finally, transport of food has been increased in the last decades as well as the environmental impacts related to these systems.

Once the food systems were pointed out to be analyzed from an environmental point of view, some works were focused on the analysis and description of the system [5] applying concepts such as the minimal resource consumption; however, they were only done in the production stage and the packaging system of all their life cycle [6].

The different stages of the life cycle of a food product have been studied deeply in the recent decades, although the production stage has been the most analyzed as the food industry is one of the world’s largest industrial sector, with a large use of energy, and the agricultural production has been pointed out as one of the hotspot in life cycle of food products [7].

Later, the focus of food system works was moved to the transport stages and the food supply chain (FSC), such as the analysis of the transport systems for distributing dessert apples in all the United Kingdom, highlighting not only the differences within imported and local products but also within different marketing systems (from 0 to 17.75 MJ/kg of energy consumed) [8]. Also for the United Kingdom, the direct relation with distance from production to delivery and the environmental impact distribution among transport stage and consumer stages (electricity consumption in packaging and storage) was analyzed [9]. Furthermore, the importance of transport for agricultural products exported from islands, such as Canary Island, has been also analyzed [10].

To sum up, the current agricultural model involves energy and CO_2 emissions due to the transport requirements [11] and some systems have been developed recently in order to increase cities' productivity and, consequently, reduce the environmental impacts related to them.

In this sense, there have been several attempts to introduce ornamental areas, like Green Roofs (GR), or productive ones in cities such as Vertical Farming (VF) or Roof Top Greenhouses (RTG), known as urban agriculture systems. Firstly, roofs of buildings were used to install GR. And, later, acclimatized systems were integrated to buildings using its walls (VF) or roofs (RTG), in order to improve a agricultural production.

In order to avoid environmental impacts related to the distribution stage, RTG systems may play a significant role in key areas, such as the Mediterranean, as transport requirements of agricultural products would be lower and, consequently, decrease the energy consumption and GEH emissions related to the distribution stage. According to IPCC [12], the main effect of the global warming in the Mediterranean area is the reduction of rainfall and water resources that could negatively affect many sectors: agriculture, water supply, energy production and health.

In this context, Barcelona is an example of a city with great potential for the application of RTG. Currently, there are 9.48 ha of green areas at roofs in Barcelona (109 buildings) and a recent study has estimated a potential surface for implementing RTG systems in the city of 95 ha [13].

Therefore, beyond works of local and imported agriculture products, this paper works in the comparison between regional agriculture and a new phenomenon of urban agriculture, considering a transformation of the model of food supply to cities towards a more self-sufficient city model.

2 Goal and objectives

The aim of this paper is to do an environmental assessment, through a Life Cycle Analysis (LCA), of the benefits associated with RTG systems in cities for the distribution stage in a real case in the Mediterranean area. In order to do this, two scenarios have been compared, whose transport and packaging requirements were quantified and analysed:

a) The current distribution chain, as a linear and regional food supply system

b) A RTG one, as a circular and local food supply system

3 Methodology

3.1 Study system

In the Mediterranean Area, the study case was situated in Barcelona city (Catalonia, Spain) as a city where RTG systems are implemented, as some studies have already worked in the roof availability for this purposes [see 13, 14].

For the case study, it has to take into account that the current agriculture production and food distribution system feeds Barcelona through MercaBarna, which is a fresh food distribution centre situated in the same city, in the logistics zone of the port of Barcelona, that concentrates 800 firms in 90 ha of area and is the most important agrifood retail centre in Catalonia.

Nowadays, the total amount of vegetables and fruit sold in Barcelona is almost 900.000 tones, and 90.2% of agricultural products sold in Barcelona city come from outside its province and some of them from very specific locations: Almería, 12.3%; France, 11%; Valencia, 9.6%; Canary Islands, 4.7% [15]. According to the data, the case of study has focused on the main flow of agricultural products, which comes from Almería to MercaBarna, and then, is distributed to the city of Barcelona.

Tomato is the second most sold vegetable, after potatoes, representing 8.7% of the total [20]. Moreover, tomato was the vegetable selected for the study as not all the agricultural products, such as potatoes, can be cultivate in RTG systems because the culture system is hydroponics (without soil).

Finally, as the main origin for tomato imports is Almeria, with almost 60% of the overall sales [15], and Almería is one of the main producer areas of Spain for tomato with the 22.2% of the total production of Spain [16], the case study analysed the distribution stage of the tomatoes from Almeria to Barcelona.

3.1.1 Functional unit

The function of the system is to transport an agriculture product and its packaging from the production site to the distribution centre to be consumed. For the case study of Barcelona, the functional unit selected for the LCA study was the distribution requirements for subministrate 1 kg of tomato to a Barcelona's consumer, from Almeria to Barcelona for the conventional scenario and from a local RTG production.

3.1.2 System boundaries

For the LCA study the system boundaries were delimited (Fig. 1) to the transport and packaging requirements from producer to retail and energy consumption for lighting the distribution centre building (MercaBarna). As it is shown, the loss of product during the distribution chain was taken into account.

3.1.3 Hypothesis

For comparative purposes, some hypothesis were defined for the two scenarios:

- Although the agriculture production stage was not included in the LCA, a same greenhouse infrastructure and a same tomato productivity was considered.
- Waste disposal of damaged product in the retail stage was not included.
- Overpackaging for retail purposes, such as films or individual plastic boxes, were not considered in the packaging subsystems.

3.1.4 Scenario 0: Current agricultural products supply system

Scenario 0 shows the current transport system for 1 kg of tomato to a consumer in Barcelona (Fig. 1): production in Alhóndiga (Almería, South Spain), transport to Almeria, transport to MercaBarna, bought and transport to retail and, finally, sold to a consumer. From them, the analysis focused on the transport stages from production to MercaBarna (Tab. 1). Note that during the Almeria - MercaBarna trip, there is a loss of 6% of the product as it is done in refrigerated trailers with dry air systems that imply evaporation of product's humidity, as well as in the retail stage there is a loss of 10%, corresponding to damaged product

Finally, there is an energy consumption in MercaBarna, corresponding to the lighting of the building of Fruit and Vegetables Market, where tomatoes are sold. According to MercaBarna, the total electricity consumption for this purpose was of 772,000 kWh in 2010 and, as 1,039,293,764 kg of products were sold [15], the specific consumption was 0.743 Wh per kg of product.

Tab.1: Specific data for the transport stages considered in Scenario 0.

Stage	Transport	Cargo capacity	Fuel consumption
Producer - Warehouse	Truck (4.5-5t)	1.5 - 2 t	0.1687L/km (EURO5)
Warehouse - Distribution Centre	Refrigerated lorry (40-45t)	20 - 25 t	0.35L/km (EURO3): - 0.33(transport) - 0.2 (refrigeration) [17]
Distribution Centre - Retail	Truck (4.5-5t)	1.5 - 2 t	0.1687L/km (EURO5)

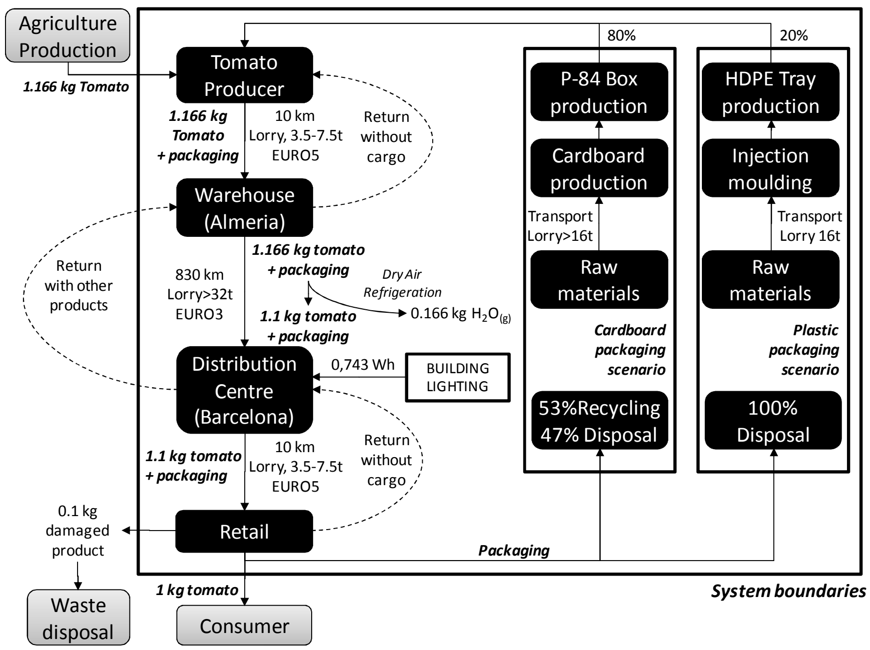

Fig.1: System boundaries for LCA study and description of the current supply system of 1 kg of tomato (Scenario 0).

Regarding packaging, according to managers of the tomato sector in MercaBarna the mix of packaging is 20% of plastic (HDPE) trays and 80% of cardboard boxes (Tab. 2). Data for the Life Cycle Inventory have been obtained from [18] and EcoInvent Database.

Tab.2: Specific data for tomato packaging options considered in Scenario 0.

Packaging	Capacity (kg)	Weight (kg)	Number of uses
Cardboard box	6	0.391	One-way
HDPE tray	6	0.500	One-way

3.1.5 Scenario 1: RTG systems in Barcelona

The implementation of RTG systems in Barcelona could represent a tomato production system without transport requirements and without product losses. Plastic (HDPE) tray were considered as packaging used for produced tomato to retail but with a timelife of 800 uses, as it is used in less intensive way (Fig.2).

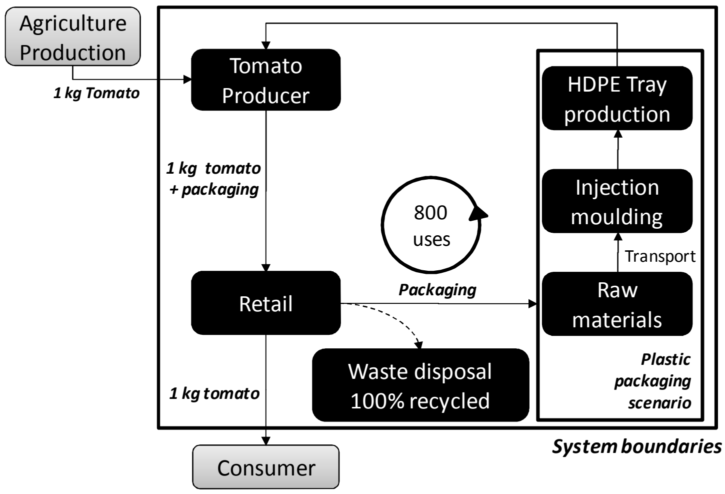

Fig.2: System boundaries for LCA study and description of the RTG system of 1 kg of tomato (Scenario 1).

3.2 Environmental tools: Life Cycle Assessment (LCA)

Having characterised the fuel consumption and packaging for each scenario, what followed were the stages of classifying and characterising the methodology for the life cycle assessment (LCA) [19], according to the CML 2 Baseline 2000 [20] methodology. The selected midpoint impact categories and their units are as follows: abiotic depletion potential (ADP, kg Sb eq.), acidification potential (AP, kg SO_2 eq.), eutrophication potential (EP, kg PO_4^{3-} eq.), global warming potential (GWP, kg CO_2 eq.), ozone layer depletion potential (ODP, kg CFC-11 eq.) and human toxicity potential (HTP, kg 1.4-DB eq.). The EcoInvent 2.0. database was used as a source of information to calculate the impact of the energy production associated to the quantified consumption flow (fossil fuels) [21] and the impact of the materials of the inventoried packaging flow [22].

4 Results and discussion

The results of the LCA show that the environmental impact associated to the distribution stage of 1 kg of tomato for a consumer of Barcelona is lower for Scenario 1 than for Scenario 0 (Tab.3). The distribution stage had a carbon footprint of 152 g. of CO_2 equivalent per each kg of tomato consumed in Barcelona for Scenario 0, while this is of less than 1 g. for Scenario 1 (Tab.3).

Tab.3: Environmental impact of the distribution stage of 1 kg of tomato for consumption, by impact category, stage and Scenario.

	ADP kg Sb eq.	**AP** kg SO_2 eq.	**EP** kg PO_4^{3-} eq.	**GWP** kg CO_2 eq.	**ODP** kg CFC-11 eq.	**HTP** kg 1.4-DB eq.
Scenario 0						
Packaging	1,32E-03	6,97E-04	1,93E-04	9,47E-02	1,89E-08	4,57E-02
T1: Producer - Warehouse	3,05E-05	1,23E-05	2,59E-06	4,91E-03	7,20E-10	5,48E-04
T2: Warehouse - Distribution Centre	3,43E-04	2,36E-04	5,09E-05	4,73E-02	8,12E-09	4,79E-03
Distribution Centre Lighting	3,25E-06	4,25E-06	3,05E-07	4,46E-04	2,41E-11	1,22E-04
T3: Distribution Centre - Retail	2,87E-05	1,16E-05	2,44E-06	4,63E-03	6,80E-10	5,17E-04
Total	1,72E-03	9,61E-04	2,50E-04	1,52E-01	2,84E-08	5,17E-02
Scenario 1						
Packaging	4,58E-06	1,57E-06	1,09E-07	3,29E-04	6,50E-11	5,07E-05

For the current distribution chain (Scenario 0) 1 kg of tomato consumed in Barcelona has different patterns in the impact categories analyzed (Fig.3). Regarding the different stages analyzed, the main burden in all the categories was the packaging (Tab.3), with values of between 62.3 and 88.4% (Fig.3). Packaging has highest contribution in HTP and ODP categories as their production has associated high levels of organic discharge in water, while the lowest percentage is in GWP category, where cardboard production has a positive effect in it as wood production represents CO_2 fixation.

Transport stage from warehouse (Almeria) to the distribution centre (Barcelona) was the second contributor to all the categories, representing between 9.3 and 31.1% of the impact in the different categories. Transport stages from producer to warehouse and from MercaBarna to retail made low contributions with values between 1.03 and 3.23% and 0.97 and 3.05%, respectively. Finally, the energy consumption of the lighting of the distribution centre of MercaBarna (Barcelona) was negligible since all the values were lower than 0.44% (Fig.3).

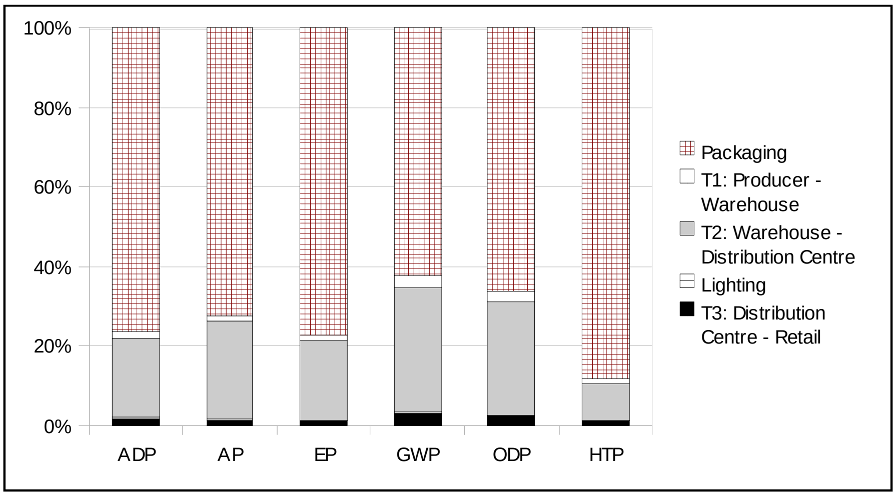

Fig.3: Environmental impact distribution by impact category and distribution stage for Scenario 0.

Comparing the two scenarios analyzed, the implementation of a RTG system, without transport requirements and with a multi-way packaging option, show an environmental impact savings of 99% for 1 kg of tomato consumed in Barcelona. Moreover, a local production in cities through RTG systems could offer a fresh product without losses during its distribution chain and without weight losses due to dry air refrigeration systems, unlike the current distribution system.

4.1 Sensitivity analysis of packaging options for tomato distribution

Environmental impact data from the LCA made possible a sensitivity analysis of the packaging options taken into account in the study case: a cardboard box and a HDPE tray (Fig. 4). On the one hand, the analysis show that the cardboard box is the best environmental option for 4 of the 6 categories analyzed representing a saving of 55.4 to 80.1% per each kg of tomato (ADP, AP, GWP and ODP). However, in EP category this kind of packaging has an environmental impact 2.5 higher than for plastic tray option. Moreover, it has to be taken into account that plastic (HDPE) trays can be used more times than the cardboard box, according to the current legislation of food packaging [23].

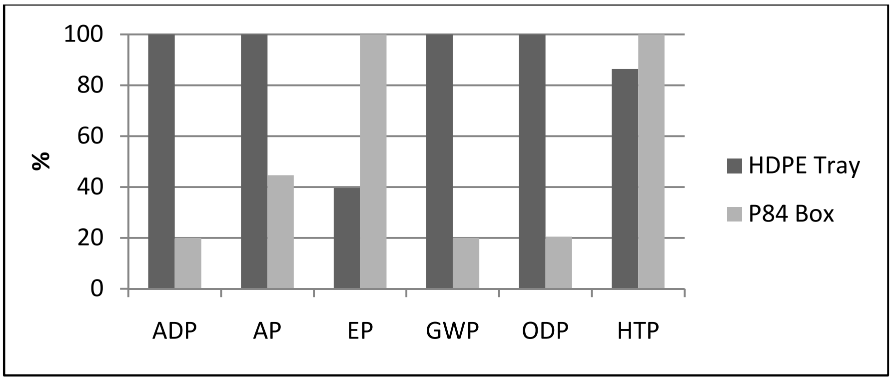

Fig.4: Environmental analysis of packaging options for Scenario 0.

5 Conclusions

According to the results, RTG systems could represent a reduction in the environmental impact of agricultural products, such as the tomato, as they could have positive effect on:

- Promoting local production, avoiding transport requirements of agricultural products and reducing the environmental impact associated to the distribution stage of them.
- Making possible the use of multi-way packaging option, in detriment of current one-way packaging, which represent between 57.0 and 86.1% of the overall impact, in the different categories analyzed.

- Avoiding the product losses during transport without dry air refrigeration systems.
- Reducing the product losses in retail stages, as agricultural products will be cultivated in nearer areas to the consumer centres.

For the case study, the implementation of RTG systems in Barcelona could represent savings of 99% of the current environmental impact burden to the distribution stage of tomato. Moreover, urban agriculture systems represent an adaptation of the city to new functions, increasing multifunctionality, as well as an aproximation to a circular model of consumption.

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