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# Environmental life cycle assessment of nectarine as produced in Southeast Spain

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**Abstract**

The aim of this work is to evaluate the environmental performance of fruit production using Life Cycle Assessment considering the case study of nectarines produced in the Murcia Region (Southeast Spain). The investigation was carried out according to ISO 14040/14044 using a cradle to grave approach that included three stages: upstream (inputs production and crop establishment), core (agricultural phase, product processing and storage) and downstream (distribution, use phase and waste management). Modelling was carried out using Simapro v.9.1, using the EF 3.0 assessment method and considering 1 kg of fresh fruit as the functional unit. Foreground inventory data was obtained from a 405 ha plot established and run by a local company. Climate change emissions were calculated at 0.76 kg $CO_2$ eq per functional unit. The life cycle stage called downstream is the one that generates the most impacts with 46.9 %, followed by 41.2 % in upstream stage and 11.9 % in core stage. The inputs production is the substage leaders in 3 of 5 impact categories; 38.1 % in climate change, 35.3 % in acidification and 32.6 % in eutrophication. The substage of distribution lead with 48.5 % of photochemical ozone formation due to diesel consumed by refrigerated transport. The substage agriculture phase is the principal contributors in water use (depriv) with 77 % due to crop fertigation. The possibilities for implementing mitigation strategies are broad and cover the main substages of the life cycle.

**Keywords: LCA, carbon footprint, climate change, stone fruit, supply chain.**

## 1. Introduction.

The special report on climate change [1] reported an estimated 23 % of the total anthropogenic greenhouse gas emissions derived from agriculture, forestry and other land. The agriculture contributes 12 % of emissions (irrigated cropland 2 % and non-irrigated cropland 10 %). The land use change and rapid land intensification use have supported the increasing production of food, feed and fibre. Since 1961, the total production of food (cereal crops) has increased by 240 % (until 2017) because of land area expansion and increasing yields [1].

Peaches and nectarines are two important fruit crops in Spain, generating 825,954 t per year of peaches and 483,555 t per year of nectarines. The regions Aragon with 28 % and Murcia with 27 % lead in the national production of peaches. The region of Aragon also leads in the national production of nectarines with 32 %, followed by Catalonia with 29 % of the total amount of Spanish peaches. The region of Murcia is in third with 16 % [2].

Life Cycle Assessment (LCA) is one of the most used methodologies to estimate environmental impact across the entire value chain. It enables the comparison of different production systems in terms of materials and processes environmental effects and sustainability [3]. **Table 1** shows a compendium of how LCA works focusing on values of climate change impact (CC) indicators of peach crops in differents Europeans countries. The CC values for peach cultivation in Spain are 0.38 kg $CO_2$ eq per year considering cradle to grave system limits. However, there is a large variability with values ranging from 0.22 kg $CO_2$ eq per year in Italy, considering a narrower system boundary, to values of 2 kg $CO_2$ eq per year in England (importing country), due to the contribution of longer distribution distances and the need for longer refrigeration storage times.

**Table 1.** Literature review on LCA in peach systems. Functional unit 1 kg of fruit.

| Country | Boundaries | Method | kg $CO_2$ eq | Reference |
|---|---|---|---|---|
| Spain | Cradle to gate | CML midpoint | 0.38 | [3] |
| U.K. | Cradle to grave | ReCiPe 2008 | 2.00 | [4] |
| Spain | Cradle to grave | Recipe Midpoint | 0.38 | [5] |

| | | | | |
|---|---|---|---|---|
| Spain | Cradle to gate | Recipe Midpoint | 0.16 | [6] |
| Italy | Cradle to gate | Impact 2002 | 0.22 | [7] |

Nectarines are the focus of this research as there is an absence of LCA research on this crop and since it holds many similarities to peach crops.

## 2. Materials and method.

The present LCA follows the guidelines and specific requirements of the ISO standard series [8], [9]. The study is located in the middle of the Murcia region (Abarán), located in the southeastern part of Spain. The specie cultivated is the nectarine (*Prunus persica* var. *nucipersica*) in an orchard of 405 ha with 667 plants per hectarea and an average yield of 35 t per hectarea during 15 years (plus 3 years of establishment)

### 2.1. Goal definition:

The principal objective of this study is to determine the environmental impacts in the life cycle of nectarines. Specific objectives are to evaluate the impacts generated at each stage of the nectarine life cycle and determine which process contributes most to the total impact.

### 2.2. Scope definition:

**2.2.1.** System boundaries: The study considers the value chain procedures, from cradle to grave (upstream / core / downstream) as shown in **Fig. 1.**

2.2.2. Functional unit (FU): 1 kg of nectarine ready to consume, including its packaging (the weight of the packaging is not included) and the non-edible parts.

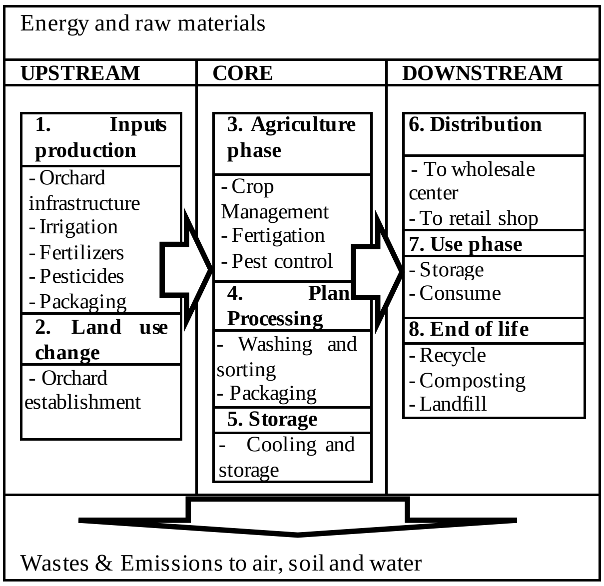


**Fig. 1.** System boundaries for cradle to grave for stone fruit production.

2.2.3. Methodological decisions and tools

The analysis was carried out using Simapro v9.1, following product category rules (PCR) for fruit and nuts [10] and using the E.F. 3.0 assessment method [11]. The impact categories considered include climate change, photochemical ozone formation (POFP), acidification, eutrophication of freshwater and water use.

2.2.4. Life cycle system stages.

2.2.4.1. Upstream: The first stage includes the substage of production and transportation of the following necessary

inputs throughout the life cycle: Fertilizer; pesticides; herbicides & fungicides with the packaging; fertigation system, fruit tree seedling and packaging materials. Orchard establishments take the soil preparation, irrigation system installation, planting and crop establishment managements into account. The production, distribution and consumption of diesel for machinery and distribution, and electricity for fertigation is also considered.

2.2.3.2. Core: This stage addresses the substage of agriculture phase which includes the crop production management with field application of herbicides, fungicides and insecticides, weed mowing (machinery), pruning (waste chipped and incorporated), fertigation and harvest. The plant processing stage starts with the transport of the fruit from the orchard to the factory, then the fruit is received, washed and sorted and finally packed. The storage phase begins with stacking the packed fruit for cooling while awaiting its distribution. The production, distribution and consumption of diesel and electricity for the demands are considered in every phase.

**Table 2.** Life cycle inventory for nectarines by functional unit (1kg of fruit) per year.

| Stages | Substages | Inputs | Units | Per year |
|---|---|---|---|---|
| UPSTREAM | Input production | Transport | t km | 8.38E-02 |
| | | Diesel | kg | 7.25E-04 |
| | Land use change | Fertilizers | kg | 3.20E-03 |
| | | Pesticides | kg | 4.47E-05 |
| | | Water | m³ | 8.57E-03 |
| | | Electricity | kW | 2.40E-03 |
| | | Diesel | kg | 1.92E-04 |
| | | Transport | t km | 2.47E-04 |
| CORE | Agriculture phase | Fertilizers | kg | 4.81E-02 |
| | | Pesticides | kg | 6.66E-04 |
| | | Water | m³ | 1.29E-01 |
| | | Electricity | kW | 3.60E-02 |
| | | Diesel | kg | 1.77E-03 |
| | | Transport | t km | 1.47E-03 |
| | Plant Processing | Water | m³ | 1.30E-04 |
| | | Electricity | kW | 9.80E-03 |
| | | Diesel | kg | 2.86E-04 |
| | | Transport | t km | 3.33E-02 |
| | Storage | Electricity | kW | 1.32E-02 |
| DOWNSTREAM | Distribution | Diesel | kg | 7.88E-03 |
| | | Transport | t km | 8.50E-01 |
| | Use phase | Water | m³ | 2.00E-04 |
| | | Electricity | kW | 6.74E-02 |
| | End of life | Diesel | kg | 1.28E-03 |
| | | Transport | t km | 7.41E-03 |

2.2.3.3. Downstream: This stage includes the substages of distribution from the time it is shipped from the plant to the wholesalers and then to retail using differents vehicles. The consumption used in the refrigeration and washing of the product is accounted in the substage of use phase. Finally, end-of-life substage considers the collection and treatment of fruit waste for municipal composting and packaging materials for the recycling company.

2.3. Life cycle inventory data.

**Table 2** shows the inventory of inputs for one average year of production in the life cycle of nectarines according to the FU described in section **2.2.2**. The inventory was elaborated on basis data from a Murcian fruit company and from plant processing and sales companies.

2.3.1. Data assumptions. Some assumptions are needed to implement the LCA study and create the inventory.

**Table 3.** LCA results for cradle to grave, functional unit (1 kg of fruit) per year.

| Impact category | Unit | Input production | Crop establishment | Crop Production | Plant processing | Storage | Distribution | Use phase | End of Life | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Climate change - Fossil | kg $CO_2$ eq | 2.9E-01 | 2.4E-02 | 6.2E-02 | 1.5E-02 | 1.2E-02 | 2.5E-01 | 6.4E-02 | 8.3E-04 | 7.2E-01 |
| Climate change - Biogenic | kg $CO_2$ eq | 1.5E-03 | 2.1E-04 | 1.5E-04 | 2.6E-05 | 3.2E-05 | 1.1E-04 | 1.6E-04 | 3.9E-02 | 4.1E-02 |
| Climate change - Land use and LU change | kg $CO_2$ eq | 3.9E-04 | 3.0E-05 | 3.8E-04 | 8.6E-05 | 1.1E-04 | 1.0E-04 | 5.8E-04 | 3.2E-07 | 1.7E-03 |
| Climate Change Total | kg $CO_2$ eq | 2.9E-01 | 2.4E-02 | 6.3E-02 | 1.5E-02 | 1.3E-02 | 2.5E-01 | 6.4E-02 | 4.0E-02 | 7.6E-01 |
| Photochemical ozone formation | kg NMVOC eq | 8.0E-04 | 2.8E-04 | 4.9E-04 | 6.1E-05 | 4.8E-05 | 1.8E-03 | 2.5E-04 | 1.5E-05 | 3.8E-03 |
| Acidification | mol $H^+$ eq | 1.8E-03 | 2.4E-04 | 6.2E-04 | 1.1E-04 | 1.1E-04 | 1.7E-03 | 5.6E-04 | 3.6E-06 | 5.1E-03 |
| Eutrophication | kg P eq | 5.8E-05 | 1.3E-05 | 4.9E-05 | 4.0E-06 | 4.8E-06 | 2.4E-05 | 2.5E-05 | 5.9E-08 | 1.8E-04 |
| Water use | $m^3$ depriv. | 1.2E-01 | 8.0E-02 | 1.1E+00 | 1.2E-02 | 8.7E-03 | 1.2E-02 | 5.3E-02 | 3.7E-05 | 1.3E+00 |

- Inputs production. The production of materials were calculated according to the ecoinvent database v3.6 [12].

- Inputs and fruit transport: For inputs it was assumed that there was transport, freight, lorry 32 t, and EURO5, from the production plant to the local point of sale 500 km (upstream). From local point of sale to orchard or plant processing there are 50 km (core). The fruit transport from orchard to plant processing is 30 km (core). The fruit freight from processing plant to wholesale center is 800 km (downstream), with transportation, freight, lorry with refrigeration machine, 16 t, EURO3, liquid refrigerant, cooling all added to the calculations. From the whole center to local retail there are 60 km (downstream) in cooled 7 t lorry EURO 3 [12].

- Change Land Use: The land occupied is arable and has been used for agriculture for a long time (18 years) according to the ecoinvent database v3.6.

- Electricity: High voltage production, transformation from high to medium and the distribution of electricity demand was estimated using information from the ecoinvent database v3.6, according to the Spanish medium voltage electricity mix [12].

- Machinery: Production emissions and diesel consumed from machinery operations were also taken from the ecoinvent database.

**-** Storage: According to data collected, the fruit is stored in a cold storage chamber (1249 $m^3$) after plant processing for a period of 3 weeks while awaiting distribution. In the use phase, the fruit is stored in a refrigerator for a week. The electricity demand of the cooling chambers in the storage phase was calculated according to PCR.

- Fruit losses: The fruit losses during cultivation, plant processing and storage substages is quantified as 3 %, the losses during the distribution substage is 15 % and fruit waste at the substage of use phase is quantified as 17 % [5].

- Diesel: Production at the petroleum refinery operation and distribution to the final consumer in Europe of diesel demand was collected using the ecoinvent database.

- Irrigation water: The orchard studied was drip irrigated with electric pumps using an ecoinvent data set from Spain, and the water draws from the company´s own irrigation well.

The fertigation diffuse emissions such as ammonia, $N_2O$, NO (direct emission) and $N_2O$ (indirect emission) in the air, and nitrates and phosphorus in the water was calculated using the PCR. The pesticide emissions were calculated with the PestLCI 2.0 model for the emissions to air, surface water and groundwater from the orchard to the environment [13].

## 3. Results and discussion.

The results of the assessed environmental impact of the production of 1 kg of nectarines, distinguishing across the life cycle stages, are presented in **Table 3** and the percent results in **Fig. 2.**

3.1. Impact assessment by categories.

3.1.1. Climate change (CC). The results obtained are 0.76 kg $CO_2$ eq per kg. **Fig. 2** presents the upstream stage contribution of 41.2 %, and shows that the production and transportation of fertilizers cause the main impacts. At the core stage with 11.9 %, fertigation accounts for more than 65 % of the impact. Downstream, with a contribution of 46.9 %, the main impact is distribution, due to the consumption of diesel for transport. The result obtained for CC is higher than that indicated by other authors [3], this is because they have not considered the distribution stage.

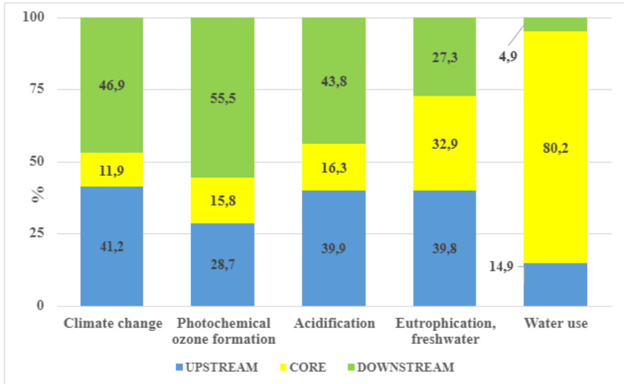


**Fig. 2.** Contribution percentage by impact category in an LCA system.

3.1.2. Photochemical Ozone Formation (POFP). The value for nectarines is 3.8 g NMVOC eq per FU. As shown in **Table 3**, in the downstream stage the distribution is the main hotspot. In particular, refrigerated transportation accounts for more than 45 % of all of the life cycle system POFP. This contribution is similar to that indicated in Frankowska, et al. study [4]. In upstream stage, fertilizers production contributes 13.6 %. The fertigation process in agriculture phase (core) contributes 11.5 %, followed by package production in imput production substage (upstream) 6 % and crop management substage (core) 5.6 %.

3.1.3. Acidification (A). The value for nectarines is 0.005 mol $H^+$ eq per FU. Roughly 32 % of A impact is caused by refrigereted transportation in distribution substage, followed by production and transport of fertilisers in input production substage with 26.9 %, the use phase with 11 % and fertigation with 9 %. Nanaki et al [14] presents fertilizer production followed by transportation as the main sources of A emissions. Once again the principal source of impact is provoked by the use of fossil fuels.

3.1.5. Freshwater Eutrophication. The main result for this impact is 0.2 g P eq per FU. In the core stage, the main contribution comes from fertigation in substage of agriculture phase with 27.4 %. This is followed by packaging production with 14.3 % and fertiliser production (input production substage), use phase (substage) with 13.9 %, and distribution (substage) with 13.4 %. Overall, fertigation and fertiliser production represent the main contributions with 41.3 %. Frankowska et al [4] show the same results for the contribution of fertilisers but at a higher value of 0.6 g P eq per FU.

3.1.6. Water use (depriv). The main result for this impact is 1.3 $m^3$ per FU. The core stage with 80.2 %, where the substage of agriculture phase the fertigation is the main cause of water use with 77 %, followed by substage input production 9.1 % in upstream stage with 14.9 %. In Martin-Gorriz et al [3] study, the water requirements in peaches is 0.10 $m^3$ per FU, which is very similar to the 0.13 $m^3$ per FU accounted for nectarines. This high demand is largely caused by the cultivation of fruit trees in regions with intense water stress, where the water requirements for irrigation are significant due to the hot climate and the reduced water supply from the environment.

## 4. Conclusions.

- The results of climate change calculation of the entire nectarine life cycle is 0.76 kg $CO_2$ eq per FU.
- The downstream stage makes a contribution of 46.9 %, the upstream stage 41.2 % and the core stage 11.9 %.
- The inputs production is the substage leader in 3 of 5 impact categories: 38.1 % in climate change, 35.3 % in acidification and 32.6 % in eutrophication.
- The substage of distribution lead with 48.5 % of photochemical ozone formation due to diesel consumed by refrigerated transport.
- The agriculture phase (substage) is the principal contributors in water use (depriv) with 77 % due to crop fertigation.
- These preliminary results show the stages and sub-stages that have the greatest influence on the environmental impact categories analyzed. The possibilities for implementing mitigation strategies are broad and cover the main substages of the life cycle.

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