Using multiregional environmentally extended input-output assessment to quantify the carbon footprint of peach production

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Abstract

The main objective of this investigation is to analyse the validity of multiregional input-output methodology to evaluate the environmental performance of peach production using a life cycle approach. The analysis is based on a detailed sectorial economic foreground inventory applicable to the region of Murcia (Southern Spain), following the principles of ISO 14040 and incorporating the methodological decisions of Environdec Product Category Rule for fruits and nuts. Total climate change emissions for 1 kg of peaches were calculated at 1.2 kg CO_2 eq, 39.2 % of which correspond to economic activity in the sectors directly affected by the expenses and a further 60.8 % to indirect emissions from induced effects. Most of the total carbon footprint (63 %) is generated by the core stage, primarily crop production and refrigerated storage, both activities being characterized by their high economic intensity and environmental factors.

Keywords: MRIO-EE, LCA, stone fruit, agriculture sector, value chain, cost inventory.

1. Introduction

Intensive agricultural activities contribute to the depletion of natural resources, emitting substantial amounts of greenhouse gases, reducing soil fertility and biodiversity and causing irreversible damage to the environment [1]. A scientific approach is essential to quantify and evaluate these burdens, and to facilitate decision making aimed at ensuring environmental protection without impairing the productivity, competitiveness and profitability of the agri-food sector.

Process based Environmental Life Cycle Assessment (E-LCA) is a well-established methodology widely used to evaluate the sustainability of food and agricultural products. The carbon footprint of peaches has been calculated at 0.22, 0.38 and 2.00 kg CO_2 eq, according to Ingrao [2], Vinyes [3] and Frankowska [4], respectively. Higher emissions correspond to scenarios considering longer transport distances and the use of energy intensive food preservation procedures.

Process based E-LCA is acclaimed as a precise and product specific methodology for sustainability assessment [5]. However, it does not take into consideration the complexity of economic systems where production systems in any given location may induce economic activity in other sectors and countries [6].

Environmentally extended multiregional input-output (MRIO-EE) [7] analysis is an econometric tool that allows the assessment of the relationships between economic activities and the environmental resources used or emitted throughout the entire value chain of a product [8], [9]. Despite its potential, the use of MRIO-EE in the agri-food sector is still scarce. Using a macroeconomic approach, Camanzi [10] calculated the GHG emissions attributable to the EU fruit food chain at 3.20 kg CO_2 eq. per euro of product consumed. Reynold [11] quantified the total GHG emissions derived from the consumption of fruit by a conventional Australian household at 0.37 kg CO_2 eq per dollar.

2. Materials and methods

2.1. Goal definition

The objective of this study is to evaluate the carbon footprint of peach production using MRIO-EE. Secondary objectives include, a) to define a precise sector economic inventory of the peach value chain; b) to evaluate the contribution of different life cycle stages and processes and c) to evaluate the contribution of direct and indirect emissions.

2.2. Scope definition

The analysis has been carried out according to the standardized framework ISO14040:2006 [12] and Environdec Product Category Rule (PCR) for fruits and nuts (PCR 2012:07 v1.1).

2.2.1. System description

The crop investigated is located in the region of Murcia (Southern Spain), it is a *Prunus persica* peach harvested in April/May. Agronomic operations include fertilization, planting, mulching, drip irrigation and harvesting.

Peach processing is carried out at a fruit and vegetable processing plant located in Murcia, where the fruit is washed, sorted, and packaged for subsequent cold storage and distribution to the main points of sale. The consumption stage considers activities such as water use for washing and energy to keep it in the refrigerator for a maximum of 5 days. End of life for fruit residues and packaging waste considers waste management options such as composting, disposal to landfill and incineration for energy recovery.

2.2.2. Functional unit

The PCR defines the functional unit as 1 kg of fresh product, including its packaging and inedible parts.

2.2.3. Life cycle structure and system boundaries

The scope of the LCA includes all the stages from cradle-to-grave. The life cycle is structured into three stages, as proposed in the PCR: Upstream for crop establishment and related activities, Core for crop production and Downstream for distribution and use (**Table 1**).

2.3. MRIO-EE methodological steps

2.3.1. Cost inventory compilation

The costs, without taking into account taxes, margins and transport, associated with the Upstream stage of the peach life cycle were obtained from a review document published by the local authorities describing the cost structure of stone fruit production [13]. Costs associated with the Core stage include electricity use in the operations carried out in a fruit processing plant (0.071 kWh/€) and transportation of fruit from the fields to the processing plant [14]. Regarding the Downstream stage, distribution costs were obtained from the same source [14]. Consumption costs considered electricity use for preserving (0.1199 kWh/€) and water use for washing (1.91 m^3/€). Finally, economic costs for end of life activities were obtained using the management mix reported for fruits and packaging in the UK [4] and the economic cost corresponding to each of these activities in Europe [15].

2.3.2. Allocation of sectors

The MRIO-EE analysis was carried out using EXIOBASE 3.4 [16], which contains input-output tables for 28 regions of the European Union, 16 regions of large economies and 5 of the rest of the world. The tables are classified by type of industry (163 sectors), taking as classification assumption the technology of the industry and product (200 products), based on the assumption of fixed product sales. **Table 1** shows each of the economic

Table 1. Description of the economic inventory, allocation of Exiobase sectors and total direct and indirect emissions in kg CO_2 equivalent at each stage of the peach production life cycle (FU = 1 kg of fresh product)

Life cycle phases	€/UF	Exiobase sector	Total emissions (kg CO_2 eq)	Direct emissions (kg CO_2 eq)	Indirect emissions (kg CO_2 eq)
Upstream	1.4E-01		1.3E-01	8.5E-02	4.3E-02
Crop establishment	**1.9E-02**		**7.7E-03**	**4.9E-03**	**2.9E-03**
Implement shed, headstock	4.0E-03	Construction work (45)	1.5E-03	2.9E-04	1.3E-03
Preparation and planting	1.4E-02	Crops nec	5.7E-03	4.5E-03	1.2E-03
Auxiliar material	9.1E-04	Fabricated metal products, except machinery and equipment (28)	4.9E-04	5.2E-05	4.3E-04
Water extraction and use	**6.8E-02**		**2.0E-02**	**5.1E-03**	**1.5E-02**
Irigation head	8.1E-03	Construction work (45)	3.1E-03	5.9E-04	2.5E-03
Drip irrigation network	8.8E-03	Construction work (45)	3.4E-03	6.4E-04	2.7E-03
PE waterproffed regulating reservoir	3.7E-03	Construction work (45)	1.4E-03	2.7E-04	1.2E-03
Irrigation	4.7E-02	Collected and purified water, distribution services of water (41)	1.2E-02	3.7E-03	8.8E-03
Phytosanitary	**1.8E-02**	Chemicals nec	**1.3E-02**	**3.2E-03**	**9.6E-03**
Fertilizer	**2.0E-02**	N-fertiliser	**7.8E-02**	**7.0E-02**	**8.0E-03**
Herbicide	**3.0E-03**	Chemicals nec	**2.1E-03**	**5.2E-04**	**1.6E-03**
Input packaging materials	**1.4E-02**		**6.7E-03**	**8.6E-04**	**5.8E-03**
Bins HDPE	1.9E-05	Plastics, basic	9.4E-06	2.8E-06	6.6E-06
Wooden pallets	1.0E-03	Wood and products of wood and cork (except furniture); articles of straw and plaiting materials (20)	4.2E-04	4.0E-05	3.8E-04
Cardboard box	9.9E-03	Paper and paper products	4.7E-03	6.0E-04	4.1E-03
Kraft paper	2.8E-03	Paper and paper products	1.4E-03	1.7E-04	1.2E-03
Film	3.1E-04	Plastics, basic	1.5E-04	4.5E-05	1.1E-04
Core	3.6E+00		7.3E-01	2.9E-01	4.4E-01
Crop production	**5.7E-01**		**4.1E-01**	**2.5E-01**	**1.6E-01**
Annual pruning	4.8E-02	Products of forestry, logging and related services (02)	3.4E-02	3.0E-02	4.4E-03
Green pruning	3.1E-02	Products of forestry, logging and related services (02)	2.2E-02	1.9E-02	2.8E-03
Crop insurance	8.1E-02	Public administration and defence services; compulsory social security services (75)	1.2E-02	8.0E-04	1.1E-02
Machinery	2.6E-02	Renting services of machinery and equipment without operator and of personal and household goods (71)	5.3E-03	4.4E-04	4.8E-03
Maintenance	5.1E-03	Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessoiries	2.4E-03	1.5E-03	8.9E-04
Electric energy	5.2E-03	Electricity mix	1.1E-01	1.3E-02	9.5E-02
Thinning	1.3E-01	Products of forestry, logging and related services (02)	9.2E-02	8.0E-02	1.2E-02
Collection	1.7E-01	Products of forestry, logging and related services (02)	1.2E-01	1.1E-01	1.5E-02
Staff	7.7E-02	Other services (93)	1.3E-02	1.4E-03	1.2E-02
Preparation, Selection and Packagi	**1.4E-01**	Electric mix	**1.4E-02**	**1.8E-03**	**1.3E-02**
Storage	**2.9E+00**	Electric mix	**3.0E-01**	**3.7E-02**	**2.7E-01**
Transport	**1.2E-02**	Other land transportation services	**4.5E-03**	**4.1E-04**	**4.1E-03**
Downstream	1.1E-01		3.0E-01	9.1E-02	2.1E-01
Distribution	**4.5E-02**	Other land transportation services	**1.7E-02**	**1.6E-03**	**1.6E-02**
Use	**9.4E-03**		**1.9E-01**	**2.3E-02**	**1.6E-01**
Electric energy	9.0E-03	Electricity mix	1.9E-01	2.3E-02	1.6E-01
Water use	3.8E-04	Collected and purified water, distribution services of water (41)	1.0E-04	3.0E-05	7.1E-05
End of life Food waste	**1.1E-02**		**4.4E-02**	**3.7E-02**	**7.3E-03**
Compost	4.1E-03	Food waste for treatment: composting and land application	9.7E-03	6.9E-03	2.8E-03
Energy recovery	9.6E-04	Food waste for treatment: incineration	6.6E-04	6.9E-05	5.9E-04
Landfill	6.2E-03	Food waste for treatment: landfill	3.4E-02	3.0E-02	3.9E-03
End of life Packaging waste	**4.5E-02**		**5.6E-02**	**3.0E-02**	**2.6E-02**
Energy recovery	1.1E-02	Plastic waste for treatment: incineration	1.8E-02	1.1E-02	6.4E-03
Landfill	3.4E-02	Plastic waste for treatment: landfill	3.8E-02	1.9E-02	1.9E-02
Total	**3.9E+00**		**1.2E+00**	**4.7E-01**	**7.0E-01**

inputs allocated. The climate change satellite account was used to calculate environmental performance.

2.3.3. MRIO-EE analysis

First order and higher order emissions [17] associated with the inventoried final demands shown in **Table 1** were calculated using standard protocols for IO analysis [9].

3. Results and interpretation

3.1. Life cycle inventory

Table 1 provides the detailed sector-based inventory of the peach system in Euros per functional unit and the allocated Exiobase sectors.

3.2. Environmental Impact Analysis

Table 1 shows direct and indirect GHG emissions associated with the life cycle of the peach system. Total climate change emissions amount to 1.2 kg CO_2 eq/FU. **Figure 1** shows the distribution of costs and climate change emission between the three life cycle stages.

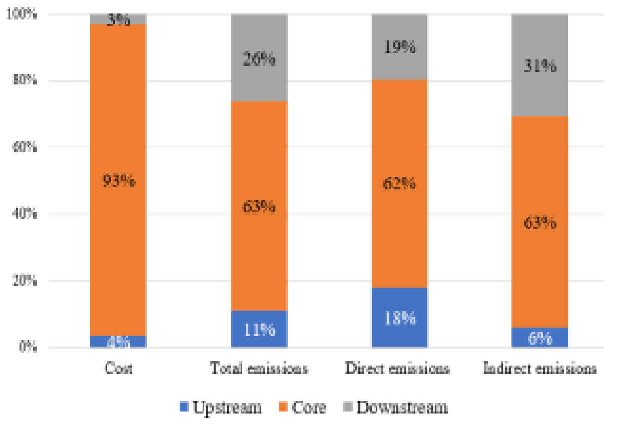

Figure 1. Contribution of the economic cost of each life cycle stage and the total direct and indirect emissions of each stage.

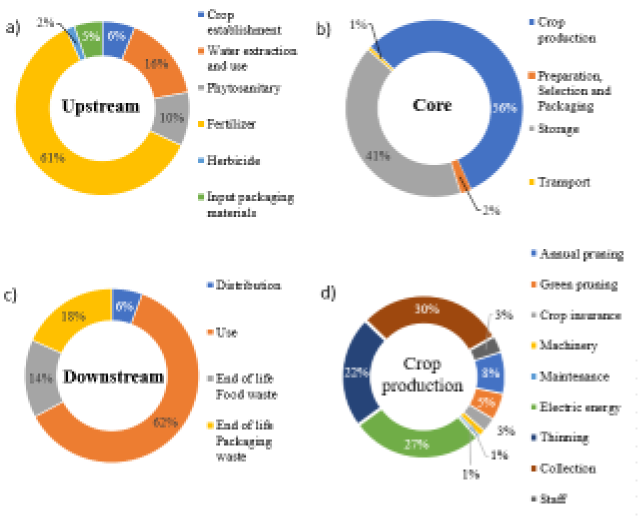

Figure 3. Contribution of life cycle stages and processes to total GHG emissions of the peach system (a) Upstream (b) Core (c) Downstream (d) Crop production (within core phase)

3.2.1. Upstream phase

This stage is responsible for 11% (**Figure 1**) of the total and 18% of the direct carbon emissions generated by the peach system. Fertilizer and electricity use during water extraction are the two processes contributing the most in this stage, as shown in section a) of **Figure 2**.

3.2.2. Core phase

Costs are strongly dominated by the core stage (93 %). This dominance is still strong but less marked in terms of GHG emissions (62-63 %), evidencing that the activities in this stage are less climate change intensive (**Figure 1**). Crop production and peach cold storage have the greatest impact, as shown in section b) of **Figure 2**. Harvesting, thinning and electricity consumption have the greatest contribution to total carbon emissions within the crop production process, due to their high economic cost and environmental factors.

3.2.3. Downstream phase

This stage absorbs only 3 % of the costs but it is responsible for 26 % (**Figure 1**) of the total carbon emissions. The use and consumption of peaches are the processes contributing the most to this stage, followed by the end of life of the packaging as shown in section c) of **Figure 2.**

3.2.4. Direct vs. indirect carbon emissions

Figure 3 shows a strong variability in the contribution of direct and indirect emissions to the total climate change impact of the peach system. In most processes, indirect emissions shall not be overlooked with contributions exceeding 75 % of the total in processes such as water extraction, phytosanitary, herbicide, packaging materials, packaging, storage, transport, distribution and use.

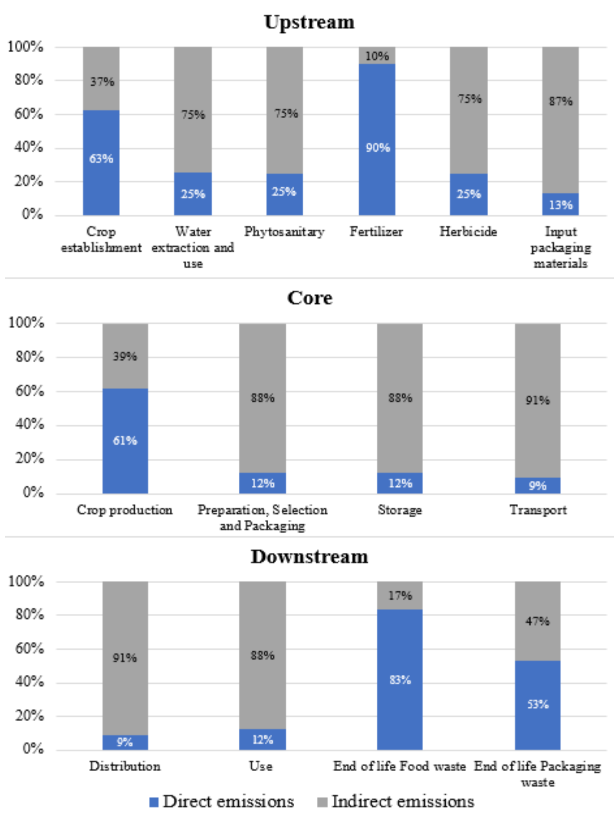

Figure 2. Proportion of direct and indirect emissions of each process that composes each stage of the peach life cycle.

4. Conclusions

- The total carbon footprint generated by the value chain of peach has been estimated using MRIO-EE at 1.2 kg CO_2 eq/kg of fresh product.

- This impact value is in the upper range of those reported for peach systems using process based LCA. This is due in part to the superior completeness of the econometric inventories, as monetary costs necessarily incorporate all inputs generated upstream of the process under consideration. Although this is a first approximation of the use of the MRIO-EE methodology for a product such as peaches, this discrepancy with the LCA will need to be addressed in future studies.

- Most of these (60.8 %) are indirect emissions generated by induced economic activity and only 39.2 % are caused directly by the economic activities defined in the inventoried sector-based expenses.

- Most of the total carbon emissions (63 %) are attributable to the Core stage. This is so despite the fact that this life cycle phase absorbs 93 % of the monetary expenses.

- The processes contributing the most to carbon emissions in the Core stage are crop production and refrigerated storage.

- Indirect emissions caused by economic activity induced by inventoried expenses should not be overlooked in the environmental analysis of agricultural products. The contribution of these indirect emissions represents 60.8 % of the total in the peach system.

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