# Carbon footprint of Argentine peanuts

*BONGIOVANNI, RODOLFO[1,2]*; TUNINETTI, LETICIA[3]; GARRIDO, GUILLERMO[3]*

## Abstract

*The general objective of this study is to perform a Carbon Footprint of peanut production, transportation and processing in Córdoba, Argentina, in order to have a better understanding of the contribution of global warming potential (GWP) emissions in each stage of peanut value chain; study the environmental sustainability performance of this value chain; and to find hotspots in the existing farming, hauling and processing systems, that may be improved for environmental purposes. The intent of the study is to generate results that can be publicly communicated to different audiences.*

*Methods: Surveys were conducted for the 2012-2013 crop season, in the province of Córdoba, with information supplied by farmers and companies that processed 46% of the total national production (1.022.516 t), i.e., 470,000 t of raw peanuts or 223,000 t of shelled peanuts. The functional unit is 'one metric ton of raw peanuts in Argentina, at the farm gate'. A Carbon footprint analysis -based on the ISO 14067 standard (ISO, 2013)- from cradle-to-gate was conducted, up to the 'port of export' located in Zárate (Argentina), including crop production, processing and transportation. The environmental load allocation was based upon economic value.*

*Results from Carbon Footprint are: Crop production and mill processing contribute with 87 kg CO2 eq (37%) and 91 kg CO2 eq (38%), respectively, while transportation contributes with 59 kg CO2 eq (25%). This analysis also considers the use of co-products, such as hull and skin. Even though its industrial use also generates some emissions, substantial environmental benefits were derived from the combustion of peanut hulls for electricity cogeneration and heat, which reduced CO2 eq emissions by 196 kg CO2 eq (-83%), reaching a final value of 41 kg CO2 eq. Without considering the use of co-products, results from Carbon footprint are 237 kg CO2 eq.*

*GWP was also estimated for a set of peanut-based final products, and expressed in terms of kg of* $CO_2$ *eq per kg of product.* $CO_2$ *values ranged from 0.4 for fried peanut, toasted peanut, and refined oil; 0.7 for peanut flour, coated peanut, caramelized peanut, and chopped peanut; 0.8 for peanut butter; and 1.0 for essential oil. In some cases, packaging environmental burdens overtake that of the products.*

*The main hotspot in the farm stage was harvesting, explained by fuel consumption. Reduced tillage and soil nutrient reposition increased* $CO_2$ *eq. emissions. In the milling stage, curing was the hotspot, due to the use of liquefied petroleum gas (LPG). Replacing road transportation by railway transportation decreases carbon footprint values.*

*Conclusions: A Carbon Footprint analysis was successfully performed on the Argentine peanut value chain. This research is the first assessment of the peanut value chain contribution to the global warming potential. Results are useful for the analysis of other food products that use peanut as ingredient.*

***Keywords:*** *Córdoba, Peanut hull, Peanut butter, Hotspots.*

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[1] Instituto Nacional de Tecnología Agropecuaria, Ruta 9 km 636, X5988AAB Manfredi, Córdoba, Argentina.
[2] Universidad Católica de Córdoba, Av. Armada Argentina 3555. X5016DHK Córdoba, Argentina.+54 9 3572 528646. Correo electrónico: bongiovanni.rodolfo@inta.gob.ar
[3] Instituto Nacional de Tecnología Industrial. Centro Regional Córdoba, Av. Vélez Sarsfield 1561, X5000JKC Córdoba, Argentina.

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## INTRODUCTION

Argentina is the largest world exporter of peanut products, followed by China, India and the USA (USDA, 2015). In 2014, the Argentine peanut industry, integrated by 24 mills and their associate farmers, exported 94% of its production to more than 106 countries worldwide (UN-COMTRADE, 2015). The peanut industry is clustered in the central province of Córdoba, representing an example of strategic competitiveness, where there are other factors, in addition to prices, that make the products attractive (BRUE & MCCONNELL, 2002). In other words, it is a regional, highly integrated, value-chain, with competitive advantages based upon technological and organizational innovations, focused in offering high-quality products (branding, image, marketing, design, place of origin, etc.), linked to a ready-to-export sector, and based upon public-private synergies (business nets and commercial agreements) (BONGIOVANNI, MORANDI, & TROILO, 2012).

The general objective of this study was to perform a Carbon Footprint of peanut production, transportation and processing in Córdoba, Argentina, in order to have a better understanding of all the life-cycle stages of the peanut value chain; study the environmental sustainability performance of this value chain; and to find hotspots in the existing farming, hauling and processing systems, that may be improved for environmental purposes. The intent of the study is to generate results that can be publicly communicated to different audiences.

The authors did not find previous scientific research of the carbon footprint of peanuts, except for partial exploratory analysis, such as the RAMSEY Report (2010) and the general study of the ENVIRONMENTAL WORKING GROUP (2011).

This study was aimed at the different stakeholders of the peanut chain: producers, processors, members of the cluster, research institutions, universities, etc., who would be able to use the results for: a) continuous improvement of the internal quality management of companies, b) benchmarking of domestic or imported peanut products, c) being used as a marketing tool for differentiated products, d) providing information to consumers and to the international markets, or e) operating as a tool to negotiate public policies to support the sector and the region.

## METHODS

Surveys were conducted for the 2012-2013 crop season, in the province of Córdoba, with information supplied by farmers and companies that processed 46% of the total national production (1.022.516 t), i.e., 470,000 t of raw peanuts or 223,000 t of shelled peanuts. A Carbon footprint analysis from cradle-to-gate was conducted, up to the ‘port of export’ located in Zárate (Argentina), due to the fact that 94% of Argentine peanut products are exported. The analysis includes the direct impact from crop production, processing and transportation. The system also comprised the indirect impacts derived from the extraction of raw materials; the energy and resources required for the agricultural practices, industrial processing; and transportation, up to the port gate.

The functional unit is ‘one metric ton of raw peanuts in Argentina, at the farm gate’. The environmental load allocation to the products and co-products was based upon economic value.

The study considered three main groups of data: 1) production and processing in the central region of Córdoba, Argentina, obtained from surveys of farmers and manufacturers, 2) databases (ECOINVENT, 2014), and 3) bibliography.

The Carbon Footprint standard based on the ISO 14067 (ISO, 2013) was implemented in the software Simapro® 8.0.3 (PRÉ-CONSULTANTS, 2014) using the CML2000 Baseline model (GUINÉE, et al., 2002). The characterization model as developed by the Intergovernmental Panel on Climate Change (IPCC) was selected for development of characterization factors. Factors are expressed as Global Warming Potential for time horizon 100 years (GWP100).

Sensitivity analyses were conducted, with regards to the tillage system, transportation, and nutrient balance. The outcomes are presented in the Results section.

### System description affecting

Crop production: peanuts must be grown on the same land no more often than one year out of four, in well-drained, sandy to sandy loam soils. On this schedule, peanuts should be rotated with crops that are resistant to nematodes, white mold and other diseases affecting peanuts. Recommended rotational crops include corn, sorghum, grass sods, and small grains. Peanuts are planted around mid-October, followed by an average of eight treatments for crop protection (weeds, insects and diseases). The grower utilizes pesticides, cultural practices, biological control and crop management techniques to help preventing these pests that affect the peanut quality and yield, producing an economic impact. Harvest starts with digging, shaking and inverting the plants from different rows, in one windrow. Digging at optimum maturity is extremely important for achieving maximum yield, grade, economic return, and consumer quality. Peanuts are normally between 35 and 50% moisture at digging. Depending upon on weather conditions, peanuts will dry to 18-24% moisture in 2-4 days. Combining is the second part of harvesting, and consists in separating the pods from the rest of the plant. After harvesting, it is a common practice to plant a cover crop, in order to protect the bare soil from late winter winds and early spring rainfall.

Milling: processing by the mills usually includes buying, pre-cleaning, cleaning, curing, grading, shelling, blanching, packing, cold storage and shipping. At the buying point, the trucks coming from the farm are weighted and sampled. If peanut passes the quality standards, the truck is unloaded, and enters the “buying and curing” process. Otherwise it is destined to the oil industry. Through aspiration and gravity, pre-cleaning equipment minimizes foreign material (FM), loose shelled kernels (LSK), and cracked or broken pods before curing. The following process is curing in drying trailers, to reduce moisture below 10%, in order to prevent molds that may produce aflatoxins. The clean, dried pods are then cleaned again and shelled, generating peanut hulls as a by-product. These are stored outside of the processing facilities. The resulting kernels go through to a selection process, both mechanical and optical, for quality and size. A first selection with a vibration method separates, by specific weight, the sound kernels from the rotten ones, as well as foreign material. A second, electronic polychromatic selection, sorts out the kernels for the oil industry. A third, gravitational selection method separates the kernels by size (according to a number of kernels per ounce).These shelled, sorted kernels can be blanched or not. In peanuts processing, the term 'blanching' refers to the process of removing the seed coat from the kernel. The blanching process starts with a heat treatment in a furnace, in order to reduce grain moisture, so the skin can be removed easily in subsequent stages. After the furnace, the kernels go through the peelers, which have rollers covered with abrasive material that allow skin extraction. Next, an electronic selection method removes the damaged grains, and those with remaining of attached skin and foreign material, through a standard color parameter. Kernels from the electronic selection process also pass a human inspection, to minimize foreign material. Finally, peanuts go through a metal detector, which is eventually removed with an air flow. The ready-to-export final product is then packed in 1.25 t big-bags, or smaller bags of 25-50 kg, and cold-stored until shipping (Figure 1).

### Environmental inventory

Table 1 shows the inventory information for the surveyed companies at the farm level, together with hauling from farm to mills, while Table 2 presents the data for the mills, including transportation of final products to the port of export.

### *Crop production*

$CO_2$ fixation by peanut crops depends on the amount of dry matter they generate. In photosynthesis, plants convert carbon dioxide and water into glucose ($C_6H_{12}O_6$) and oxygen, according to the following reaction: 6 $CO_2$ (g) + 6 $H_2O$ (l) --> sunlight --> 6 $O_2$ (g) + $C_6H_{12}O_6$ (g). Solving this equation of the stoichiometry in photosynthesis ($6CO_2+6H_2O = C_6H_{12}O_6 + 6O_2$), plants uptake 1.47 grams of $CO_2$ per gram of dry matter. Since peanuts produce an average of 1.5 t/ha of dry matter (Haro, Otegui, Collino, & Dardanelli, 2007), it is estimated that the crop uptakes 2.205 t/ha of $CO_2$. Additionally, the cover crop (wheat, oats or barley) produces 3.437 t/ha of dry matter, fixing 5.05 t/ha of $CO_2$ (BAIGORRIA & CAZORLA, 2010). Therefore, total carbon uptake by the crop is 7.25 t/ha of $CO_2$. Nevertheless, and according to the Carbon Footprint standard ISO 14067:2013, the amount of $CO_2$ uptake of biomass and the equivalent amount of $CO_2$ emissions from the biomass at the point of complete oxidation results in zero net $CO_2$ emissions.

The weighted average model was based upon an average yield of 3.05 t/ha (BOLSA DE CEREALES DE CÓRDOBA, 2013). The seeds are the peanut kernels that come from the mill, which are coated with a protective polymer and a fungicide. They are transported from the plant to the farm in 1.25 t big-bags, which are reused 1.5 times/year. Planting is performed with a 16-row at 0.7 m, no-till planter, pulled by a tractor. Peanut seeds are transported by truck from the mills to the farm.

The model also considered the use of a pickup truck, and diesel consumption for technical assistance of a certified crop consultant, for an average of ten round trips. It included field survey, mapping, weed scouting, pesticide application, crop scouting and harvest control activities.

The surveyed diesel consumption of the 24-m-width self-propelled sprayer is reported in Table 1. Water consumption for spraying was pumped from a well, including cleaning of the field sprayer. The plastic packaging (mainly drums) generated about 0.5 kg/ha of toxic solid residues, due to containers abandoned in the field and not properly disposed. All pesticides were accounted for, considering its active ingredient (obtained from the labels), and being available at a local warehouse. An active ingredient is the constituent in a pesticide that is biologically active. Some pesticide products may contain more than one active ingredient. In contrast with the active ingredients, the inactive ingredients are usually called excipients. Emissions to the atmosphere of the associated pesticide application were not taken into account, due to lack of information.

The cover crop can be wheat, oats or barley.

The environmental impact of agricultural machinery and the infrastructure for protection and maintenance was also included in the model.

### *Milling*

Raw peanuts were hauled from farm to the milling processing facilities by 22.5 t trucks.

In the initial stage of "buying and curing", a combination of natural gas and liquefied petroleum gas (LPG), as well as electricity from the national energy matrix mix (natural gas: 44.5%, hydro: 35.5%, oil: 12.3%, nuclear: 5.9%, coal: 1.8%) is used for curing (Secretaría de Energía, 2014). The remains of the peanut samples are destined to the oil industry. There are also some losses due to evaporation and pre-cleaning, when dirt and foreign materials are excluded from raw peanuts. Economic value was used as the allocation method in all processes. Factors used for economic allocation are shown in Table 3.

The second part of the peanut mill process is shelling, where the kernels are separated from the hull, and assorted by size and quality. Electricity, lubricants and water are used in this process. Part of the kernels is destined to the oil industry, whereas there is also a weighted average of 23% weight loss, corresponding to the hulls derived from shelling. The allocation method considered the economic

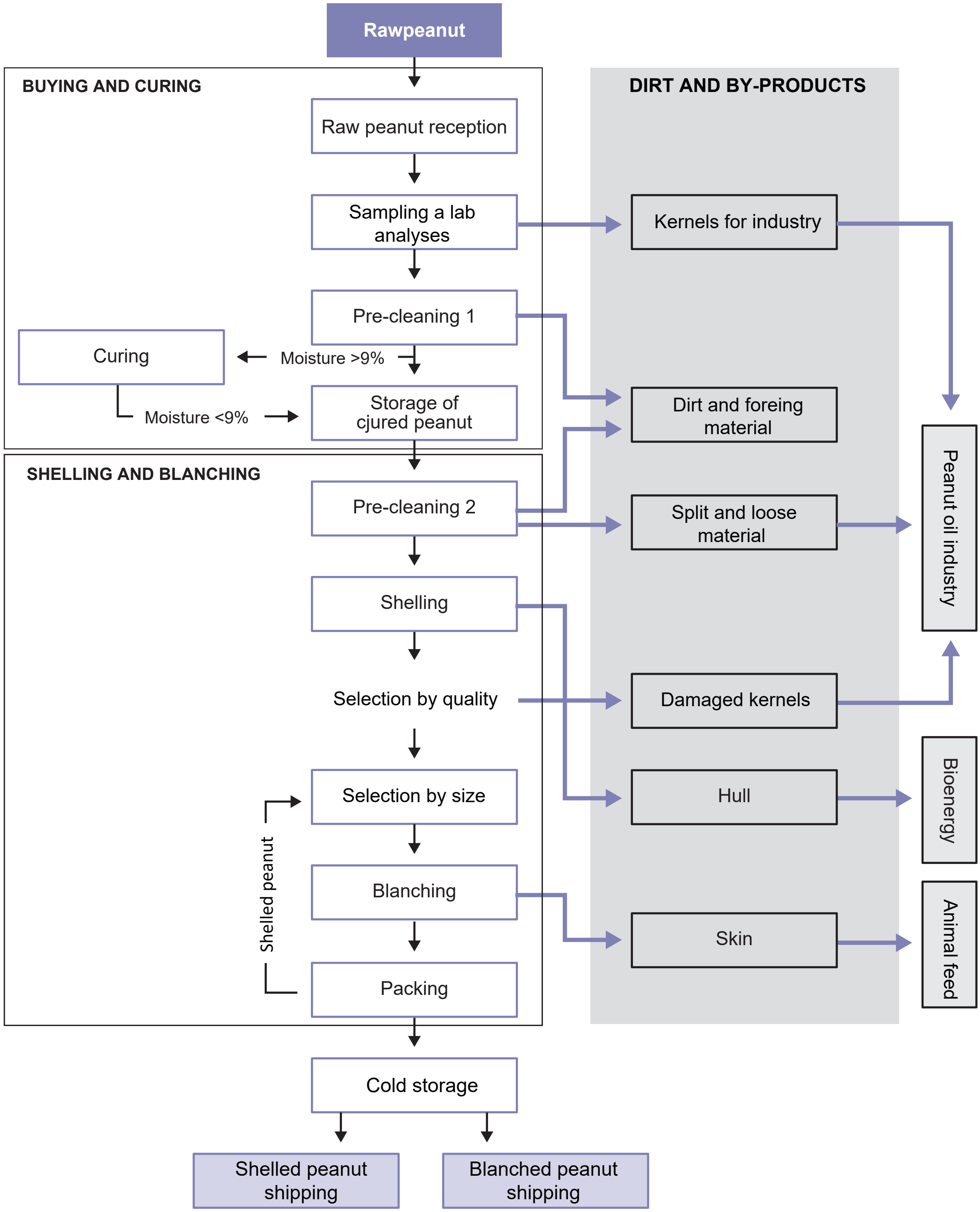

**Figure 1.** Phases of peanut processing.

value criteria for the three products (shelled peanut, hulls and peanut for oil).

Shelled peanut is preserved in cold storage warehouses in 1.25 t big bags, waiting to be used for blanching or for the consolidation process. Electricity, LPG and diesel are used here.

Blanching is a heat treatment, to reduce grain moisture, and to remove the skin. The blanched peanut goes through

| Company | C5 | C4 | C3 | C2 | C1 |
|---|---|---|---|---|---|
| **Production (%)** | 47.91% | 6.43% | 18.95% | 13.84% | 12.86% |
| **Peanut crop** | | | | | |
| Yield (t/ha) | 3.05 | 3.50 | 3.05 | 4.79 | 3.05 |
| Rain water during crop cycle (m3 per FU) | 2525 | 1710 | 2960 | 1120 | 1340 |
| Vehicle use (km per FU) | 6.54 | 12.86 | 4.72 | 15.87 | 3.41 |
| Vehicle use (kg diesel per FU) | 0.55 | 1.29 | 0.44 | 1.20 | 0.26 |
| Transportation of seeds, by truck (tkm) | 47.50 | 32.50 | 37.50 | 16.56 | 47.79 |
| Transportation of seeds, by truck (kg diesel per FU) | 0.22 | 0.13 | 0.17 | 0.09 | 0.25 |
| Planting of peanut crop (kg of seed per FU) | 40.98 | 42.62 | 40.98 | 28.21 | 44.26 |
| Planting of peanut crop (kg diesel per FU) | 0.90 | 1.59 | 1.27 | 0.76 | 2.13 |
| Tractor, production (kg per FU) | 0.13 | 0.10 | 0.13 | 0.08 | 0.13 |
| Planter, production (kg per FU) | 0.06 | 0.05 | 0.06 | 0.04 | 0.06 |
| Shed (m2 per FU) | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| **Crop protection** | | | | | |
| Spraying (kg diesel per FU) | 1.17 | 1.31 | 0.75 | 0.86 | 1.34 |
| Sprayer, production (kg per FU) | 0.32 | 0.19 | 0.32 | 0.14 | 0.22 |
| Shed (m2 per FU) | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Water from well (L per FU) | 252 | 249 | 420 | 167 | 420 |
| Glyphosate (kg per FU) | 0.87 | 0.64 | 0.47 | 0.35 | 0.56 |
| Adherent (kg per FU) | 0.01 | 0.16 | 0.12 | 0.11 | 0.18 |
| Herbicides, other (kg per FU) | 0.57 | 0.40 | 0.50 | 0.27 | 0.42 |
| Insecticides, other (kg per FU) | - | - | 0.001 | - | - |
| Lactophen (kg per FU) | - | - | - | 0.02 | 0.04 |
| Fungicides, other (kg per FU) | 0.14 | 0.12 | 0.16 | 0.14 | 0.14 |
| 2,4-DB (kg per FU) | 0.10 | 0.24 | 0.11 | 0.14 | 0.22 |
| 2,4-D (kg per FU) | 0.26 | 0.25 | 0.17 | 0.15 | 0.23 |
| Phosphoric acid (kg per FU) | 0.34 | 0.01 | - | 0.01 | 0.02 |
| White mineral oil (kg per FU) | 0.66 | 0.29 | 0.36 | 0.21 | 0.33 |
| HDPE bottles (kg per FU) | 0.16 | 0.14 | 0.19 | 0.10 | 0.16 |
| **Harvest** | | | | | |
| Digging (kg diesel per FU) | 3.05 | 2.66 | 1.91 | 1.34 | 3.66 |
| Tractor, production (kg per FU) | 0.13 | 0.40 | 0.13 | 0.31 | 0.48 |
| Digger, production (kg per FU) | 0.05 | 0.16 | 0.05 | 0.12 | 0.19 |
| Shed (m2 per FU) | 0.13 | 0.004 | 0.001 | 0.003 | 0.004 |
| Combining (kg diesel per FU) | 4.57 | 3.45 | 3.19 | 3.48 | 4.57 |
| Tractor, production (kg per FU) | 0.13 | 0.40 | 0.13 | 0.38 | 0.60 |
| Combine, production (kg per FU) | 0.06 | 0.19 | 0.06 | 0.19 | 0.29 |
| Shed (m2 per FU) | 0.001 | 0.004 | 0.001 | 0.003 | 0.01 |
| **Cover crop** | | | | | |
| Planting of cover crop (kg of rye seed per FU) | 9.84 | - | 13.11 | - | 26.23 |
| Planting of cover crop (kg diesel per FU) | 1.98 | - | 0.46 | - | 0.17 |
| Tractor, production (kg per FU) | 0.25 | - | 0.13 | - | 0.02 |
| Spreader, production (kg per FU) | 0.02 | - | 0.01 | - | 0.002 |
| Shed (m2 per FU) | 0.002 | - | 0.001 | - | 0.00002 |
| **Transportation** | | | | | |
| Farm to industry (kg diesel per FU) | 5.21 | 5.07 | 5.49 | 3.59 | 4.86 |
| **Final waste flows** | | | | | |
| HDPE bottles (kg per FU) | 0.16 | 0.14 | 0.19 | 0.10 | 0.16 |

**Table 1.** Inventory of the surveyed companies (C5 to C1) at the farm level.

selection and packing in big-bags of 1.25 t, or smaller bags of 25-50 kg, which are also stored in a cold warehouse. This process uses electricity and LPG. Co-products are skin (weighted average of 1%) (for animal feed), and damaged kernels (for the oil industry). The environmental impact of the production of bags, big-bags, and other packaging material is also included.

The lower quality kernels are separated from the main flow and are destined to oil production. The average distance to the oil plant is 55 km. In the peanut oil industry, 20%

| **Company** | **C5** | | **C4** | | **C3** | | **C2** | | **C1** | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Buying and curing** | **Input** | **Output** | **Input** | **Output** | **Input** | **Output** | **Input** | **Output** | **Input** | **Output** |
| Raw peanut (dirty) | **1** | | **1** | | **1** | | **1** | | **1** | |
| Foreign material (FM) | | 39.60 | | 98.80 | | 58.20 | | 49.20 | | 119.90 |
| Dirt | | 29.70 | | | | 70.40 | | 36.60 | | |
| Moisture | | 19.90 | | 18.00 | | 25.60 | | 25.60 | | 21.70 |
| Sampling (to the oil mill) | | 1.10 | | 1.10 | | 1.10 | | 1.10 | | 1.10 |
| *Peanut to shelling* | | **910** | | **882** | | **845** | | **888** | | **857** |
| Electricity (kwh) | 27.40 | | 21.90 | | 13.70 | | 17.30 | | 9.40 | |
| Natural gas (m3) | 5.40 | | 1.60 | | 8.40 | | 3.60 | | | |
| LPG (propane) (kg) | | | 0.30 | | | | 0.30 | | 4.10 | |
| Diesel (L) | 0.30 | | | | 0.90 | | | | | |
| **Shelling** | | | | | | | | | | |
| Raw peanut (clean and dried) | **910** | | **882** | | **845** | | **888** | | **857** | |
| Dirt | | | | | | 5.90 | | | | 42.90 |
| Foreign material (FM) | | | | | | 31.00 | | | | |
| Shelling (without foreign material) | | | | | | 25.00 | | | | |
| Hull | | 247.20 | | 266.10 | | 180.60 | | 270.00 | | 203.50 |
| Peanut to the oil mill | | 148.30 | | 127.70 | | 130.70 | | 123.40 | | 76.40 |
| *Shelled peanut* | | **514** | | **488** | | **471** | | **494** | | **535** |
| Electricity (kwh) | 44.20 | | 48.20 | | 46.90 | | 39.90 | | 51.70 | |
| Diesel (L) | 0.40 | | 1.00 | | 1.00 | | | | | |
| **Cold storage** | | | | | | | | | | |
| *Shelled peanut* | **514** | | **488** | | **471** | | **494** | | **535** | |
| Diesel (L) | 0.10 | | 0.50 | | 0.20 | | 0.70 | | 0.80 | |
| Electricity (kwh) | 5.80 | | 6.30 | | 4.20 | | | | 5.80 | |
| LPG (propane) (kg) | | | | | | | 0.50 | | 0.40 | |
| **Blanching** | | | | | | | | | | |
| *Shelled peanut* | **334** | | **254** | | **356** | | **198** | | **428** | |
| Skin | | 11.70 | | 5.20 | | 6.40 | | 10.90 | | 7.50 |
| Moisture | | 5.00 | | 5.20 | | 7.10 | | | | 8.60 |
| Peanut to the oil mill | | 16.70 | | 29.20 | | 12.50 | | | | 15.00 |
| Blanched peanut | | **301** | | **215** | | **330** | | **187** | | **397** |
| Electricity (kwh) | 10.00 | | 10.60 | | 11.70 | | 10.10 | | 9.90 | |
| Natural gas (m3) | 2.70 | | 4.70 | | 8.10 | | 3.80 | | 5.30 | |
| Diesel (L) | | | | | 0.0 | | | | | |
| LPG (propane) (kg) | | | | | | | 0.10 | | 0.0 | |
| **Transportation** | | | | | | | | | | |
| Truck to port-of-export (km) | 10 | | | | 495 | | 542 | | 551 | |
| Train to port-of-export (km) | 522 | | | | | | | | | |

**Table 2.** Inventory data for the mills of the surveyed companies (C5 to C1). Values are in kg, except indicated otherwise

| Product | USD/t |
|---|---|
| Essential oil | 5 |
| Flour | 2,5 |
| Refined oil | 1,5 |
| Oil | 1,114 |
| Blanched | 750 |
| Shelled | 750 |
| Peanut for oil | 420 |
| Skin | 300 |
| Expeller | 280 |
| Skin | 150 |
| Hull | 10 |

**Table 3.** Factors for economic allocation.

of oil is extracted by cold pressing, and 80% is obtained through solvent extraction. Data for the cold press industrial unit was surveyed, while data for extraction by solvent was taken from the ecoinvent database (ECOINVENT, 2014). A co-product of oil extraction is expeller, for animal feed. Economic value was used as allocation method.

The environmental impact of industrial machinery and infrastructure was taken into account.

### *Transportation of final products to port.*

The big bags of shelled and blanched peanuts are hauled to the port of Zárate, either by 22.5 t trucks, or by train. Table 4 provides detailed information of GWP of transportation, from farm to industry and from industry to port).

### *Co-product valorization*

Out of the total hull biomass, 71% is used for local cogeneration of electricity and steam; 27% is crushed to be used for heating in the cement industry (440 km round trip transport); and the remaining 2% is locally used for animal feed.

Considering the total energy contained in the biomass, 7% is transformed in electricity and 57% in heat, while the rest of the energy is lost (Goti, 2015). In the cement industry, 82% of the energy contained in the hull replaces natural gas (18% is lost), according to its calorific value, which is 17.6 MJ/kg for the peanut hull and 39 MJ/kg for natural gas.

| kg CO$_2$ eq per ton of raw peanuts | C5 | C4 | C3 | C1+2* | Sector | STD |
|---|---|---|---|---|---|---|
| Total w/o valorization of co-products | 229 | 236 | 256 | 254 | 237 | 13 |
| Total with co-product valorization | -1.1 | -4 | 110 | 93 | 41.1 | 61 |
| **Agricultural phase** | **92** | **80** | **79** | **85** | **87** | **6** |
| Vehicle use | 3 | 6 | 2 | 1 | 2 | **2** |
| Planting (seed and seeding) | 17 | 15 | 15 | 16 | 16 | **1** |
| Chemicals production | 19 | 17 | 14 | 15 | 17 | **2** |
| Spraying | 7 | 7 | 7 | 7 | 7 | **0** |
| Harvesting. Digging | 16 | 16 | 16 | 16 | 16 | **0** |
| Harvesting. Combining | 19 | 19 | 19 | 19 | 19 | **0** |
| Cover crop (seeds and seeding) | 12 | 0 | 6 | 11 | 10 | **3** |
| **Transportation** | **51** | **67** | **73** | **78** | **59** | **12** |
| Farm to industry | 33 | 22 | 35 | 31 | 32 | **6** |
| Industry to port | 18 | 45 | 38 | 48 | 27 | **13** |
| **Industrial phase** | **87** | **90** | **105** | **90** | **91** | **8** |
| Buying and curing | 33 | 27 | 37 | 24 | 31 | **6** |
| Shelling and processing | 23 | 27 | 26 | 28 | 25 | **2** |
| Storage | 4 | 5 | 3 | 7 | 5 | **2** |
| Blanching | 12 | 16 | 26 | 21 | 17 | **6** |
| Packaging | 3 | 3 | 2 | 3 | 3 | **0** |
| Oil production and transportation | 13 | 12 | 11 | 7 | 11 | **2** |
| **Co-product valorization** | **-231** | **-240** | **-146** | **-160** | **-196** | **48** |
| Hull use | -228 | -239 | -145 | -160 | -195 | **47** |
| Skin use | -2.3 | -1.0 | -1.3 | 0.0 | -1.4 | **1** |

**Table 4.** GWP by phase and company C1 to C5 (kg of CO2 eq impact per ton of raw peanuts).

* Companies C1 and C2 were considered as one unit. Even though they were surveyed separately, this decision was made due to the lack of data of some processes, and the similarities of operation of both companies.

| $kg\ CO_2\ eq$ / kg product | With co-product valorization | Without valorization |
|---|---|---|
| Peanut paste, all packaging* | 0.5 | 0.9 |
| Peanut paste, 1/2 kg container | 0.8 | 1.2 |
| Caramelized | 0.7 | 1.0 |
| Coated | 0.7 | 1.0 |
| Fried | 0.4 | 0.7 |
| Toasted | 0.4 | 0.8 |
| Refined oil | 0.4 | 0.5 |
| Essential oil | 1.0 | 1.6 |
| Meal | 0.7 | 1.1 |
| Chopped | 0.7 | 1.0 |

**Table 5.** GWP impact by final products (kg of CO2 eq per kg of product).

*A weighted average of peanut paste packed in plastic bins, steel drums, and cardboard boxes with polypropylene bags.

In the use of peanut hulls for animal feed, the environmental credit comes from the replacement of sorghum bales, based upon its fiber content in a 1:1 ratio (DE LEON, 2014).

The skin is also used for animal feed, replacing soybean meal, according to its protein content. Peanut skin contains 13% of protein, while soybean meal has 47% (GROSSO, 2014).

## RESULTS

A weighted average model was built (see “Sector” in Table 4), according to the market share of the five peanut mills surveyed. These mills process 46% of total national production, i.e., 470,000 t of raw peanuts out of a total production of 1 million t, which resulted in 223,000 t of shelled peanuts. Table 4 shows the individual contribution to GWP of each of the phases for companies number 1 through 5 (C1...C5), the weighted average of the sector (Sector) and the standard deviation (STD).

Results from Carbon Footprint are: Crop production and mill processing contribute with *87 kg $CO_2$ eq* (37%) and *91 kg $CO_2$ eq* (38%), respectively, while transportation contributes with *59 kg $CO_2$ eq* (25%). This analysis also considers the environmental benefits from the use of co-products, such as hull and skin. Even though its industrial use also generates some emissions, substantial environmental benefits were derived from the combustion of peanut hulls for electricity cogeneration and heat, which reduced $CO_2$ eq emissions by *196 kg $CO_2$ eq* (-83%), reaching a final value of *41 kg $CO_2$ eq*.

Without considering the environmental savings from the use of co-products, results from Carbon Footprint are *237 kg $CO_2$ eq*.

In the field stage, the ‘hotspot’ was ‘harvesting’ (41%), dominated by emissions from fuel combustion, followed by production of glyphosate (8.8%), which is the single most used pesticide and generates 10.5 kg $CO_2$ eq per kg of product. Other herbicides such as 2,4-D (9.3%); and fungicides (1.8%). In the mills, the ‘hotspot’ was ‘buying and curing’ activities (34%), mainly due to LPG burning as the source of energy for heating. Transportation ‘from farm to the mill´ (by truck) contributed with 54%, and ‘from mill to port’ (by truck and train) with 46%.

### Results for final products

Only one of the five surveyed companies produced some end-consumer products, such as peanut paste, toasted, fried, caramelized, coated, refined oil, essential oil, meal, and chopped peanuts. Results in Table 5 are expressed in kg $CO_2$ eq per kg of final product, following THE INTERNATIONAL EPD® SYSTEM, (2012).

Table 5 shows the results of the whole life cycle for the products considered. Shelled and blanched peanuts were considered as the raw material. Other inputs were energy (electricity and natural gas), wheat flour, sugar, salt, refined oil, and packaging.

Packaging has a significant impact on the results. It was more important when the product was presented in smaller sizes. In some products, like coated peanuts, there is a substantial contribution to GWP from other ingredients, such as flour, sugar, salt, flavoring, etc., representing 50% of the total weight. Since allocation was based upon economic value, the high impact of the essential oil is explained mainly by its high price.

### Sensitivity analysis

Scenario 1: In Argentina, no-till planting is a common practice in peanut crops. Nevertheless, few farmers still prefer to perform a reduced-till, since they consider that surface soil removal may be beneficial for the peanut pods. Therefore, the scenario considers crop production with reduced-till instead of no-till. Results show a 5% increase in GWP, due to lower yields (-15%).

Scenario 2: In Central Córdoba, the train system has been assigned by the government to only one milling company by a long-term contract. Therefore, access of other companies to transportation by train is limited. This scenario considers the transportation of finished products by train instead of truck plus train. Even though the distance is the same, hauling by train is cleaner, reducing GWP by 6%, due to lower fuel consumption per unit of product transported.

Scenario 3: Nutrient balance. Since no fertilizers are commonly used in peanuts, creating a negative externality on the environment and on the rotation crops, the nutrient balance approach (IPNI, 2010) was used to estimate the amount of fertilizers required to compensate soil nutrients extraction: 3.05 t/ha of peanuts need 132.5 kg/ha of nitrogen (N), 27.4 kg/ha of phosphorous ($P_2O_5$), 40.3 kg/ha of potassium ($K_2O$), and 9 kg/ha of sulfur (S). Therefore, the balance considers the application of 288 kg/ha of urea ($CH_4N_2O$), 137.06 kg/ha of diammonium phosphate ($(NH_4)2HPO_4$), 67.20 kg/ha de potassium chloride (KCl), and 50 kg/ha of calcium sulfate ($CaSO_4$). The use of a tractor and an applicator is considered. Using data from the ecoinvent database (Ecoinvent, 2014), results show that production and application of fertilizers in peanut crops increase GWP by 160%, keeping yields constant. A limitation of this scenario is that no marginal yield increases were considered, because this is a hypothetical situation: the data used here comes from regional average yields, peanut crops are not fertilized at all, and crop yield simulation models exceed the scope of this research. It should be highlighted that only global warming impact is considered here, without taking into account other impacts, such as soil erosion, etc.

Scenarios 1 and 2 do not significantly influence the results, while scenario 3 does. These values do not take into account the valorization of co-products, which would further reduce GWP by -196 kg $CO_2$ eq.

## CONCLUSIONS

A Carbon Footprint analysis was successfully performed on the Argentine peanut value chain. This research is the first assessment of peanut value chain contribution to the global warming potential (GWP). Results can be available as an input in future research of the environmental impact of other food products that use peanut as ingredient.

Results from the Carbon Footprint analysis in the base-case scenario lead to the conclusion that the main stages of peanut production have approximately the same environmental impact. *Crop production* and *mill processing* contributed with 37% and 38%, respectively to the total GWP of the peanut value chain, while *transportation* contributes with 25%. The valorization of co-products reduces GWP by -83%.

At the *crop production* level, there are opportunities to optimize the use of diesel consumption, especially during harvest; as well as in the quantities of pesticides used. Hotspots in *crop production* stage are harvesting (41%), followed by production of glyphosate (8.8%), other herbicides (9.3%), and fungicides (1.8%).

In the *milling stage*, the hotspot were buying and curing activities (34%) due to the use of fossil fuels, especially LPG in those mills that do not have access to natural gas. In *transportation*, *farm-to-mill* has a greater impact (54%) than *mill-to-port* (46%), because of the use of train, and because the load is half of the reference flow (one t of raw peanuts at farm gate), even though the distance nearly triples.

It should be noted that the total weight transported ‘from farm to mill´ is approximately twice as much as that ‘from mill to port’, but the latter distance is three times greater than that ‘from farm to mill. Nevertheless, transportation ‘from mill to port’ has a lower impact, due to the use of a combination of truck and train.

Regarding final products, results show that the smaller the fractionation size, the greater the relative impact.

Sensitivity analysis shows that reduced till has a greater impact (+5%) than no till, due to the lower yields obtained (-15%). Transportation by train has a lower impact (-6%) than transportation by truck. Nutrient balance increases GWP by 159%, due to the production of urea (81%), diammonium phosphate (15%) and potassium chloride (3%).

Recommendations: to improve the system, we suggest fine-tuning the rate of glyphosate used in the crop in the first place, which has a GWP of 10.5 kg per kg of product. On the other hand, using a spreader for seeding the cover crop (barley) has a significantly lower impact than a drill. Pre-cleaning raw peanuts at farm gate would help to avoid transportation of dust and foreign material. Curing peanut at the farm should be evaluated as well. The sector would benefit from infrastructure for providing natural gas, as a cleaner alternative to LPG. Investment projects can be proposed for several ways of using peanut-hull, especially for those involving production of electricity and heat. Strategies for extending the use of train as a mean of transport should be considered. Peanuts packaging should be chosen based upon its environmental impact.

This analysis points the way for further research. One limitation of this study is that the peanut crop considered involves only one season, in a four-year rotation with other crops, such as corn, soybeans, and wheat; or with pastures for animal production. A comprehensive model should consider the peanut crop as a component of a larger production system.

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Conflict of Interest

The authors declare that they have no conflict of interest.