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Life Cycle Assessment of the Peanut Value Chain in Central Argentina

LCA of Peanuts in Argentina

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Abstract

This study presents a comprehensive Life Cycle Assessment (LCA) of seven peanut-derived products processed in central Argentina, aiming to quantify their environmental impacts from agricultural production to end-of-life. The research is framed within the development of Environmental Product Declarations (EPD) in accordance with ISO 14025, 14067 and 14040 standards, using primary data from three farms and one industrial facility representative of the sector. IPCC Tier 2 methodology was applied, with emission factors specific for Argentina, enabling a precise and context-sensitive environmental evaluation. Results show that the agricultural stage is the main source of greenhouse gas emissions (40–66%), particularly due to soil and crop residue management. International distribution, mainly maritime, also represents a significant burden (16–24%). Compared to equivalent products from Brazil and the USA, Argentine peanut products show environmental advantages in terms of carbon footprint, which was 67% lower for peanut butter than in the USA, and 21%lower for blanched peanuts than those from Brazil. The assessment identified opportunities to improve precision agriculture, renewable energy use, and estimation of soil carbon changes, and to optimize packaging. This work provides novel data for the region, strengthens the international competitiveness of Argentina's peanut sector, and offers valuable inputs for public policy making and business strategies focused on sustainability.

Keywords: life cycle assessment (LCA); environmental product declaration (EPD); peanut value chain; carbon footprint; sustainability

Introduction

The peanut complex

In Argentina, peanut (*Arachis hypogaea* L.) crop, which is mostly concentrated in the province of Córdoba, has shown a notable capacity to adapt to adverse climatic conditions. With a total of 532,991 hectares planted nationally and an estimated production of 1.81 million tons, the 2024/25 season has reached historic records, positioning Argentina among the top peanut-exporting countries globally. At the provincial level, Córdoba stands out as the leading peanut-producing region, accounting for 70% of the cultivated area in the country, with over 374,000 hectares. It is followed by the provinces of Buenos Aires, which covers nearly 85,000 hectares (16% of the national total), and La Pampa with 37,000 hectares (7%). This growth not only reflects improved yields (4.13 t/ha in Córdoba), but also a strategic decision by producers to diversify in response to the declining profitability of crops such as soybean and corn (Bolsa de Comercio de Rosario, 2025).

In the 2024/25 crop season, Argentina has ranked as the world's leading peanut exporter, with exports reaching 35 million tons. India holds the second place, with 0.98 million tons of projected exports, and China ranks third, with 0.65 million tons. Exported products included shelled peanuts (USD 527 million), roasted peanuts and peanut butter (USD 81 million), peanut oil (USD 64 million) and pellet/expeller (USD 5.1 million). The European Union is the main importer from Argentina, accounting for 60% of the total Argentine exports (Ferrari, Ramseyer, & Terré, 2025).

Peanut industry in Argentina has become a significant regional economic activity, providing more than 12,000 jobs and with exports exceeding USD 1000 million annually. The industrial sector has state-of-the-art processing plants, with many of them having installed production capacity higher than the actual production, which enables to project an increase in processing volume (Cámara Argentina del Maní, 2022).

The growing global awareness about climate change and sustainability has exerted unprecedented pressure on agri-food supply chains. International markets, regulators and consumers demand transparency of the environmental impact of products; in this context, quantification tools have turned into a strategic imperative. Thus, the Life Cycle Assessment (LCA) has become the principal method to evaluate the environmental impacts of a product along its entire value chain. The Environmental Product Declarations (EPDs) emerged as a standardized and verifiable mechanism to communicate the LCA results, in compliance with international regulations, such as ISO 14025, 14067 and 14040 standards. A Type III EPD represents a formal validation of the environmental performance of a product and serves as a fundamental tool for differentiating the product in highly competitive markets and for meeting the commercial demands of a globalized world.

The LCA has been the focus of studies in the agricultural sector in diverse geographic regions. However, no complete LCA has been conducted for peanuts in the world. Argentina, one of the world's leading peanut producers and exporters, lacks a thorough "cradle-to-grave" study. There is no accurate knowledge about the complete environmental profile of a vertically integrated supply chain, one that simultaneously evaluates agricultural production and industrialization of several byproducts, from raw peanut to the most complex processed products. The lack of regional data of life cycle inventory and emission factors for Argentina is a critical gap of scientific knowledge, especially regarding the influence of soil management practices, like conventional tillage and its impact on carbon emissions. The studies often focus on geographical areas where energy matrices and agricultural practices differ significantly from the local ones. There are some reference studies of peanut products that have quantified environmental footprints in highly productive areas and that have provided valuable reference information for the industry and the academia. For instance, in the USA, a mean carbon footprint of 2.88 kg CO_2 equivalent (CO_2eq) was calculated per kg of peanut butter produced and traded at the national level (McCarty J. A., Sandefur, Matlock, & Kim, 2014) (McCarty, Ramsey, & Sandefur, 2016) (McCarty, Matlock, Ramsey, & Sandefur, 2016). Likewise, an impact of 0.67 kg CO_2eq/kg was calculated for blanched peanuts in Brazil (Ramos N. P., et al., 2023). This value is very useful for comparisons with our findings, since peanut cropping practices in both countries are similar.

Results of a cradle-to-grave analysis for peanuts in Argentina would make a great contribution. Quantifying environmental footprints results in a roadmap for continuous improvement. Identifying the stages of greatest impact, i.e., hotspots, allows producers or industries to direct their investments to cleaner technologies, optimize processes and reduce costs, thereby strengthening their competitiveness in international markets. Knowledge of the environmental profile of local products boosts transparency for consumers and validates the commitment of the peanut sector to sustainability; thus, this knowledge becomes a differentiating factor and an added value, both crucial aspects in international trade.

The aim of this work was to determine the environmental impacts along the value chain of seven peanut products elaborated in the central region of Argentina, from agricultural production to the end-of-life. An LCA was performed, which can inform EPD and support continuous improvement and sustainability validation. This work follows the authors' research line (Bongiovanni, Tuninetti, & Garrido, 2016), using the LCA method to evaluate the entire value chain, from cradle-to-grave of peanut products, but also including the environmental impact categories required by EPD as well as the carbon footprint.

Materials and Methods

Life Cycle Assessment.

Life Cycle Assessment is a methodological frame standardized by ISO 14040 and ISO 14044, which allows us to account for the environmental burden generated by a product or service along its life cycle. Its theoretical basis lies in a systemic approach that goes beyond the emission measurements at a specific point of the production process and encompasses from the extraction of raw materials (cradle) to a product's end-of-life (grave). This comprehensive approach contrasts sharply with the partial environmental impact assessments, such as a simple measurement of emissions at the farm gate or factory gate, offering a holistic and objective view of environmental externalities. The products evaluated in this study are commercialized under a Business-to-Business (B2B) model.

The robustness of LCA lies in its capacity to identify the transfer of environmental burdens along the value chain, a phenomenon that specific measurements fail to detect. For example, an analysis of the emissions at the processing plant might detect a low impact but would ignore the high impacts generated during agricultural production or long-distance transportation. The LCA's "cradle-to-grave" approach allows an accurate diagnosis of the environmental hotspots, providing a roadmap for continuous improvement.

Declared Units

The declared units followed the Central Product Classification CPC 21421: 1 kilogram of shelled peanuts and 1 kilogram of blanched peanuts. In addition, following CPC 21495: 1 kilogram of roasted peanuts, 1 kilogram of peanut granules, 1 kilogram of fried peanuts, 1 kilogram of peanut paste, and 1 kilogram of peanut butter were considered. For each product, 1 kilogram does not include the packaging weight.

Geographical and Temporal Scope

Data were obtained from three farms representative of peanut production in Argentina: two in the province of Córdoba (Tercero Arriba and General Roca departments) and one in Buenos Aires province (Lincoln district). The industry is located in Hernando, Córdoba province, and the products are mostly exported to Europe. The analysis covers the 2023/2024 peanut crop season and the calendar year 2024 for industrial data.

Primary peanut production on the farm

The following factors were included: production and use of agricultural inputs (agrochemicals, fertilizers, fuel, seeds), production of their packaging, emissions from the use of fuels for transport and agricultural activities (planting, spraying, and digging and harvesting), emissions from the application of nitrogen fertilizers, and those from above- and below-ground residue decomposition. Data of use of fuels and inputs were taken from the records of each farm.

Weighted averages of the results obtained from the farms were calculated so that the input to the industry represents output from the field

For the agricultural stage, direct emissions from the application of nitrogen fertilizers—which were used only in low rates as foliar feeding—as well as from decomposition of above- and below-ground crop residues, were considered. These emissions were calculated using Intergovernmental Panel on Climate Change (IPCC) tier 2 methodology, with default equations and emission factors specific for Argentina, taken from the Biennial Update Reports of the Ministry of Environment and Sustainable Development (MAyDS, 2023). This approach improves accuracy, since it uses disaggregated activity data.

On the farm located in Tercero Arriba department, Córdoba, yield was 4000 kg/ha of in-shell peanut. Fungicide/insecticide-treated seeds were planted at a density of 175 kg/ha using paratill, weeder, double action disc harrow and conventional planter. Crop fertilization consisted of 1.57 kg/ha of compound fertilizer and 0.63 kg/ha of micronutrients, i.e., a total rate of 2.2 kg/ha. Crop

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protection included the application of herbicides (4.88 kg/ha of ai), insecticides (0.091 kg/ha ai) and fungicides (3.95 kg/ha ai). The amount of agrochemical packaging waste was 0.54 kg/ha of plastic material, which was destined for recycling. Fuel consumption was 67.67 L/ha of diesel; for technical assistance, a truck travelled 2 km per cultivated ha. Input transport required 8 km by truck (3.5 to 7.5 t load capacity). Transport of in-shell peanuts from the farm to the processing plant was also 8 km by truck (16 to 32 t load capacity). Transport of agrochemical packaging waste covered 115 km by truck (3.5 to 7.5 t load capacity). Crop residues were left on the soil surface as cover and no cover crops were used.

On the farm of Lincoln district, Buenos Aires, yield was 5,700 kg/ha of in-shell peanuts. Fungicide/insecticide-treated seeds were planted at a density of 175 kg/ha, using double action disc harrow, and conventional tillage. No fertilization was applied to the crop. Crop protection consisted of the application of herbicides (6.14 kg/ha ai), insecticides (0.10 kg/ha ai) and fungicides (3.39 kg/ha ai). The amount of agrochemical packaging waste was 0.58 kg/ha of plastic material, which was destined for recycling. Fuel consumed amounted to 58.23 L/ha of gas oil; for technical assistance, a pick-up truck travelled 23.34 km per cultivated ha. Transport of inputs covered 28.75 km by truck (3.5 to 7.5 t load capacity). Transport of in-shell peanuts from the farm to the processing plant covered 505 km by truck (16 to 32 t load capacity). Transport of agrochemical packaging waste covered 65 km by truck (3.5 to 7.5 t load capacity). Crop residues were left on the soil surface as cover and no cover crops were used.

On the farm of General Roca department, Córdoba, yield was 6,200 kg/ha of in-shell peanut. Treated seeds were planted at a density of 175 kg/ha, using weeder and no-till planter. No fertilization was applied. Crop protection included herbicides (7.09 kg/ha ai), insecticides (0.088 kg/ha ai) and fungicides (3.12 kg/ha ai). The amount of agrochemical packaging waste was 0.62 kg/ha of plastic material, which was destined for recycling. Gas oil consumed amounted to 48.99 L/ha, and 12.47 km were travelled by pick-up truck for technical assistance per cultivated ha. Input transport covered 6 km by truck (3.5 to 7.5 t load capacity). Transport of in-shell peanuts from the farm to the processing plant covered 300 km by truck (16 to 32 t load capacity). Transport of packaging waste covered 82 km by truck (3.5 to 7.5 t load capacity). Crop residues were left on the surface as cover and no cover crops were used.

Peanut processing industry

Primary data of peanut processing to obtain products, like shelled peanuts, blanched peanuts and their byproducts, were provided by a company representative of the sector, located in Hernando, Córdoba. For each product, the company identified the use of inputs, fuel and energy, the suppliers involved, the process losses and the byproducts obtained.

Regarding logistics, all the types of packaging materials used for the commercialization of each product were included; they were calculated according to the percentage of participation in the total volume exported. The analysis takes into account the terrestrial transportation by truck to the port and the marine transportation to the final destination. Lastly, final disposal of packaging materials was considered, thereby completing the product's life cycle.

Figure 1 shows the stages included in the study, with the division between upstream, core and downstream processes, as requested by the Product Category Rules (PCR). All the declared units and their relationships are shown.

The industrial process starts with the reception of in-shell peanuts, which are dirty and moist, in bulk in trucks. Upon arrival at the plant, each truck is weighed, and samples are collected for further laboratory analysis, following quality rules. If peanuts comply with the requirements, they are received at the plant. Once unloaded, peanuts are subjected to mechanical pre-cleaning using aspiration and screening procedures to remove large foreign materials, like stones, stems, leaves and other visible debris. Then, to avoid fungal development, peanuts are dried, if necessary, to reach less than 10% moisture. This process is conducted in double-floor drying wagons, through which air at room or high temperature –depending on the environmental humidity– is blown. Once dried, peanuts are stored in bins until processing. These processes entail losses due to dirt, foreign materials and moisture.

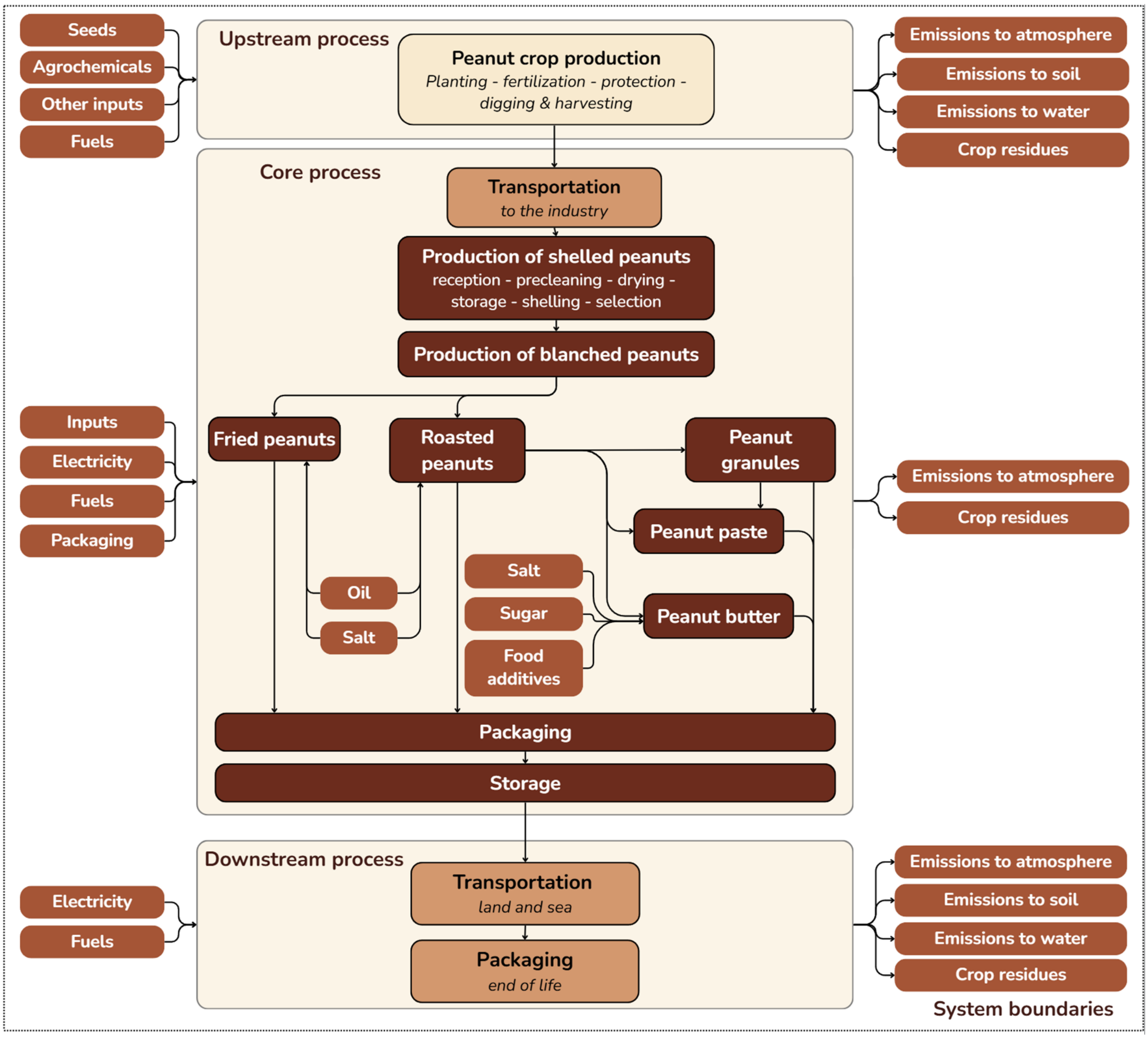

Figure 1. Stages of the production system and system boundaries.

At the cleaning stage, in-shell peanuts pass through a series of devices that remove heavy elements, like stones, dust and leaves, through aspiration. After this process, the in-shell peanuts are introduced into the shelling machine, where the shell is removed by some rollers and the shell remains are separated from the grain. Then the grains undergo a three-type sorting process: sorting by size and color, and a visual sorting. At this initial stage, the shelled peanuts are obtained, which are stored in big bags until the next stage or commercialization. In addition, shells are obtained as a byproduct that is sold for energy generation; peanuts rejected during processing are sold to the oil industry, and there are losses due to dirt or foreign materials.

To produce blanched peanuts, shelled peanut grains are heated in an oven; then they are cooled to achieve seed contraction and skin loosening. Then grains pass between rollers with rough surface that retain and aspire the skin, and then by a series of screens for final skin removal. Then there is another sorting stage, when whole grains are separated from the split ones, and are classified by size. Byproducts recovered from the sorter are obtained; they can be derived to other lines; the skin is sold for energy generation, and sorter rejects are used in the oil industry. There are also losses due to moisture. Blanched peanuts are stored in big bags.

Roasted peanuts can be produced using both shelled and blanched peanuts, with the latter being the most used. Roasting involves putting the peanuts in an oven at controlled temperature (160 to

180 C). After this process, peanuts are rapidly cooled with air to stop the roasting process. Besides roasted peanuts with or without skin, salted peanuts can also be obtained; in this case, oil is added before roasting. Once the products are cooled, they are packed and stored.

Fried peanuts can also be produced using both shelled and blanched peanuts, most commonly using peanuts without skin. Unlike roasted peanuts, peanuts are fried in oil at about 160 C, then they are placed on a mesh conveyor where they are cooled, and the excess oil is drained. Finally, peanuts are salted in a rotating cylinder. At the end of the process, fried peanuts pass along a belt for packaging and further storage.

Peanut butter is produced with roasted peanuts without skin. Peanut grains are ground with rollers, until a creamy consistency is obtained. Then salt, sugar and stabilizer are added, and the butter is homogenized. Finally, the product is packaged using the different packaging options offered by the company.

Peanut paste is produced in a similar way to that of peanut butter, but no ingredients are added. Once the desired consistency is obtained by grinding, it can be packed as a finished product, or granules can be added to obtain a crunchier paste.

Finally, peanut granules are produced by partially grinding roasted peanuts without skin; then they are packaged and stored.

Production Seasonality and Emissions

Industrial processes depend on the peanut harvest time. Peanut reception at the industry starts between March and April and ends in July. The peaks of electricity consumption occur in the transformers feeding the selection plant, blanching and unloading in bins. Peaks of natural gas consumption occur in the drying process, immediately after reception at the plant.

Transportation and Logistics

Transport at the primary production stage includes the supply of agricultural inputs, raw materials, and fuel for peanut production, as well as the transport to (loaded) and from (empty) the processing plant (203 km) in Hernando. For the processing stage, the transportation of inputs, fuel and associated packaging was included. In addition, waste similar to urban waste, which is disposed of at the dump site of Hernando, 5 km away from the plant, and hazardous waste, which is disposed of in Córdoba city, 150 km away, were considered.

All the finished products analyzed are mainly destined for export. The distance covered by truck from the plant to the Buenos Aires port (620 km) was considered, as well as the marine transportation (11,928 km) to Europe, as reported by the company.

All the packaging materials required, including plastic containers, cardboard boxes, polythene bags, multilayered bags, big bags, metal drums, and pallets, among other elements, were assumed to be disposed of in a sanitary landfill at the end of their shelf life. This conservative model was selected, since there is no information on how companies buying the inputs manage packaging waste.

Models for the characterization of environmental impact

Selection of models for the characterization of environmental impact used are in line with the scientific principles that describe the environmental phenomena evaluated. The impact categories recommended by the PCR of the EPD system (https://www.environdec.com/pcr/env-perf-indic/gpi5) applied in this study are detailed in Table 1.

Table 1. Categories of environmental impact, parameters evaluated and models applied |.

Environmental impact category	Parameter	Model
Climate change– total	kg CO_2 eq	IPCC's baseline model of GHG emissions for a 100-year timescale (IPCC, 2021)
Ozone depletion potential	kg CFC-11 eq	Ozone destruction exceeds ozone creation (EU-ILCD, 2010; WMO, 2014)

Environmental impact category	Parameter	Model
Acidification	mol H+ eq	Proton release or acid rain (Seppälä et al., 2006; Posch et al., 2008).
Eutrophication—freshwater	kg P eq	Excessive nutrients in freshwater, ReCiPe (Struijs et al., 2009; Huijbregts et al., 2017; Eutrend, 2021)
Eutrophication – aquatic marine	kg N eq	Excessive nutrients in marine environment, ReCiPe (Struijs et al., 2009; Huijbregts et al., 2017; Eutrend, 2021).
Eutrophication—terrestrial	mol N eq	Excessive nutrients in soils (Seppälä et al., 2006; Posch et al., 2008)
Photochemical ozone creation	kg NMVOC eq	Degradation (NOx, VOCs) in the presence of sunlight. ReCiPe Method. (Struijs et al., 2009; van Zelm and Hollander, 2008).
Depletion of abiotic resources – minerals and metals	kg Sb eq	kg Sb eq/MJ, CML Method (van Oers and Guinée, 2016; Guinée et al., 2002).
Depletion of abiotic resources – fossil fuels	MJ, net calorific value	kg Sb eq / kg of extracted resource, CML Method (van —and Guinée, 2016; Guinée et al., 2002).
Water deprivation	m^3 world eq of deprived water	AWARE (Available Water Remaining) method + ISO 14046 2014 (Boulay et al., 2018).

Allocation of Environmental Burdens

Within the frame of the LCA, allocation of environmental burdens is a crucial theoretical challenge in modelling production of processed peanuts to avoid over- or underestimating impacts. Allocation theory determines that environmental burdens generated during a shared process should be distributed among the different co-products and byproducts that have economic value. In this study, the allocation method was based on a biophysical criterion, specifically by mass of products and byproducts (e.g., shell, skin), following the guidelines of the PCR for “Food and Beverage Products” (International EPD System, 2025). The selected method ensures an equal distribution of environmental burdens, reflecting the actual material burden of the production system.

Figure 2 shows the processes of allocation. Since all the products share some part of the production chain, all the declared units are affected by at least one allocation. Table 2 presents the allocation of environmental burden to the products and byproducts.

Table 2. Percentage of environmental burden allocated based on mass in the industry.

Allocation of environmental burdens	Percent allocated based on mass (%)
Production of shelled peanuts (1)	
Shelled peanuts	64.3%
Byproduct- Peanuts recovered from sorter: peanuts rejected by sorter, which can be recovered through reprocessing or use as raw material in other lines.	3.8%
Byproduct—Peanut shell: sold for generation of energy	23.5%
Production of blanched peanuts (2)	
Blanched peanuts	80.5%
Byproduct- Peanuts recovered from sorter: peanuts rejected by sorter, which can be recovered through reprocessing or use as raw material in other lines.	13.8%
Byproduct—Skin: sold for generation of energy.	3.8%

Allocation of environmental burdens	**Percent allocated based on mass (%)**
Byproduct—Peanuts for industry: sold for the peanut oil industry.	2.0%
Production of roasted peanuts (3)	
Roasted peanuts without additives	86.6%
Byproduct—Peanuts for industry: sold for the peanut oil industry.	13.4%
Production of fried peanuts (4)	
Fried peanuts without additives	99.0%
Byproduct—Peanuts for industry: sold for the peanut oil industry.	1.0%
Production of peanut granules (5)	
Peanut granules	80.1%
Byproduct— Peanut flour: traded as a product	4.4%
Byproduct—Peanuts for industry: sold for the peanut oil industry.	15.6%

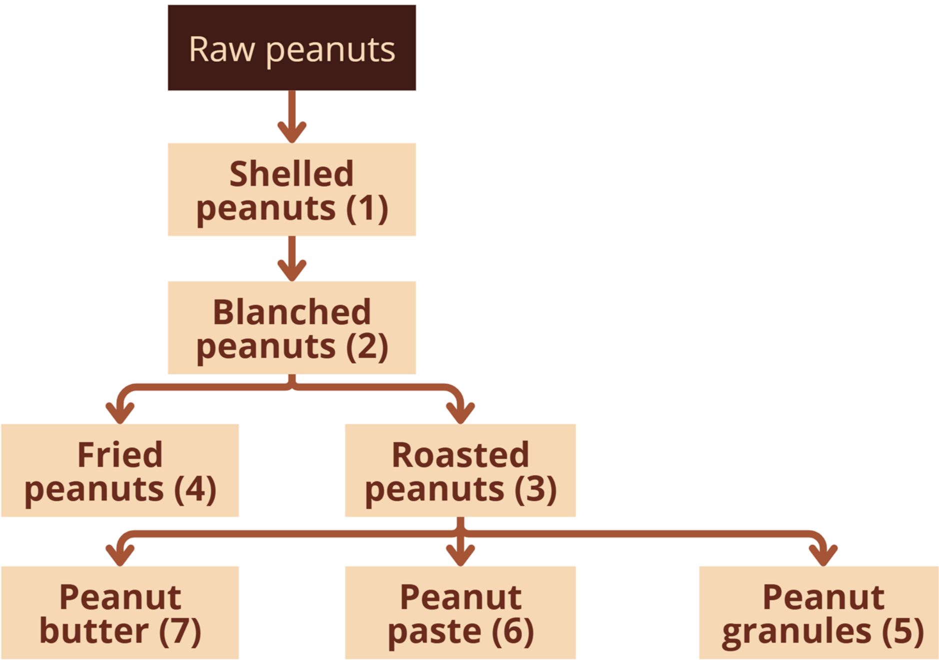

Figure 2. Diagram of product integration with identification of allocation points. Numbers in parenthesis correspond to numbers of products in Table 2.

For peanut butter and paste, environmental burdens were also allocated based on mass because they generate byproducts for the oil industry. However, they were not included in the table because the amount was lower than 0.1%.

After the input and output inventories of each operation and stage were generated, the unit emissions associated with each input were obtained: inputs, raw materials and energy referring to the corresponding declared unit. Then, the amounts used of each "input" were associated with their unit emissions to obtain the environmental impact for each inventory element.

Results and Discussion

The results of the LCA of peanut products (shelled peanuts, blanched peanuts, roasted peanuts, peanut granules, fried peanuts, peanut paste and peanut butter), from peanut production in the field, through industrial processes to elaborate each product, packaging and storage, to their commercialization in international markets, are detailed in Tables 3 to 9. Results are grouped into upstream, core and downstream processes, and their corresponding substages.

Table 3. Indicators of impact category and of use of resources for the declared unit 1 kilogram of packaged SHELLED peanuts delivered to the customer.

PARAMETER		**UNIT**	**Upstream**		**Core**	
			Agricultural production	**Packaging production**	**Transport from field**	**Industry**
Global warming potential (GWP)	Fossil	kg CO_2 eq	6.99E-2	8.00E-3	2.47E-2	3.00E-2
	Biogenic		9.99E-2	9.43E-5	9.95E-7	2.27E-4
	Land use and land use change		2.49E-1	1.06E-5	7.15E-7	4.08E-4
	TOTAL		4.19E-1	8.11E-3	2.47E-2	3.06E-2
Ozone depletion potential (ODP)		kg CFC 11 eq	2,39E-7	2.16E-10	3.28E-10	5.29E-10
Acidification potential (AP)		mol H+ eq	6,54E-4	2.85E-5	6.12E-5	4.77E-5
Eutrophication potential (EP)	Aquatic freshwater	kg P eq	5.58E-5	2.01E-6	4.97E-7	5.11E-7
	Aquatic marine	kg N eq	2.09E-4	7.46E-6	2.14E-5	1.17E-5
	Aquatic terrestrial	mol N eq	2.21E-3	6.59E-5	2.34E-4	1.23E-4
Photochemical ozone creation potential (POCP)		kg NMVOC eq	6.91E-4	3.90E-5	9.14E-5	7.88E-5
Abiotic depletion potential (ADP)	Metals and minerals	kg Sb eq	2.11E-8	1.25E-9	1.45E-9	1.30E-9
	Fossil resources	MJ, net calorific value	1.02E+0	1.88E-1	3.27E-1	5.26E-1
Water deprivation potential (WDP)		m^3 world eq deprived	1.03E-2	4.26E-3	3.01E-4	2.62E-2
Primary energy resources —Renewable	Use as energy carrier	MJ, net calorific value	2.23E-2	1.66E-2	5.24E-4	7.14E-2
	Used as raw materials		0.00E+0	1.02E-2	0.00E+0	0.00E+0
	TOTAL		2.23E-2	2.68E-2	5.24E-4	7.14E-2
Primary energy resources —Non-renewable	Use as energy carrier		1.02E+0	1.88E-1	3.27E-1	5.26E-1
	Used as raw materials		0.00E+0	8.51E-2	0.00E+	0.00E+0
	TOTAL		1.02E+0	2.73E-1	3.27E-1	5.26E-1

PARAMETER		**UNIT**	**Downstream**		**TOTAL**
			Distribution	**End-of-life**	
Global warming potential (GWP)	Fossil	kg CO_2 eq	1.49E-1	3.51E-5	**2.82E-1**
	Biogenic		5.40E-6	1.67E-9	**1.00E-1**
	Land use and land use change		4.28E-6	1.11E-9	**2.49E-1**
	TOTAL		1.49E-1	3.51E-5	**6.31E-1**

Ozone depletion potential (ODP)		kg CFC 11 eq	2.10E-9	4.79E-13	**2.42E-7**
Acidification potential (AP)		mol H+ eq	2.38E-3	1.41E-7	**3.17E-3**
Eutrophication potential (EP)	Aquatic freshwater	kg P eq	1.93E-6	7.85E-10	**6.08E-5**
	Aquatic marine	kg N eq	5.64E-4	5.74E-8	**8.13E-4**
	Aquatic terrestrial	mol N eq	6.27E-3	6.28E-7	**8.91E-3**
Photochemical ozone creation potential (POCP)		kg NMVOC eq	1.78E-3	2.12E-7	**2.68E-3**
Abiotic depletion potential (ADP)	Metals and minerals	kg Sb eq	4.99E-9	1.92E-12	**3.01E-8**
	Fossil resources	MJ, net calorific value	1.90E+0	4.62E-4	**3.96E+0**
Water deprivation potential (WDP)		m^3 world eq deprived	1.23E-3	4.24E-7	**4.24E-2**
Primary energy resources — Renewable	Use as energy carrier	MJ, net calorific value	3.35E-3	1.01E-6	**1.14E-1**
	Used as raw materials		0.00E+0	0.00E+0	**1.02E-2**
	TOTAL		3.35E-3	1.01E-6	**1.24E-1**
Primary energy resources —Non-renewable	Use as energy carrier		1.90E+0	4.62E-4	**3.96E+0**
	Used as raw materials		0.00E+0	0.00E+0	**8.51E-2**
	TOTAL		1.90E+0	4.62E-4	**4.05E+0**

Table 4. Indicators of impact category and of use of resources for the declared unit 1 kilogram of packaged BLANCHED peanuts delivered to the customer.

PARAMETER		**UNIT**	**Upstream**			**Core**	
			Agricultural production	**Packaging**	**Pre-industry**	**Transport**	**Industry**
Global warming potential (GWP)	Fossil	kg CO_2 eq	7.13E-2	8.00E-3	2.98E-2	2.52E-2	3.68E-2
	Biogenic		1.02E-1	9.43E-5	2.25E-4	1.02E-6	1.01E-4
	Land use and land use change		2.54E-1	1.06E-5	4.05E-4	7.31E-7	1.75E-4
	TOTAL		4.27E-1	8.11E-3	3.04E-2	2.52E-2	3.71E-2
Ozone depletion potential (ODP)		kg CFC 11 eq	2,43E-7	2.16E-10	5.25E-10	3.36E-10	7.00E-10
Acidification potential (AP)		mol H+ eq	6,67E-4	2.85E-5	4.73E-5	6.26E-5	3.50E-5
Eutrophication potential (EP)	Aquatic freshwater	kg P eq	5.69E-5	2.01E-6	5.11E-7	5.09E-7	3.99E-7
	Aquatic marine	kg N eq	2.13E-4	7.46E-6	1.16E-5	2.18E-5	9.34E-6

	Aquatic terrestrial	mol N eq	2.25E-3	6.59E-5	1.22E-4	2.40E-4	9.85E-5
Photochemical ozone creation potential (POCP)		kg NMVOC eq	7.05E-4	3.90E-5	7.87E-5	9.35E-5	7.64E-5
Abiotic depletion potential (ADP)	Metals and minerals	kg Sb eq	2.15E-8	1.25E-9	1.30E-9	1.48E-9	4.88E-10
	Fossil resources	MJ, net calorific value	1.04E+0	1.88E-1	5.22E-1	3.34E-1	6.08E-1
Water deprivation potential (WDP)		m^3 world eq deprived	1.05E-2	4.26E-3	2.60E-2	3.08E-4	1.16E-2
Primary energy resources—Renewable	Use as energy carrier	MJ, net calorific value	2.27E-2	1.66E-2	7.08E-2	5.36E-4	3.18E-2
	Used as raw materials		0.00E+0	1.02E-2	0.00E+0	0.00E+0	0.00E+0
	TOTAL		2.27E-2	2.68E-2	7.08E-2	5.36E-4	3.18E-2
Primary energy resources—Non-renewable	Use as energy carrier		1.04E+0	1.88E-1	5.22E-1	3.34E-1	6.08E-1
	Used as raw materials		0.00E+0	8.51E-2	0.00E+0	0.00E+0	0.00E+0
	TOTAL		1.04E+0	2.73E-1	5.22E-1	3.34E-1	6.08E-1

PARAMETER		**UNIT**	**Downstream**		**TOTAL**
			Distribution	**End-of-life**	
Global warming potential (GWP)	Fossil	kg CO_2 eq	1.49E-1	3.51E-5	**3.20E-1**
	Biogenic		5.40E-6	1.67E-9	**1.02E-1**
	Land use and land use change		4.28E-6	1.11E-9	**2.54E-1**
	TOTAL		1.49E-1	3.51E-5	**6.77E-1**
Ozone depletion potential (ODP)		kg CFC 11 eq	2.10E-9	4.79E-13	**2.47E-7**
Acidification potential (AP)		mol H+ eq	2.38E-3	1.41E-7	**3.22E-3**
Eutrophication potential (EP)	Aquatic freshwater	kg P eq	1.93E-6	7.85E-10	**6.23E-5**
	Aquatic marine	kg N eq	5.64E-4	5.74E-8	**8.27E-4**
	Aquatic terrestrial	mol N eq	6.27E-3	6.28E-7	**9.05E-3**
Photochemical ozone creation potential (POCP)		kg NMVOC eq	1.78E-3	2.12E-7	**2.77E-3**
Abiotic depletion potential (ADP)	Metals and minerals	kg Sb eq	4.99E-9	1.92E-12	**3.11E-8**
	Fossil resources	MJ, net calorific value	1.90E+0	4.62E-4	**4.59E+0**

Water deprivation potential (WDP)		m^3 world eq deprived	1.23E-3	4.24E-7	**5.40E-2**
Primary energy resources — Renewable	Use as energy carrier	MJ, net calorific value	3.35E-3	1.01E-6	**1.46E-1**
	Used as raw materials		0.00E+0	0.00E+0	**1.02E-2**
	TOTAL		3.35E-3	1.01E-6	**1.56E-1**
Primary energy resources —Non-renewable	Use as energy carrier		1.90E+0	4.62E-4	**4.59E+0**
	Used as raw materials		0.00E+0	0.00E+0	**8.51E-2**
	TOTAL		1.90E+0	4.62E-4	**4.68E+0**

Table 5. Indicators of impact category and of use of resources for the declared unit 1 kilogram of packaged ROASTED peanuts delivered to the customer.

PARAMETER		**UNIT**	**Upstream**				**Core**	
			Agriculture	**Additives**	**Packaging**	**Pre-industry**	**Transport**	**Industry**
Global warming potential (GWP)	Fossil	kg CO_2 eq	7.36E-2	5.21E-4	4.61E-2	5.17E-2	3.05E-2	9.13E-2
	Biogenic		1.05E-1	9.83E-7	1.76E-3	2.89E-4	1.23E-6	2.46E-4
	Land use and land use change		2.62E-1	4.38E-7	1.47E-4	5.18E-4	8.83E-7	4.28E-4
	TOTAL		4.41E-1	5.23E-4	4.81E-2	5.25E-2	3.05E-2	9.19E-2
Ozone depletion potential (ODP)		kg CFC 11 eq	2,51E-7	5.13E-11	1.20E-9	9.41E-10	4.06E-10	1.75E-9
Acidification potential (AP)		mol H+ eq	6.89E-4	4.81E-6	2.14E-4	6.86E-5	7.65E-5	8.40E-5
Eutrophication potential (EP)	Aquatic freshwater	kg P eq	5.88E-5	2.31E-7	1.45E-5	7.55E-7	6.14E-7	1.00E-6
	Aquatic marine	kg N eq	2.20E-4	1.47E-6	7.37E-5	1.73E-5	2.69E-5	2.30E-5
	Aquatic terrestrial	mol N eq	2.33E-3	2.07E-5	5.98E-4	1.82E-4	2.95E-4	2.42E-4
Photochemical ozone creation potential (POCP)		kg NMVOC eq	7.28E-4	3.00E-6	2.48E-4	1.25E-4	1.14E-4	1.96E-4
Abiotic depletion potential (ADP)	Metals and minerals	kg Sb eq	2.22E-8	1.42E-9	2.15E-8	1.62E-9	1.79E-9	1.14E-9
	Fossil resources	MJ, net calorific value	1.08E+0	4.95E-3	8.64E-1	8.85E-1	4.04E-1	1.51E+0
Water deprivation potential (WDP)		m^3 world eq deprived	1.09E-2	1.43E-4	1.90E-2	3.35E-2	3.72E-4	2.84E-2
Primary energy resources	Use as energy carrier	MJ, net calorific value	2.35E-2	1.79E-4	8.95E-1	9.12E-2	6.48E-4	7.79E-2

— Renewable	Used as raw materials		0.00E+0	0.00E+0	6.32E-1	0.00E+0	0.00E+0	0.00E+0
	TOTAL		2.35E-2	1.79E-4	1.53E+0	9.12E-2	6.48E-4	7.79E-2
Primary energy resources —Non-renewable	Use as energy carrier		1.08E+0	4.95E-3	8.65E-1	8.85E-1	4.04E-1	1.51E+0
	Used as raw materials		0.00E+0	0.00E+0	2.58E-1	0.00E+0	0.00E+0	0.00E+0
	TOTAL		1.08E+0	4.95E-3	1.12E+0	8.85E-1	4.04E-1	1.51E+0

PARAMETER		**UNIT**	**Downstream**		**TOTAL**
			Distribution	**End-of-life**	
Global warming potential (GWP)	Fossil	kg CO_2 eq	1.61E-1	8.62E-5	**4.55E-1**
	Biogenic		5.88E-6	4.11E-9	**1.08E-1**
	Land use and land use change		4.65E-6	2.72E-9	**2.63E-1**
	TOTAL		1.61E-1	8.62E-5	**8.26E-1**
Ozone depletion potential (ODP)		kg CFC 11 eq	2.27E-9	1.18E-12	**2.58E-7**
Acidification potential (AP)		mol H+ eq	2.49E-3	3.47E-7	**3.63E-3**
Eutrophication potential (EP)	Aquatic freshwater	kg P eq	2.14E-6	1.93E-9	**7,80E-5**
	Aquatic marine	kg N eq	5.93E-4	1.41E-7	**9.55E-4**
	Aquatic terrestrial	mol N eq	6.60E-3	1.54E-6	**1.03E-2**
Photochemical ozone creation potential (POCP)		kg NMVOC eq	1.88E-3	5.19E-7	**3.29E-3**
Abiotic depletion potential (ADP)	Metals and minerals	kg Sb eq	5.58E-9	4.71E-12	**5.53E-8**
	Fossil resources	MJ, net calorific value	2.06E+0	1.13E-3	**6.81E+0**
Water deprivation potential (WDP)		m^3 world eq deprived	1.36E-3	1.04E-6	**9.36E-2**
Primary energy resources — Renewable	Use as energy carrier	MJ, net calorific value	3.63E-3	2.49E-6	**1.09E+0**
	Used as raw materials		0.00E+0	0.00E+0	**6.32E-1**
	TOTAL		3.63E-3	2.49E-6	**1.72E+0**
Primary energy resources —Non-renewable	Use as energy carrier		2.06E+0	1.13E-3	**6.81E+0**
	Used as raw materials		0.00E+0	0.00E+0	**2.58E-1**
	TOTAL		2.06E+0	1.13E-3	**7.07E+0**

Table 6. Indicators of impact category and of use of resources for the declared unit 1 kilogram of packaged FRIED peanuts delivered to the customer.

PARAMETER		UNIT	Upstream				Core	
			Agriculture	Additives	Packaging	Pre-industry	Transport	Industry
Global warming potential (GWP)	Fossil	kg CO_2 eq	6.95E-2	3.98E-2	3.00E-2	6.33E-2	3.11E-2	1.58E-1
	Biogenic		9.92E-2	7.67E-5	4.88E-4	3.13E-4	1.26E-6	2.71E-4
	Land use and land use change		2.47E-1	3.20E-5	6.49E-5	5.58E-4	9.03E-7	4.69E-4
	TOTAL		4.16E-1	3.99E-2	3.06E-2	6.42E-2	3.11E-2	1.59E-1
Ozone depletion potential (ODP)		kg CFC 11 eq	2.37E-7	3.99E-9	6.72E-10	1.17E-9	4.15E-10	3.07E-9
Acidification potential (AP)		mol H+ eq	6.50E-4	3.67E-4	1.40E-4	7.86E-5	7.86E-5	1.29E-4
Eutrophication potential (EP)	Aquatic freshwater	kg P eq	5.54E-5	1.80E-5	7.67E-6	8.70E-7	6.28E-7	1.66E-6
	Aquatic marine	kg N eq	2.07E-4	1.12E-4	4.05E-5	2.00E-5	2.77E-5	3.71E-5
	Aquatic terrestrial	mol N eq	2.19E-3	1.58E-3	3.87E-4	2.11E-4	3.04E-4	3.90E-4
Photochemical ozone creation potential (POCP)		kg NMVOC eq	6.86E-4	2.25E-4	1.70E-4	1.48E-4	1.17E-4	3.27E-4
Abiotic depletion potential (ADP)	Metals and minerals	kg Sb eq	2.10E-8	1.11E-7	1.14E-8	1.72E-9	1.83E-9	1.72E-9
	Fossil resources	MJ, net calorific value	1.02E+0	3.75E-1	5.93E-1	1.08E+0	4.13E-1	2.59E+0
Water deprivation potential (WDP)		m^3 world eq deprived	1.03E-2	1.12E-2	1.43E-2	3.62E-2	3.80E-4	3.13E-2
Primary energy resources —Renewable	Use as energy carrier	MJ, net calorific value	2.21E-2	1.39E-2	7.80E-1	9.86E-2	6.62E-4	8.69E-2
	Used as raw materials		0.00E+0	0.00E+0	4.99E-1	0.00E+0	0.00E+0	0.00E+0
	TOTAL		2.21E-2	1.39E-2	1.28E+0	9.86E-2	6.62E-4	8.69E-2
Primary energy resources —Non-renewable	Use as energy carrier		1.02E+0	3.75E-1	5.93E-1	1.08E+0	4.13E-1	2.59E+0
	Used as raw materials		0.00E+0	0.00E+0	1.96E-1	0.00E+0	0.00E+0	0.00E+0
	TOTAL		1.02E+0	3.75E-1	7.89E-1	1.08E+0	4.13E-1	2.59E+0

PARAMETER		UNIT	Downstream		TOTAL
			Distribution	End-of-life	
Global warming	Fossil	kg CO_2 eq	1.60E-1	4.12E-4	**5.52E-1**
	Biogenic		5.82E-6	1.97E-8	**1.00E-1**

potential (GWP)	Land use and land use change		4.60E-6	1.30E-8	**2.48E-1**
	TOTAL		1.60E-1	4.13E-4	**9.01E-1**
Ozone depletion potential (ODP)		kg CFC 11 eq	2.25E-9	5.62E-12	**2.49E-7**
Acidification potential (AP)		mol H+ eq	2.47E-3	1.66E-6	**3.91E-3**
Eutrophication potential (EP)	Aquatic freshwater	kg P eq	2.12E-6	9.22E-9	**8.64E-5**
	Aquatic marine	kg N eq	5.86E-4	6.74E-7	**1.03E-3**
	Aquatic terrestrial	mol N eq	6.52E-3	7.37E-6	**1.16E-2**
Photochemical ozone creation potential (POCP)		kg NMVOC eq	1.86E-3	2.48E-6	**3.53E-3**
Abiotic depletion potential (ADP)	Metals and minerals	kg Sb eq	5.51E-9	2.25E-11	**1.54E-7**
	Fossil resources	MJ, net calorific value	2.04E+0	5.43E-3	**8.10E+0**
Water deprivation potential (WDP)		m^3 world eq deprived	1.34E-3	4.98E-6	**1.05E-1**
Primary energy resources — Renewable	Use as energy carrier	MJ, net calorific value	3.59E-3	1.19E-5	**1.01E+0**
	Used as raw materials		0.00E+0	0.00E+0	**4.99E-1**
	TOTAL		3.59E-3	1.19E-5	**1.51E+0**
Primary energy resources —Non-renewable	Use as energy carrier		2.04E+0	5.43E-3	**8.10E+0**
	Used as raw materials		0.00E+0	0.00E+0	**1.96E-1**
	TOTAL		2.04E+0	5.43E-3	**8.30E+0**

Table 7. Indicators of impact category and of use of resources for the declared unit 1 kilogram of packaged peanut BUTTER delivered to the customer.

PARAMETER		**UNIT**	**Upstream**				**Core**	
			Agriculture	**Additives**	**Packaging**	**Pre-industry**	**Transport**	**Industry**
Global warming potential (GWP)	Fossil	kg CO_2 eq	6.65E-2	5.95E-2	1.56E-1	1.29E-1	4.37E-2	1.52E-2
	Biogenic		9.50E-2	1.07E-3	1.10E-3	4.84E-4	1.77E-6	1.69E-4
	Land use and land use change		2.37E-1	-2.61E-2	3.60E-4	8.53E-4	1.27E-6	2.97E-4
	TOTAL		**3.98E-1**	**3.45E-2**	**1.58E-1**	**1.31E-1**	**4.37E-2**	**1.57E-2**
Ozone depletion potential (ODP)		kg CFC 11 eq	2.27E-7	3.67E-9	3.81E-9	2.47E-9	5.84E-10	2.63E-10

Acidification potential (AP)		mol H+ eq	6,22E-4	1.11E-3	6.36E-4	1.42E-4	1.13E-4	2.75E-5
Eutrophication potential (EP)	Aquatic freshwater	kg P eq	5.31E-5	1.88E-5	3.66E-5	1.79E-6	8.84E-7	2.28E-7
	Aquatic marine	kg N eq	1.98E-4	6.45E-4	1.49E-4	3.77E-5	4.03E-5	6.14E-6
	Aquatic terrestrial	mol N eq	2.10E-3	4.89E-3	1.52E-3	4.01E-4	4.42E-4	6.46E-5
Photochemical ozone creation potential (POCP)		kg NMVOC eq	6.57E-4	4.13E-4	8.54E-4	2.92E-4	1.69E-4	4.31E-5
Abiotic depletion potential (ADP)	Metals and minerals	kg Sb eq	2.01E-8	1.64E-7	2.33E-8	3.78E-9	2.58E-9	3.98E-10
	Fossil resources	MJ, net calorific value	9.72E-1	4.73E-1	3.65E+0	2.17E+0	5.81E-1	2.84E-1
Water deprivation potential (WDP)		m^3 world eq deprived	9.83E-3	1.99E-2	5.63E-2	5.59E-2	5.35E-4	1.95E-2
Primary energy resources — Renewable	Use as energy carrier	MJ, net calorific value	2.12E-2	3.09E+0	1.54E+0	1.53E-1	9.32E-4	5.28E-2
	Used as raw materials		0.00E+0	0.00E+0	9.53E-1	0.00E+0	0.00E+0	0.00E+0
	TOTAL		2.12E-2	3.09E+0	2.49E+0	1.53E-1	9.32E-4	5.28E-2
Primary energy resources —Non-renewable	Use as energy carrier		9.72E-1	5.22E-1	3.65E+0	2.17E+0	5.81E-1	2.84E-1
	Used as raw materials		0.00E+0	0.00E+0	1.70E+0	0.00E+0	0.00E+0	0.00E+0
	TOTAL		9.72E-1	5.22E-1	5.36E+0	2.17E+0	5.81E-1	2.84E-1

PARAMETER		**UNIT**	**Downstream**		**TOTAL**
			Distribution	**End-of-life**	
Global warming potential (GWP)	Fossil	kg CO_2 eq	1.69E-1	1.20E-3	**6.41E-1**
	Biogenic		6.17E-6	5.73E-8	**9.79E-2**
	Land use and land use change		4.88E-6	3.79E-8	**2.12E-1**
	TOTAL		**1.69E-1**	**1.20E-3**	**9.51E-1**
Ozone depletion potential (ODP)		kg CFC 11 eq	2.38E-9	1.64E-11	**2.40E-7**
Acidification potential (AP)		mol H+ eq	2.62E-3	4.83E-6	**5.27E-3**
Eutrophication potential (EP)	Aquatic freshwater	kg P eq	2.25E-6	2.68E-8	**1.14E-4**
	Aquatic marine	kg N eq	6.22E-4	1.96E-6	**1.70E-3**
	Aquatic terrestrial	mol N eq	6.92E-3	2.15E-5	**1.64E-2**

Photochemical ozone creation potential (POCP)		kg NMVOC eq	1.97E-3	7.24E-6	**4.41E-3**
Abiotic depletion potential (ADP)	Metals and minerals	kg Sb eq	5.85E-9	6.57E-11	**2.20E-7**
	Fossil resources	MJ, net calorific value	2.16E+0	1.58E-2	**1.03E+1**
Water deprivation potential (WDP)		m^3 world eq deprived	1.42E-3	1.45E-5	**1.63E-1**
Primary energy resources —Renewable	Use as energy carrier	MJ, net calorific value	3.81E-3	3.47E-5	**4.86E+0**
	Used as raw materials		0.00E+0	0.00E+0	**9.53E-1**
	TOTAL		3.81E-3	3.47E-5	**5.81E+0**
Primary energy resources —Non-renewable	Use as energy carrier		2.16E+0	1.58E-2	**1.04E+1**
	Used as raw materials		0.00E+0	0.00E+0	**1.70E+0**
	TOTAL		2.16E+0	1.58E-2	**1.21E+1**

Table 8. Indicators of impact category and of use of resources for the declared unit 1 kilogram of packaged peanut PASTE delivered to the customer.

PARAMETER		**UNIT**	**Upstream**			**Core**	
			Agricultural production	**Packaging**	**Pre-industry**	**Transport**	**Industry**
Global warming potential (GWP)	Fossil	kg CO_2 eq	7.38E-2	1.54E-1	1.44E-1	5.44E-2	4.40E-2
	Biogenic		1.05E-1	2.97E-4	5.45E-4	2.21E-6	4.89E-4
	Land use and land use change		2.63E-1	1.14E-4	9.61E-4	1.58E-6	8.58E-4
	TOTAL		**4.42E-1**	**1.54E-1**	**1.46E-1**	**5.44E-2**	**4.53E-2**
Ozone depletion potential (ODP)		kg CFC 11 eq	2,52E-7	1.14E-9	2.76E-9	7.27E-10	7.59E-10
Acidification potential (AP)		mol H+ eq	6.90E-4	6.47E-4	1.59E-4	1.42E-4	7.94E-5
Eutrophication potential (EP)	Aquatic freshwater	kg P eq	5.89E-5	5.65E-5	2.00E-6	1.10E-6	6.58E-7
	Aquatic marine	kg N eq	2.20E-4	1.54E-4	4.21E-5	5.06E-5	1.77E-5
	Aquatic terrestrial	mol N eq	2.33E-3	1.58E-3	4.48E-4	5.54E-4	1.86E-4
Photochemical ozone creation potential (POCP)		kg NMVOC eq	7.29E-4	5.65E-4	3.26E-4	2.11E-4	1.24E-4
Abiotic depletion	Metals and minerals	kg Sb eq	2.23E-8	6.79E-7	4.21E-9	3.21E-9	1.15E-9

potential (ADP)	Fossil resources	MJ, net calorific value	1.08E+0	1.83E+0	2.42E+0	7.24E-1	8.20E-1
Water deprivation potential (WDP)		m^3 world eq deprived	1,09E-2	3.38E-2	6.30E-2	6.67E-4	5.64E-2
Primary energy resources — Renewable	Use as energy carrier	MJ, net calorific value	2.35E-2	1.27E+0	1.72E-1	1.16E-3	1.52E-1
	Used as raw materials		0.00E+0	7.37E-1	0.00E+0	0.00E+0	0.00E+0
	TOTAL		2.35E-2	2.01E+0	1.72E-1	1.16E-3	1.52E-1
Primary energy resources —Non-renewable	Use as energy carrier		1.08E+0	1.83E+0	2.42E+0	7.24E-1	8.20E-1
	Used as raw materials		0.00E+0	1.51E-1	0.00E+0	0.00E+0	0.00E+0
	TOTAL		1.08E+0	1.98E+0	2.42E+0	7.24E-1	8.20E-1

PARAMETER		**UNIT**	**Downstream**		**TOTAL**
			Distribution	**End-of-life**	
Global warming potential (GWP)	Fossil	kg CO_2 eq	1.66E-1	1.32E-3	**6.37E-1**
	Biogenic		6.03E-6	6.29E-8	**1.07E-1**
	Land use and land use change		4.77E-6	4.16E-8	**2.65E-1**
	TOTAL		**1.66E-1**	**1.32E-3**	**1.01E+0**
Ozone depletion potential (ODP)		kg CFC 11 eq	2.33E-9	1.80E-11	**2.59E-7**
Acidification potential (AP)		mol H+ eq	2.60E-3	5.30E-6	**4.32E-3**
Eutrophication potential (EP)	Aquatic freshwater	kg P eq	2.18E-6	2.95E-8	**1.21E-4**
	Aquatic marine	kg N eq	6.18E-4	2.15E-6	**1.10E-3**
	Aquatic terrestrial	mol N eq	6.87E-3	2.36E-5	**1.20E-2**
Photochemical ozone creation potential (POCP)		kg NMVOC eq	1.96E-3	7.95E-6	**3.92E-3**
Abiotic depletion potential (ADP)	Metals and minerals	kg Sb eq	5.65E-9	7.21E-11	**7.16E-7**
	Fossil resources	MJ, net calorific value	2.11E+0	1.74E-2	**9.00E+0**
Water deprivation potential (WDP)		m^3 world eq deprived	1.38E-3	1.59E-5	**1.66E-1**
Primary energy resources	Use as energy carrier	MJ, net calorific value	3.73E-3	3.81E-5	**1.62E+0**

—Renewable	Used as raw materials		0.00E+0	0.00E+0	**7.37E-1**
	TOTAL		3.73E-3	3.81E-5	**2.36E+0**
Primary energy resources —Non-renewable	Use as energy carrier		2.11E+0	1.74E-2	**9.00E+0**
	Used as raw materials		0.00E+0	0.00E+0	**1.51E-1**
	TOTAL		2.11E+0	1.74E-2	**9.15E+0**

Table 9. Indicators of impact category and of use of resources for the declared unit 1 kilogram of packaged peanut GRANULES delivered to the customer.

PARAMETER		**UNIT**	**Upstream**			**Core**	
			Agricultural production	**Packaging**	**Pre-industry**	**Transport**	**Industry**
Global warming potential (GWP)	Fossil	kg CO_2 eq	7.36E-2	4.69E-2	1.43E-1	3.02E-2	6.33E-2
	Biogenic		1.05E-1	1.09E-3	5.35E-4	1.22E-6	7.01E-4
	Land use and land use change		2.62E-1	1.07E-4	9.45E-4	8.75E-7	1.23E-3
	TOTAL		**4.41E-1**	**4.81E-2**	**1.45E-1**	**3.02E-2**	**6.52E-2**
Ozone depletion potential (ODP)		kg CFC 11 eq	2.51E-7	1.21E-9	2.74E-9	4.02E-10	1.09E-9
Acidification potential (AP)		mol H+ eq	6.89E-4	2.03E-4	1.57E-4	7.57E-5	1.14E-4
Eutrophication potential (EP)	Aquatic freshwater	kg P eq	5.88E-5	1.24E-5	1.98E-6	6.09E-7	9.44E-7
	Aquatic marine	kg N eq	2.20E-4	6.23E-5	4.17E-5	2.66E-5	2.54E-5
	Aquatic terrestrial	mol N eq	2.33E-3	5.50E-4	4.44E-4	2.92E-4	2.67E-4
Photochemical ozone creation potential (POCP)		kg NMVOC eq	7.28E-4	2.58E-4	3.24E-4	1.13E-4	1.78E-4
Abiotic depletion potential (ADP)	Metals and minerals	kg Sb eq	2.22E-8	1.71E-8	4.18E-9	1.78E-9	1.65E-9
	Fossil resources	MJ, net calorific value	1.08E+0	9.82E-1	2.40E+0	4.00E-1	1.18E+0
Water deprivation potential (WDP)		m^3 world eq deprived	1.09E-2	1.90E-2	6.20E-2	3.68E-4	8.08E-2
Primary energy resources —Renewable	Use as energy carrier	MJ, net calorific value	2.35E-2	8.34E-1	1.69E-1	6.42E-4	2.18E-1
	Used as raw materials		0.00E+0	5.60E-1	0.00E+0	0.00E+0	0.00E+0
	TOTAL		2.35E-2	1.39E+0	1.69E-1	6.42E-4	2.18E-1
Primary energy resources	Use as energy carrier		1.08E+0	9.82E-1	2.40E+0	4.00E-1	1.18E+0

—Non-renewable	Used as raw materials		0.00E+0	3.74E-1	0.00E+0	0.00E+0	0.00E+0
	TOTAL		1.08E+0	1.36E+0	2.40E+0	4.00E-1	1.18E+0

PARAMETER		UNIT	Downstream		TOTAL
			Distribution	End-of-life	
Global warming potential (GWP)	Fossil	kg CO_2 eq	1.61E-1	5.27E-4	5.19E-1
	Biogenic		5.87E-6	2.51E-8	1.08E-1
	Land use and land use change		4.64E-6	1.66E-8	2.65E-1
	TOTAL		**1.61E-1**	**5.27E-4**	**8.91E-1**
Ozone depletion potential (ODP)		kg CFC 11 eq	2.26E-9	7.18E-12	2.59E-7
Acidification potential (AP)		mol H+ eq	2.49E-3	2.12E-6	3.73E-3
Eutrophication potential (EP)	Aquatic freshwater	kg P eq	2.14E-6	1.18E-8	7.69E-5
	Aquatic marine	kg N eq	5.91E-4	8.60E-7	9.68E-4
	Aquatic terrestrial	mol N eq	6.58E-3	9.41E-6	1.05E-2
Photochemical ozone creation potential (POCP)		kg NMVOC eq	1.87E-3	3.17E-6	3.48E-3
Abiotic depletion potential (ADP)	Metals and minerals	kg Sb eq	5.56E-9	2.88E-11	5.26E-8
	Fossil resources	MJ, net calorific value	2.06E+0	6.93E-3	8.10E+0
Water deprivation potential (WDP)		m^3 world eq deprived	1.35E-3	6.36E-6	1.74E-1
Primary energy resources — Renewable	Use as energy carrier	MJ, net calorific value	3.62E-3	1.52E-5	1.25E+0
	Used as raw materials		0.00E+0	0.00E+0	5.60E-1
	TOTAL		3.62E-3	1.52E-5	1.81E+0
Primary energy resources —Non-renewable	Use as energy carrier		2.06E+0	6.93E-3	8.10E+0
	Used as raw materials		0.00E+0	0.00E+0	3.74E-1
	TOTAL		2.06E+0	6.93E-3	8.47E+0

Environmental Impact Parameters for Each Declared Unit

Global Warming Potential

This parameter was considerably higher in the products with greater degree of industrial processing, with values ranging from 0.631 kg CO2 eq per kg for shelled peanuts to 1.009 kg CO2 eq per kg for peanut paste. In all cases, most of the GHG emissions were concentrated in the agricultural production stage, accounting for 40% to 66% of the total (Table 10). In the field, 80% of the emissions were from carbon loss through soil management and from harvest residues. In two of the farms, conventional planting was used, which has a greater impact on soil carbon content than no-till. The second most significant stage in terms of GWP was distribution of finished products, with a 16%-24% contribution to the total. Environmental burden at this stage was distributed between marine and land transport, with the former being up to 2% higher than the latter. Emissions from products with higher added value tend to concentrate at the industrial stage, with the use of electricity and burning of fossil fuels being the main factors increasing total emissions, besides the addition of other inputs, like salt, sugar and other additives。

Table 10. Distribution of the Global Warming Potential impact by product and by stage.

Stage / Products	Shelled	Blanched	Roasted	Fried	Butter	Paste	Granules
Agricultural production	66.4%	63.1%	53.4%	46.2%	41.9%	43.8%	49.5%
Production of additives	0.0%	0.0%	0.1%	4.4%	3.6%	0.0%	0.0%
Packaging production	1.3%	1.2%	5.8%	3.4%	16.6%	15.3%	5.4%
Farm-industry transportation	3.9%	3.7%	3.7%	3.5%	4.6%	5.4%	3.4%
Pre-processing	0.0%	4.5%	6.4%	7.1%	13.7%	14.5%	16.3%
Processing	4.9%	5.5%	11.1%	17.7%	1.7%	4.5%	7.3%
Distribution	23.6%	22.0%	19.5%	17.7%	17.8%	16.4%	18.1%
End of life	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%

Based on this analysis, we made a direct comparison of the carbon footprint of similar products from the USA and Brazil. We found a competitive advantage in local production sustainability. Although Argentine production is destined mainly for export to European markets, with the consequent significant footprint from marine transportation, the study shows that the carbon footprint of local peanut butter is up to 67% lower than that produced in the USA. Similarly, locally produced blanched peanut was found to have a 21% lower impact than that produced in Brazil. This finding suggests that the efficiency of the agricultural and industrial production stages in central Argentina is so significant that by far outweighs the additional environmental impact of long-distance transportation. This is a novel and valuable finding for the industry.

Ozone Depletion Potential

For all the products, this impact category was concentrated (94-99%) in peanut production on the farm due to the use of fungicides and herbicides.

Acidification Potential

For the products that contain no additives, such as shelled, blanched and roasted peanuts, emissions of nitrogen oxides and sulfur dioxide related to fuel burning during final product distribution accounted for more than 69% of this impact category. Agricultural production ranked second, with 21% of the total, whereas for fried peanut, peanut paste and peanut butter, emissions were associated with production of additives and more complex packaging.

Eutrophication Potential—Freshwater

For shelled and blanched peanuts, this parameter was concentrated (more than 90%) in field production due to the use of herbicides. For roasted peanuts and peanut granules, field contribution decreased to 75% due to emissions associated with packaging production, especially pallets, corrugated cardboard supplies, big bags (1.2 t) and bags.

Eutrophication Potential—Marine Aquatic

In most of the products, more than 50% of marine eutrophication impact corresponded to product distribution, with the contribution of marine transportation being much higher than that of land transportation. Agricultural production ranked second, with at least 20% of emissions, which are attributable to the use of fossil fuels in agricultural practices. Peanut butter production was an exception to this trend, with the production of additives, specifically sugar and stabilizers, being hotspots, amounting to 37.9%.

Eutrophication Potential—Terrestrial

The principal hotspot in terrestrial eutrophication was the distribution of the final product. In all cases, the emissions associated with burning of heavy fuel oil in maritime transportation made the greatest contribution to this category.

Photochemical Ozone Creation Potential

In all the studied products, the emissions contributing to this parameter were mainly concentrated in the distribution of the finished product, being 45 to 66% higher in products with low industrial processing. The greatest proportion corresponded to maritime transportation, with emissions of nitrogen oxides, followed by peanut production on the farm (about 21%), caused largely by the use of fuels in agricultural practices and, to a lesser extent, to the use of herbicides.

Abiotic Resources (Metals and Minerals) Depletion Potential

The results show significant variations among products; yet all the impacts were concentrated in the upstream stage. For shelled and blanched peanuts, field production accounted for approximately 70% of the total impact, which is associated with the use of agrochemicals. Field production was also dominant in roasted peanuts and peanut granules, with 41% of the impact, followed by packaging production, which contributed nearly 36%. Packaging was the dominant factor in peanut paste, accounting for 95% of the impact, with a great influence of the metal drum. Finally, the impact for fried peanut and peanut butter was concentrated in the production of additives, which represented about 73%, followed by peanut production and packaging production.

Abiotic Resources (Fossil Fuels) Depletion Potential

Depletion of fossil abiotic resources was directly associated with the use of fossil fuels. The stages that most contributed to this indicator were the distribution of finished products, followed by agricultural production, the latter being related to fuel consumption in agricultural practices. Depletion of fossils increases in products with a higher degree of industrial processing. In addition, hotspots were recorded in packaging of peanut butter and paste, due to the use of plastic buckets and metal drums, respectively.

Water Deprivation Potential

Water deprivation potential was concentrated in the industrial processes (46% to 82%). This result can be attributed to the electricity consumption in the Argentine energy matrix, with a high percentage coming from hydroelectric sources that store water. According to the method used to calculate electricity consumption, the water resource is considered consumed when it evaporates from the reservoirs.

Sensitivity Analysis

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This analysis consists of modifying a variable of interest and analyzing the effects of this change on the result of each environmental impact category. Sensitivity analyses were performed by modifying yield (scenarios 1 and 2) and management type (scenario 3). A 25% increase in yield reduced total GWP by 7% to 12%, but a 25% decrease increased GWP by 14% to 20%; yield losses caused larger penalties than the benefits of yield increase (Tables 11 and 12). Table 13 shows the change of agricultural practices, with no-tillage and cover crops.

Table 11. Scenario 1: Effects of mean 25% INCREASE in peanut harvest yield per ha, in absolute and relative values.

Parameter / Products	Shelled	Blanched	Roasted	Fried	Butter	Paste	Granules
Global warming	5.56E-1	6.00E-1	7.47E-1	8.26E-1	8.80E-1	9.29E-1	8.11E-1
Ozone depletion	1.94E-7	1.99E-7	2.08E-7	2.01E-7	1.95E-7	2.09E-7	2.09E-7
Acidification	3.04E-3	3.09E-3	3.49E-3	3.78E-3	5.15E-3	4.19E-3	3.59E-3
Fresh water eutrophication	4.96E-5	5.09E-5	6.62E-5	7.53E-5	1.03E-4	1.10E-4	6.51E-5
Marine water eutrophication	7.71E-4	7.84E-4	9.11E-4	9.90E-4	1.66E-3	1.06E-3	9.24E-4
Terrestrial eutrophication	8.46E-3	8.60E-3	9.80E-3	1.12E-2	1.59E-2	1.15E-2	1.00E-2
Photochemical ozone creation potential	2.54E-3	2.63E-3	3.15E-3	3.40E-3	4.28E-3	3.77E-3	3.33E-3
Metals and minerals	2.59E-8	2.67E-8	5.08E-8	1.50E-7	2.16E-7	7.11E-7	4.81E-8
Fossil fuels	3.76E+0	4.38E+0	6.59E+0	7.90E+0	1.01E+1	8.78E+0	7.88E+0
Water deprivation	4.03E-2	5.19E-2	9.15E-2	1.03E-1	1.62E-1	1.64E-1	1.72E-1
Global warming	-12%	-11%	-10%	-8%	-8%	-8%	-9%
Ozone depletion	-20%	-20%	-19%	-19%	-19%	-19%	-19%
Acidification	-4%	-4%	-4%	-3%	-2%	-3%	-4%
Fresh water eutrophication	-18%	-18%	-15%	-13%	-9%	-10%	-15%
Marine water eutrophication	-5%	-5%	-5%	-4%	-2%	-4%	-5%
Terrestrial eutrophication	-5%	-5%	-5%	-4%	-3%	-4%	-4%
Photochemical ozone creation potential	-5%	-5%	-4%	-4%	-3%	-4%	-4%
Metals and minerals	-14%	-14%	-8%	-3%	-2%	-1%	-8%
Fossil fuels	-5%	-5%	-3%	-3%	-2%	-2%	-3%
Water deprivation	-5%	-4%	-2%	-2%	-1%	-1%	-1%

Table 12. Scenario 2: Effects of mean 25% DECREASE in peanut harvest yield per ha, in absolute and relative values.

Parameter / Products	Shelled	Blanched	Roasted	Fried	Butter	Paste	Granules
Global warming	7.57E-1	8.05E-1	9.59E-1	1.03E+0	1.07E+0	1.14E+0	1.02E+0
Ozone depletion	3.21E-7	3.28E-7	3.42E-7	3.28E-7	3.16E-7	3.43E-7	3.43E-7
Acidification	3.39E-3	3.44E-3	3.86E-3	4.13E-3	5.48E-3	4.55E-3	3.96E-3

Fresh water eutrophication	7.94E-5	8.12E-5	9.76E-5	1.05E-4	1.31E-4	1.41E-4	9.65E-5
Marine water eutrophication	1.50E-3	1.53E-3	1.68E-3	1.71E-3	2.35E-3	1.83E-3	1.69E-3
Terrestrial eutrophication	1.83E-2	1.86E-2	2.01E-2	2.09E-2	2.53E-2	2.19E-2	2.03E-2
Photochemical ozone creation potential	2.91E-3	3.01E-3	3.54E-3	3.76E-3	4.63E-3	4.16E-3	3.72E-3
Metals and minerals	3.72E-8	3.82E-8	6.27E-8	1.61E-7	2.26E-7	7.23E-7	6.00E-8
Fossil fuels	4.30E+0	4.94E+0	7.17E+0	8.44E+0	1.06E+1	9.36E+0	8.46E+0
Water deprivation	4.58E-2	5.75E-2	9.73E-2	1.08E-1	1.67E-1	1.70E-1	1.78E-1
Global warming	20%	19%	16%	14%	13%	13%	15%
Ozone depletion	33%	33%	32%	32%	32%	32%	32%
Acidification	7%	7%	6%	6%	4%	5%	6%
Fresh water eutrophication	31%	30%	25%	21%	16%	16%	25%
Marine water eutrophication	84%	85%	76%	66%	38%	66%	75%
Terrestrial eutrophication	105%	106%	96%	80%	54%	82%	94%
Photochemical ozone creation potential	9%	8%	7%	6%	5%	6%	7%
Metals and minerals	23%	23%	13%	5%	3%	1%	14%
Fossil fuels	9%	8%	5%	4%	3%	4%	4%
Water deprivation	8%	7%	4%	3%	2%	2%	2%

Table 13. Scenario 3: Use of no-tillage and cover crops.

Emissions				
Global warming ($kg\ CO_2\ eq$)	**Fossil**	**Biogenic**	**Land use and land use change**	**Total**
Shelled peanuts	2.82E-1	7.50E-2	1.32E-1	**4.88E-1**
Blanched peanuts	3.20E-1	7.65E-2	1.34E-1	**5.31E-1**
Roasted peanuts	4.55E-1	8.09E-2	1.39E-1	**6.76E-1**
Fried peanuts	5.52E-1	7.53E-2	1.31E-1	**7.59E-1**
Peanut butter	6.41E-1	7.38E-2	1.00E-1	**8.15E-1**
Peanut paste	6.37E-1	8.01E-2	1.40E-1	**8.58E-1**
Peanut granules	5.19E-1	8.10E-2	1.41E-1	**7.40E-1**
Relative changes with respect to the baseline (Tables 3 to 9)				
Global warming ($kg\ CO_2\ eq$)	**Fossil**	**Biogenic**	**Land use and land use change**	**Total**
Shelled peanuts	0%	-25%	-47%	**-23%**
Blanched peanuts	0%	-25%	-47%	**-22%**
Roasted peanuts	0%	-25%	-47%	**-18%**
Fried peanuts	0%	-25%	-47%	**-16%**
Peanut butter	0%	-25%	-53%	**-14%**
Peanut paste	0%	-25%	-47%	**-15%**
Peanut granules	0%	-25%	-47%	**-17%**

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Comparative Analysis

The following comparisons were performed in terms of the indicator "global warming potential". Agricultural peanut production was compared with environmental profiles published in the Ecoinvent database, corresponding to different regions: average rest-of-the-world excluding China, India and Brazil. For all the categories, the impact of the Argentine product was lower, except for ozone depletion. This result is due to the use of fungicides, which are not included in the inventories of the profiles used for the comparison.

Results of blanched peanuts were compared with the LCA of blanched peanuts produced in São Paulo, Brazil (Ramos et al., 2023). That study covered the agricultural and industrial stages and detected an impact of 0.67 kg CO2eq/ kg of the product. In our study, blanched peanuts, analyzed from cradle to gate, were 21% lower.

Finally, peanut butter produced in the USA in 2012 generated mean emissions of 2.88 kg CO2 eq per kg of product (McCarty J. A., Sandefur, Matlock, & Kim, 2014). That work calculated the emissions from the production and trade of the product at a national scale. The system boundaries were from cradle to grave, including peanut field production, shelling, blanching, roasting, butter production, use by consumer and packaging disposal.

Although there are differences in trade logistics for peanut butter between the USA and Argentina, the results of both studies can be compared in terms of the emissions in the production stages. Results for the USA show that stages of use and disposal by the consumer and retail activities amount to 1.35 kg CO2 eq; therefore, peanut butter up to the industry gate amounts to 1.53 kg CO2 eq. In this study, GHG emissions at the peanut butter production plant up to the industry gate were 0.78 kg CO2 eq, i.e., 49% lower than that reported by (McCarty J. A., Sandefur, Matlock, & Kim, 2014). The comparison of the entire life cycle of peanut butter between countries shows that, despite the international transportation (terrestrial and maritime) included in the case of Argentina, the impact is 0.95, which is 67% lower than in the USA, where commercialization is at the country level.

The analysis of the environmental profile reveals that the hotspots are not static but vary significantly among impact categories. Agricultural production is the major contributor to global warming, accounting for 40 to 66% of the total impact, whereas the distribution of the final product is the main hotspot involved in acidification, marine eutrophication photochemical ozone creation potential. This complexity reveals that an effective mitigation strategy should be multifaceted and oriented to different stages of the value chain, which is possible through the LCA theoretical framework.

Conclusions

The LCA revealed the main hotspots in the environmental performance of the products analyzed. Agricultural production stood out as the most determinant stage in most of the environmental impact indicators, particularly in global warming (40 to 66% of the emissions, mostly associated with soil management) and freshwater eutrophication (up to 90%). Agricultural production also contributed significantly to depletion of abiotic resources (metals and minerals) due to the use of agrochemicals, as well as important impacts on acidification, marine eutrophication and photochemical ozone creation potential, which are related to use of both agrochemicals and fuels.

Production of inputs had important impacts associated with packaging and additives, which contribute to depletion of abiotic resources (metals and minerals, and fossils) as well as to marine and freshwater eutrophication.

Industrial production generated important impacts on depletion of abiotic resources (fossils) and water deprivation (up to 82%), as well as a contribution to global warming (5 to 25%).

Finally, distribution was the most critical stage in terms of acidification, marine and terrestrial eutrophication, and photochemical ozone creation potential mainly due to marine transportation with heavy fuels. This stage also accounts for 16 to 24% of GHG emissions of the entire life cycle.

In this context, the improvement opportunities are oriented to: 1) optimize the use of inputs through precision agriculture and/or regenerative agriculture; 2) increase the use of renewable resources and gradually replace fossil fuels; 3) reduce the amount of packaging and give priority to reusable or recyclable packaging; and 4) improve the accuracy of the estimation of changes in soil organic carbon stock, which influences CO_2 removal or emission.

The comparison of our results with those of other works at the global level demonstrates that peanut production studied in this work in Argentina is intrinsically sustainable. Indeed, peanut butter has up to 67% lower carbon footprint than that in the USA; in addition, blanched peanut production has a 21% lower impact than that in Brazil.

The results of this work are relevant to several stakeholders. First, the peanut industry in the central region of Argentina, since the work provides a scientific and verifiable method to demonstrate production sustainability and to enter demanding markets. The identification of hotspots offers a clear pathway towards continuous improvement. Second, public policy makers, since the results of the LCA and the sensitivity analysis provide reliable data to promote more sustainable agricultural practices (like precision agriculture) and improved energy efficiency in the industry. Third, the scientific community, because this study contributes primary data and specific emission factors. Finally, consumers and diverse actors of the value chain benefit from greater transparency about the environmental impact of the products, which allows them to make more informed purchasing decisions in line with their own sustainability strategies.

Despite the robustness of the study, it is important to mention some limitations. Because of the lack of emission factors specific for peanuts in some areas, such as indirect nitrogen emissions, it was necessary to use assumptions. The lack of inventory data of the life cycle for certain inputs, such as hydrogenated oil or sugar, required the use of international database profiles. However, while they are the most representative, they may not capture the characteristics of local production. These limitations, though typical of any work of this kind, reveal areas for future research.

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