



Analysis, measurement, and interpretation

of the environmental footprint of the alpaca value chain based
on a Life Cycle Analysis

ALPACA GARMENT MANUFACTURING REPORT



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Environmental footprint of alpaca fiber in its complete value chain using the Life Cycle Analysis tool

This report summarizes the study of the Life Cycle Analysis (LCA) of alpaca fiber throughout its value chain to find its environmental footprint. The study was conducted following the LCA methodology, according to the ISO 14040 and 14044 standards.





1. GOAL

Identify, analyze, and calculate the environmental impacts of the alpaca fiber at each stage of the life cycle, as well as the drivers of these impacts. Results, conclusions, and recommendations of this study will aid in decision-making that contributes to the sustainability and competitiveness of the business sector.

2. SCOPE

The product evaluated in this study is a garment made with alpaca fiber. In this market, Peru has a productive hegemony with more than 70% of world participation. Based on the LCA, the scope of the study including pastures, breeding, shearing, spinning, dyeing, garment manufacturing, and transport to port.

The environmental impacts of the life cycle of the alpaca fiber garment must be referenced to a functional unit (FU). The FU is based on providing a reference from which all the input and output data of the production system are mathematically normalized (Aranda et al., 2006). Therefore, the FU selected for the study is 1 kg of manufactured alpaca fiber garment.

3. INVENTORY

Inventory is the identification and quantification of all inputs (resources, materials, or energy) and outputs (waste, effluents, or emissions) at each stage of the life cycle of the product. These amounts should be referenced to the FU.

Information from primary sources, in the form of questionnaires and interviews with those responsible for the different processes throughout the life cycle of alpaca fiber, were mainly used during data collection. The production systems of each of these companies and organizations were modeled and then combined according to their participation in production. There are two companies that are involved in the spinning and dyeing stages of fiber processing in Peru. Due to a lack of provided information, we assumed an impact allocation of 50% of total spinning production to each company, and used only one company's data for dyeing. For the manufacturing stage, each company was assigned an impact allocation value according to its annual production volume (Kero, 4.15%; Incalpaca 94.05%, Brisán, 1.79%). In this study, we considered the alpaca fiber obtained in the regions of Puno, Arequipa, Pasco, and Huancavelica. Transportation from the alpaca fiber obtaining regions to Arequipa, and from Arequipa to Lima was also included in the inventory.

Secondary sources used in this study included IPCC guidelines for national GHG inventories, Peru soil erosion atlas, and undergraduate theses from the regions involved in the study. We assumed an average nitrogen excretion of 8.7 g N per alpaca per day (Condori Mamani, 2017), average methane emissions of 17.7 g CH₄



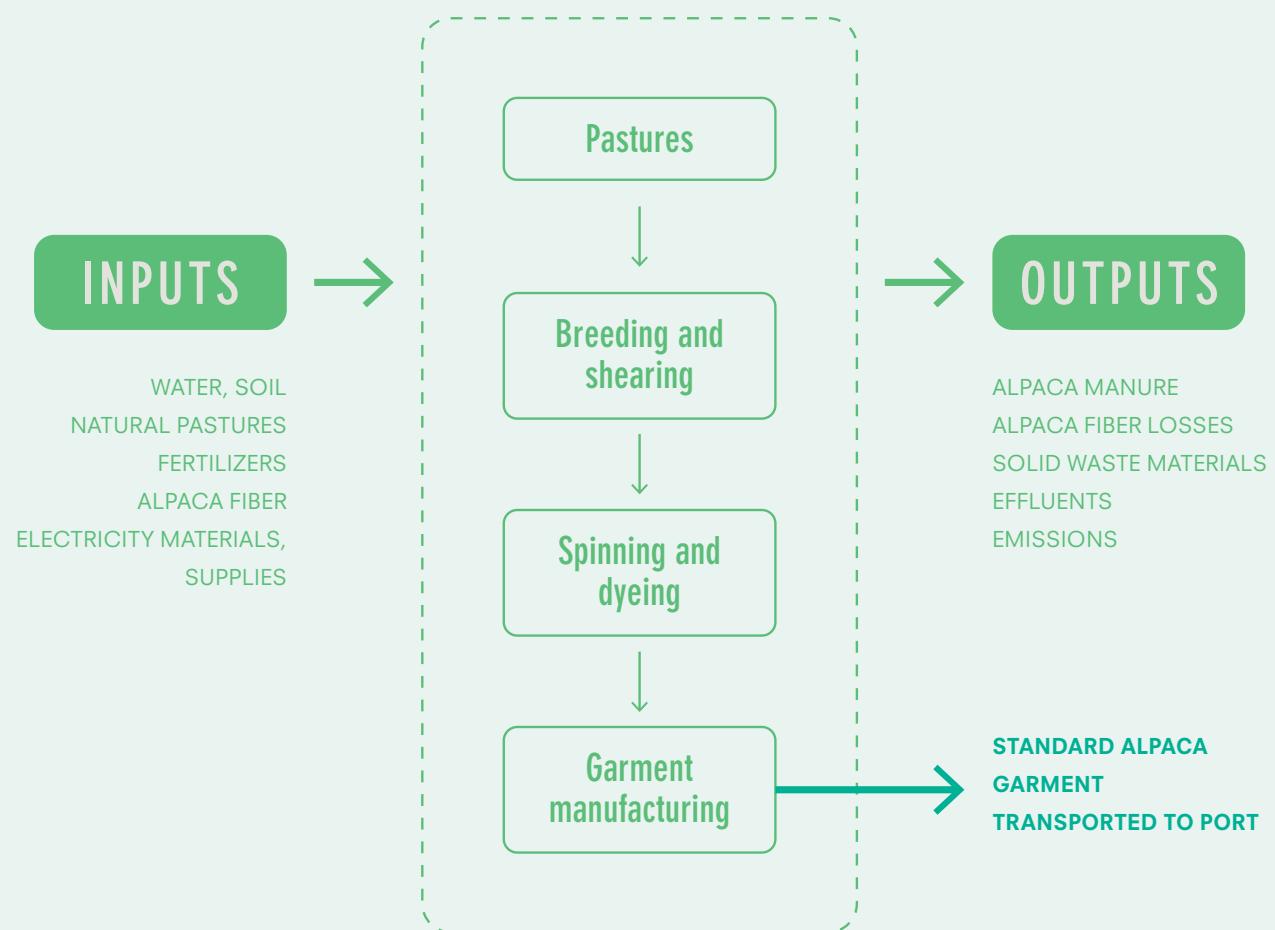
per alpaca per day, based on typical values for alpacas fed in Andean pastures (Quispe Chacon, 2017), and average soil erosion in high Andean areas of 26.4 t / ha (Sabino et al., 2017).

For the materials and components used in production processes and their transportation, the impacts were modeled using the database Ecoinvent ® v. 9.1.1.1. Faculty.

The questionnaires carried out in the natural pastures, breeding, and shearing stages were validated by officials of the General Directorate of Agrarian Development. Questionnaires from the spinning, dyeing, and clothing stages were validated by professionals from the companies involved.

The inventory analysis includes all the inputs and outputs of the processes related to the stages of obtaining the fiber (natural pastures, breeding, and shearing), as well as the subsequent processes related to factory production (spinning, dyeing, and garment manufacturing), as shown in Figure 1.

FIGURE 1. STUDY SYSTEM INPUTS AND OUTPUTS





4. ENVIRONMENTAL IMPACT ASSESSMENT

For the environmental footprint, environmental impacts were calculated in four categories: global warming, eutrophication, water consumption and abiotic depletion (fossil fuels). Table 1 shows the categories and their corresponding environmental assessment methodologies.

TABLE 1. ENVIRONMENTAL IMPACT CATEGORIES AND METHODOLOGIES

METHODOLOGY	IMPACT CATEGORY	REFERENCE UNIT
IPCC - 2013	Global warming	kg CO ₂ -eq
CML - 2013	Eutrophication	kg PO ₄ -eq
ReCiPe 2016	Water consumption	m ³
CML- 2013	Abiotic depletion (fossil fuels)	MJ

The emissions from the stage associated with natural pastures, breeding and shearing (including enteric fermentation, decomposition of excreta, and phosphorus content in soils, among others) were modeled using global formulas and secondary sources such as publications from the Ministry of Agriculture and undergraduate theses. In addition, factors, and methods of evaluation of emissions from agricultural systems were considered, for example, the leaching factors for pastures of Nemecek and Schnetzer, (2011).

The environmental impact allocation of the alpaca system was assigned 50% for obtaining alpaca fiber and 50% for the alpaca meat, according to an interview with Daniel Aristegui, Manager of the International Alpaca Association (IAA).



Table 2 shows that the impact associated with 1 kg of alpaca fleece is lower in Pasco with 45 kg CO₂- eq / kg of fleece than in other regions. In Huancavelica, the region with the highest impact, 2.4 times more CO₂-eq emissions are generated per kg of fleece than in Pasco.

TABLE 2. ENVIRONMENTAL IMPACT FOR 1 KG OF ALPACA FLEECE ACCORDING TO REGION

	AREQUIPA	PASCO	PUNO	HUANCAYELICA
Global warming (kg CO₂ – eq)	82.4	45.0	62.6	109.0

While the sources of greenhouse gas emissions are the same in the four alpaca fiber-producing regions, the impacts per kg of fleece vary considerably from region to region. The main reason for these differences is the average percentage of the alpaca herd shorn, which in 2019 reached 84% in Pasco, while in Huancavelica only accounted for 34%.

A low percentage of animals shorn translates into high environmental impacts per unit of fleece because all alpacas emit, for example, methane, including those that are not shorn. It should be mentioned that the primary data used in this study is from one year and that factors such as fiber prices and context also influence the decisions of alpaca producers and, therefore, also determine the percentage of animals shorn annually in each herd. For this reason, the management of alpaca units could be better reflected by using data from several years.

Table 3 shows the environmental impacts generated to obtain 1 kg of alpaca fiber manufactured by each region (Arequipa, Pasco, Puno, and Huancavelica) and for each category of environmental impact. For each region, the environmental impact values were calculated assuming that all fiber was produced in that region using the values for the percentage of alpacas shorn and yield of kg fleece per alpaca for that region.

The values for the percentage of alpacas shorn are: 46% in Arequipa, 84% in Pasco, 45% in Puno and 34% in Huancavelica, and the values for the yield of kg fleece per alpaca are: 2.12 in Arequipa, 2.30 in Pasco, 3.13 in Puno and 2.33 in Huancavelica.



TABLE 3. ENVIRONMENTAL IMPACTS FOR 1 KG OF ALPACA FIBER MANUFACTURED ACCORDING TO REGION

IMPACT CATEGORY	LIFE CYCLE STAGES	AREQUIPA
Global warming (kg CO₂-eq)	Pastures, breeding, and shearing	107.9
	Spinning and dyeing	7.6
	Garment manufacturing	4.5
	Total	120
Eutrophication (kg PO₄-eq)	Pastures, breeding, and shearing	0.230
	Spinning and dyeing	0.014
	Garment manufacturing	0.015
	Total	0.259
Water consumption (m³)	Pastures, breeding, and shearing	0
	Spinning and dyeing	0.27
	Garment manufacturing	0.25
	Total	0.52
Abiotic depletion - fossil fuels (MJ)	Pastures, breeding, and shearing	0
	Spinning and dyeing	298
	Garment manufacturing	172
	Total	470



TABLE 3. ENVIRONMENTAL IMPACTS FOR 1 KG OF ALPACA FIBER MANUFACTURED ACCORDING TO REGION

PASCO	PUNO	HUANCAVELICA
59	82	142.8
7.6	7.6	7.6
4.5	4.5	4.5
71.1	94.1	154.9
0.0746	0.113	0.131
0.014	0.014	0.014
0.015	0.015	0.015
0.1036	0.142	0.160
0	0	0
0.27	0.27	0.27
0.25	0.25	0.25
0.52	0.52	0.52
0	0	0
300	298	300
172	172	172
472	470	472



It is worth mentioning the difference and relationship between Table 2 (environmental impacts of 1 kg of alpaca fleece), and Table 3 (environmental impacts of 1kg of alpaca fiber). According to data, 1.31kg of fleece is needed to obtain 1 kg of manufactured alpaca fiber. Table 3 then shows the environmental impacts for 1.0 kg of manufactured fiber (or 1.31 kg of fleece).

The study also included improvement scenarios, increasing the % of alpacas shorn in the herd, from 45% to 76% (alpacas with more than one year in the herd that could have been shorn) and the fiber yield from 3.13 to 4 kg (top values from some alpaca producers in the region) fleece/alpaca in Puno. We chose this region because of the best performance of fleece shearing, higher production, and participation in the market. The results are shown in Table 4.

TABLE 4. ENVIRONMENTAL IMPACTS FOR 1 KG OF ALPACA FIBER MANUFACTURED - IMPROVED SITUATION IN PUNO

IMPACT CATEGORY	LIFE CYCLE STAGES	IMPROVED SITUATION
Global warming (kg CO₂ – eq)	Pastures, breeding, and shearing	38.1
	Spinning and dyeing	7.6
	Garment manufacturing	4.5
	Total	50.2
Eutrophication (kg PO₄-eq)	Pastures, breeding, and shearing	0.052
	Spinning and dyeing	0.014
	Garment manufacturing	0.015
	Total	0.081



5. HIGG INDEX COMPARISON

The Sustainable Apparel Coalition (SAC) has calculated and valued the environmental impact of alpaca fiber through the Higg index of sustainability of materials. Table 5 shows the results of the SAC and the PUCP research group in three impact categories, where the same LCA methodology was used.

TABLE 5. COMPARATIVE RESULTS FOR 1KG OF MANUFACTURED ALPACA FIBER

	GLOBAL WARMING (KG CO ₂ -EQ)	EUTROPHICATION (KG PO ₄ -EQ)	ABIOTIC DEPLETION-FOSSIL FUELS (MJ)	REFERENCE UNIT
SAC	82.5	0.212	135	
PUCP	[50.2 – 155]	[0.081 – 0.259]	[470 – 472]	
Higg Index - SAC	77.8 points	222 points	9.22 points	309 points
Higg Index - PUCP	[47.3 – 146.2] points	[84.8 – 271] points	[32 – 32.2] points	[164 – 449] points

From Table 5 we can see a wide difference between both studies, mainly because in this study, data has been obtained from the same alpaca fiber producers in four Peruvian regions with different realities. In addition, the primary data obtained from the PUCP study are from 2019 and the secondary data, for the most part, are typical of the alpaca Peruvian regions. Likewise, in this report and in Table 5 various scenarios are shown with current data and with improvement scenarios that reflect the importance of the performance factors of fleece and % of alpacas shorn.



Another difference lies in the assumptions used for each study (% of impact allocation), in the scope and included data (alpaca producers, producing regions, or companies), and in the adaptation and use of scarce secondary data. For example, the phosphorus in the soil of the prairies where alpacas are raised, the extension of the hectares for this activity, and the characterization of the emissions of the alpacas (enteric fermentation or manure), based on the practices used in the Peruvian regions (highland areas, feeding of natural pastures, use of wetlands).

6. CONCLUSIONS

- * The pastures, breeding and shearing stage is the one with the highest contribution for the global warming and eutrophication categories, with 70% and 65% on average, respectively.
- * The main cause of impact in the global warming category is enteric fermentation.
- * The main causes of the impact in the eutrophication category are emissions of Nitrate (NO_3) and Phosphorus (P) due to excreta and soil erosion, respectively.
- * The fiber processing stage (including spinning and dyeing) is the highest contributor for the water depletion category. Water consumption in this stage occurs indirectly through the consumption of electricity and natural gas.
- * The processing and manufacturing stage is the one with the greatest contribution to the depletion of abiotic - fossil resources due to the consumption of natural gas and electricity.

7. RECOMMENDATIONS

To achieve a reduction in impacts, the following are recommended:

- * Evaluate the causes of the low alpaca shearing rates in some regions and develop measures to increase them.
- * Develop strategies to improve the efficiency of alpaca systems to increase fleece yield per animal and per herd.
- * Review the technology and/or methodology used to heat the water in the dyeing stage.
- * Attach environmental information in addition to the garment care instructions: indicate that alpaca fiber garments do not need to be washed after each use, recommend recycling the product.
- * Rethink the export strategies of the final products considering a change of means of transport from plane to cargo ship.

For future studies of the Environmental Footprint of Alpaca fiber, the following are recommended:

- * Carry out studies on carbon sequestration in wetlands.
- * Collect detailed information on the irrigation of the pastures.
- * Perform soil analysis to estimate the amount of phosphorus and soil erosion (t soil / ha) in the study area.
- * Deepen the studies of alpaca manure in its chemical transformation at the soil-air interface.



- ⌘ Design studies on protein metabolism in alpacas to obtain data for the calculation of the allocation factors.
- ⌘ Incorporate the AWARE methodology to estimate impacts on water resources.
- ⌘ Perform analysis of wastewater from spinning mills, dry cleaners and incorporate the operations of the water treatment plants in future LCA studies.
- ⌘ Complement the research with socioeconomic studies for the design of strategies and policies that contribute to sustainability throughout the value chain of alpaca fiber garments.

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