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REGULAR ARTICLES

Estimation of carbon footprint and sources of emissions of an extensive alpaca production system

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Abstract
A cradle-to-farm gate life cycle assessment was conducted following international standards (ISO 14040, 2006) to estimate sources of greenhouse gas emissions of an extensive alpaca production system in the Peruvian Andes with a focus on carbon footprint. The assessment encompasses all supply chain processes involved with the production of alpaca fiber and meat. Direct (i.e., enteric fermentation, manure, and manure management) and indirect emissions (i.e., electricity, fuel, and fertilizer) of carbon dioxide, nitrous oxide, and methane were estimated according to the (IPCC (Intergovernmental Panel on Climate Change). 2006. IPCC 2006 for National Greenhouse Gas Inventories. Volume 2, Chapter 3. Mobile Combustion. Volume 4, Chapter 10. Emissions from livestock and manure management. Chapter 11. N2O emissions from managed soils and CO2 emissions derived from the application of lime and urea. https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html). Carbon footprint was calculated based on a mass, economic, and biophysical allocation. The functional unit of the economic and mass allocations was 1 kg of LW as the main product and 1 kg of white or colored fiber as co-products. The functional unit of the biophysical allocation was 1 kg of live weight and 1 kg of fiber. The largest source of greenhouse gas emissions came from enteric fermentation (67%), followed by direct and indirect nitrous oxide emissions (29%). The estimated carbon footprint of the extensive alpaca production system, considering a 20% offtake rate, was 24.0 and 29.5 kg of carbon dioxide equivalents per kg of live weight for the economic and mass allocations, respectively, while for the biophysical allocation was 22.6 and 53.0 kg of carbon dioxide equivalents per kg of alpaca live weight and alpaca fiber, respectively. The carbon footprint per area was 88.6 kg carbon dioxide equivalents per ha.

Keywords Allocation · Life cycle · Methane · South American camelids

Introduction

Agricultural sector in Peru is one of the main contributors of greenhouse gas (GHG), representing 15% of total emissions (MINAM (Ministry of Environment), 2016). Consequently, research has been carried out to quantify GHG emissions from several production systems in Peru (Bartl et al., 2011) to establish an initial benchmark against which mitigation strategies that aim to reduce system emissions can be evaluated.

Alpacas are valuable animals because of the fiber, meat, and other by-products they provide. It is one of the most prized natural fibers in the world due to its softness, lightness, and durability (Wang et al., 2003). Its low-fat meat has a high nutritional value, its skin has ideal characteristics for the leather industry, and its blood contains a unique class of immunoglobulin G_H used to produce therapeutic medical products (MINAGRI (Ministry of Agriculture), 2019). Even though most alpacas are in Peru (MINAGRI (Ministry of Agriculture), 2018), and most alpaca farms rely on natural grasslands (INEI (National Institute of Statistics and Informatics), 2013), there is no published information on the carbon footprint (CF) of alpaca products produced under a natural grassland-based system.

The CF is an indicator to identify and measure each GHG emission activity found in a production system (Pandey and

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Agrawal, 2014). The CF is used to characterize the GHG profile of a product, providing a baseline on which mitigation objectives can be established and progress measured (Jones et al., 2013). Therefore, this study aimed to (1) identify the GHG emission sources and (2) estimate the CF of an extensive alpaca production system per kg of live weight (LW) and fiber, based on a life cycle assessment approach.

Materials and methods

The CF was calculated based on alpaca production records from 2018, in accordance with ISO 14040 (2006), which describes the analysis of the life cycle assessment of a product considering the emissions derived from the process and the guidelines established by the Intergovernmental Panel on Climate Change (IPCC, 2006).

Description of the production system

The study was performed at the Quimsachata Research and Production Center (CIP) in the district of Santa Lucia, Puno in Peru (4200 m.a.s.l.; latitude, 15°44′S; longitude, 70°41′W).

The system under study was an alpaca extensive production system, which produced animals for sale (commonly farmed for their meat) and fiber. The system has 6280 ha, where animals grazed native grassland composed of *Mhulembergia peruviana*, *Hipochoeris stenocephala*, *Festuca dolichophylla*, and *Stipa ichu*, for 8–10 h per day with supplementation of oat hay during the dry season (i.e., May to December). Pasture management followed a rotational grazing management composed of seven active grazing areas with a 6-month rest period for each grazing area. Animal load was 1.2 animal units (i.e., one animal unit is equivalent to an adult female alpaca with her calf). During the rainy season (i.e., January to April), animals grazed in the highest areas (5000 m.a.s.l.), whereas during the dry season, animals were taken to the low areas (4200 m.a.s.l.). During grazing, both feces and urine were naturally incorporated into the soil.

On average, the alpaca system has an 80% fertility rate (i.e., percentage of pregnant alpacas with respect to the total number of mated alpacas), 54% birth rate (i.e., percentage of offspring born of total number of pregnant alpacas, in a population during a specific period), and 20% offtake rate (i.e., percentage of animals sold for various reasons as a proportion of the total population).

All data required for the CF estimation were recorded from field notebooks, production records, and accounting documents of the CIP. The use of fuel was classified into activities inside of the research center (e.g., transportation of personnel to the grazing areas) and activities outside of the research center (e.g., purchase of hay). The electrical energy consumption included the total energy used in offices, administrative buildings, and facilities of the research station.

Boundaries and functional units of the cradle-to-farm gate life cycle assessment

The boundaries of the system included all supply chain processes associated with the primary production of alpaca fiber and meat to the farm gate. The GHG emissions from agricultural activities included direct and indirect emissions of CO_2, N_2O, and CH_4 (Peri et al., 2020). Direct GHG emissions are those produced on the farm (i.e., CH_4 emissions from enteric fermentation and manure deposited in the grazed grassland, and N_2O from manure management), while indirect emissions are those produced outside of the farm but are still related to farm activities (i.e., electricity used to light the offices, fuel from transportation, and fertilizer used).

The functional unit of the life cycle assessment was calculated based on 1 kg LW (i.e., live animal commercialization with 38 and 60 kg of LW for young and adult animals, respectively) as the main product sold off the farm and 1 kg of white and colored greasy fiber (i.e., 1.9 and 2.6 kg of greasy fiber produced per year by young and adult animals, respectively) as co-products.

Allocation system

Based IDF (International Dairy Federation) (2015)CF was expressed in three types of allocations: economic, mass, and biophysical (i.e., protein requirement index) and per unit of surface (ha). For the economic allocation, the GHG emissions were assigned in proportion to the economic value of each product (i.e., LW, white greasy fiber, and colored greasy fiber), which is attributed to the main product (i.e., LW). For the biophysical allocation, the GHG emissions were calculated based on protein requirement established for physiological functions (i.e., animal growth and fiber production) and protein content of products and co-products following the LEAP (Livestock Environmental Assessment and Performance Partnership), 2014) guide for the Evaluation and Environmental Performance of Livestock:

$$Economic\ allocation\ factor = LW * LW_{price} / \left(LW * LW_{price} + WF_{weight} * WF_{price} + CF_{weight} * CF_{price}\right)$$

$$Mass\ allocation\ factor = LW / \left(LW + WF_{weight} + CF_{price}\right)$$

$$Biophysical\ allocation\ factor = 100 * Protein_{growth} / \left(Protein_{growth} + Protein_{fiber}\right)$$

where LW is the live weight (kg); LW_{price}, WF_{price}, and CF_{price} are the sale price of LW, white, and colored greasy fiber, respectively (USD/kg); WF_{weight} and CF_{price} are the white and colored greasy fiber weight, respectively (kg); and $Protein_{growth}$ and $Protein_{fiber}$ are the protein requirement for growth and fiber, respectively (g/day).

In 2018, 17,828 kg of LW of alpacas, 343 kg of white greasy fiber, and 681 kg of colored greasy fiber were sold at a price of S/4.0/kg (~ USD 1.06), S/35.6/kg (~ USD 9.47), and S/13.3/kg (~ USD 3.54), respectively. The $Protein_{growth}$ and $Protein_{fiber}$ were calculated assuming that 72.6% of the total protein requirement was used for growth and the remaining 27.4% was used for fiber production.

Furthermore, the carbon dioxide equivalent (CO_2-e) per unit of grazed area (ha) was calculated by multiplying the annual CO_2-e per animal by the total number of animals in the grazed area (units) and dividing by the total grazed area (ha).

Emission calculations

The global warming potentials of emissions were established in relation to CO_2 over a 100-year time horizon. Additionally, the potential GHG emission established by the IPCC was expressed in kg of CO_2-e, considering an equivalence of 1 CO_2-e for one molecule of CO_2, 25 CO_2-e for one molecule of CH_4, and 298 CO_2-e for one molecule of N_2O (Oertel et al., 2016). The emission factors (EFs) for calculating GHG emissions (CH_4, N_2O, and CO_2) from manure, fuel, electricity, and fertilizers were provided by the IPCC (2006) using Tier 1 equations (Table 1).

The CF was then determined by multiplying the allocation factor (i.e., economic, mass, or biophysical allocation) by the environmental impact of the process (i.e., kg of CO_2-e produced/year) and divided by the total output expressed in kg of LW.

$$\text{Carbonfootprint} = \text{AF} * \mathit{Total\ CO_{2-e}}/\mathit{Totaloutput}$$

where AF is the allocation factor, Total CO_2-e is the environmental impact of the process (kg), and total output is the total output as product and co-products (kg).

The Monte Carlo simulation was performed by randomly choosing a value for each EF, performing a total of 5000 interactions. The intervals within which the simulation would randomly choose a value for each EF were defined by the standard deviation of the EF, based on the uncertainty ranges proposed by the IPCC (2006) (Table 2). For the case of EF for enteric CH_4 of each animal category (i.e., young, tuis, and adults), a 20% increase was considered according to the EF standard deviations obtained by Gómez et al. (2021). The Monte Carlo simulation was performed using Microsoft Excel 2010.

Results

Table 3 presents the average annual alpaca population (including infertile animals) by category as well as inputs and outputs of the system under study. Table 4 shows the annual GHG emission and its contribution per emission source, as well as the emissions per kg of product. The total emissions produced inside the system were greater than those outside the system. Methane from enteric fermentation contributed the highest percentage in emissions, followed by N_2O and CH_4 from manure management.

Table 5 shows the estimation of CF with different types of allocation (mass, economic, and biophysical allocations), as well as the amount of GHG emissions per unit area (hectare).

As a matter of exercise and using biophysical allocation, the CF was determined by considering different offtake rates (i.e., 10%, 15%, 20%, 25%, and 30%) based on the range of offtake rates commonly found in alpaca production systems in Peru (Gutiérrez, 1993). To achieve this objective, a population scenario was developed using productive and reproductive parameters derived from the means of the last 4 years in the production system under study. The CF for fiber estimated at 10%, 15%, 20%, 25%, and 30% offtake rates was 58, 54, 53, 51, and 48 kg CO_2-e/kg fiber, while the CF for LW was 66, 45, 23, 19, and 14 kg CO_2-e/kg LW, respectively.

The increase of one parameter at a time affected the CF, as shown in Table 6. The three parameters that caused the highest increase in total CF were the EF used for direct N_2O emissions from excreta deposited during grazing, the EF used for enteric CH_4 emissions in adult alpacas, and the EF used for indirect emissions of N_2O caused by ammonia volatilization.

Results showed that individual parameters can have a significant impact on total CF. By varying one parameter at a time within reasonable limits, the CF changed by up to 24%. The prediction interval (between 2.5% and 97.5% of the uncertainty distribution) was 15.3 and 33.2 kg of CO_2-e/kg of LW of alpaca produced, with a corresponding coefficient of variation at 19% (Fig. 1).

Discussion

The life cycle assessment of any agricultural product should consider the peculiarities of each country within its context of analysis (Ruviaro et al., 2012). In this sense, the life cycle assessment of the present study took into consideration the type of grazing, the use of supplementation during the dry season, and the management of manure. The nutritional,

Table 1 Equations to estimate greenhouse gas emissions in the form of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) produced outside and inside of the production center

GHG produced outside the production center

1. Total emission fuel (kg CO_2-e/year)

Annual fuel consumption = transportation within the grazing areas + transportation outside the grazing areas

Annual fuel consumption = Gasoline consumption + Diesel consumption

Total emission gasoline (TJ) = (Gasoline consumption × Dg / 1000) / 1,000,000 × CVg

Total emission diesel (TJ) = (Diesel consumption × Dd / 1000) / 1,000,000 × CVd

Total emission fuel (TJ) = Total emission gasoline + Total emission diesel

Total emission fuel (kg CO_2-e /year) = (Total emission fuel (TJ) × EF_{CO2} × 1) + (Total emission fuel (TJ) × EF_{CH4} × 25) + (Total emission fuel (TJ) × EF_{N2O} × 298)

where Dg and Dd are the gasoline density (719.7 kg/m^3; Vohra 2011) and diesel density (832 kg/m^3; Gutierrez 2017), respectively; CVg and CVd are the gasoline calorific value (43.2 MJ/kg; Gutierrez 2017) and diesel calorific value (43.1 MJ/kg; Gutierrez 2017), respectively; and EF_{CO2} = 69,300 kg/TJ, EF_{CH4} = 25 kg/TJ, and EF_{NO2} = 8 kg/TJ (IPCC, 2006)

2. Total emission electricity (kg CO_2-e/year)

Total emission electricity = Annual electricity consumption (MW/year) × EF (CO_2-e/MW)

where MW is megawatts and EF_{CO2} is the emission factor (0.547 tCO_2/MWh; Ponce and Rodríguez, 2016)

3. Total emission fertilizers for oat production (kg CO_2-e/year)

N_2O direct from manure soils (kg CO_2-e/year) = Fsn × EF_1 × 44/28

N_2O indirect from manure soils (kg CO_2-e/year) = Fsn × Frac(gasf) × EF_2 × 44/28

N_2O indirect from leaches of manure soils (kg CO_2-e/year) = Fsn × Frac(leaching) × EF_3 × 44/28

Total emission fertilizers (kg CO_2-e/year) = N_2O direct from manure soils (kg CO_2-e/year) + N_2O indirect from manure soils (kg CO_2-e/year) + N_2O indirect from leaches of manure soils (kg CO_2-e/year)

where Fsn is the annual amount of nitrogen applied to soils in the form of synthetic fertilizer (kg/year), EF_1 is the emission factor for N_2O emissions from nitrogen inputs (0.01 kg N^{-1}; IPCC, 2006), EF_2 is the emission factor for N_2O emissions from atmospheric deposition of nitrogen in soils and on water surfaces (0.01 kg N^{-1}; IPCC, 2006), EF3 is the emission factor for N_2O emissions from nitrogen leaching and runoff, Frac(gasf) is the fraction of nitrogen from synthetic fertilizers that volatilizes as NH_3 and NO_x (0.1 kg N^{-1}; IPCC, 2006), and Frac(leaching) is the fraction of all nitrogen added to managed soils in regions where leaching occurs (0.3 kg N^{-1}; IPCC, 2006)

GHG produced within the production center

1. Total emission CH_4 by enteric fermentation (kg CO_2-e/year)

Total emission CH_4 by enteric fermentation = $EF_{ef(young)}$ × N° animals + $EF_{ef(tuis)}$ × N° animals + $EF_{ef(adults)}$ × N° animals

where $EF_{ef(young)}$ = emission factor for enteric CH_4 emissions from young alpacas (5.24 kg CH_4/$head^{-1}$/$year^{-1}$; Gómez et al., 2021), $EF_{ef(tuis)}$ is the emission factor for enteric CH_4 emissions from tuis alpacas (7.97 kg CH_4/$head^{-1}$/$year^{-1}$; Gómez et al., 2021), and $EF_{ef(adults)}$ is the emission factor for enteric CH_4 emissions from adults alpacas (12.58 kg CH_4/$head^{-1}$/$year^{-1}$; Gómez et al., 2021)

2. Total emission CH_4 by manure management (kg CO_2-e/year)

Total emission CH_4 by manure management = $EF_{mm(young)}$ × N° animals + $EF_{mm(tuis)}$ × N° animals + $EF_{mm(adults)}$ × N° animals

where $EF_{mm(young)}$ is the emission factor for manure CH_4 emissions from young alpacas (1.28; kg CH_4/$head^{-1}$/$year^{-1}$; IPCC, 2006), $EF_{mm(tuis)}$ is the emission factor for manure CH_4 emissions from young alpacas (1.28; kg CH_4/$head^{-1}$/$year^{-1}$; IPCC, 2006), and $EF_{mm(adults)}$ is the emission factor for manure CH_4 emissions from young alpacas (1.28; kg CH_4/$head^{-1}$/$year^{-1}$; IPCC, 2006)

3. Total emission N_2O by manure management (kg CO_2-e/year)

N_2O direct = [∑ (Nt × Nex × MS)] × EF_d × 44/28

N_2O indirect = (Nvol-MMS × EF_i) × 44/28

Total emission N_2O by manure management = N_2O direct + N_2O indirect

where Nt is the number of alpacas per category, Nex is the nitrogen excretion per animal category (kg nitrogen per animal per year), MS is the fraction of total annual nitrogen excretion of each animal that is managed in the manure management system (1; IPCC, 2006), EF_d is the emission factor of direct N_2O emissions from the manure management (0.01 kg N_2O/kg N; IPCC, 2006), Nvol-MMS is the quantity of nitrogen from manure that is lost because of ammonia volatilization NO_x (kg N/year), and EF_i is the emission factor for N_2O emissions resulting from atmospheric nitrogen deposition in the soil or water surface (kg N_2O-N [kg NH_3-N + volatilized NO_x-N] – 1) (0.01; IPCC, 2006)

Table 2 Range of uncertainty coefficient of variation, emission factor (EF) used, and standard deviation (SD) of the predominant emission sources

Parameters	Range of uncertainty[a]	EF	SD
Enteric CH_4 emissions in adults	0.26	12.13	3.14
Direct N_2O emissions from manure management	0.003–0.03	0.01	0.005
Indirect N_2O emissions from manure management	0.002–0.05	0.01	0.005

[a]Ranges provided by the IPCC (2006) except for 0.26 that was obtained from Gómez et al. (2021)

Table 3 Alpaca population by categories, inputs, and outputs of the extensive alpaca production system in 2018

Alpaca population in 2018 (units)			Annual inputs and outputs of the system in 2018		
Males	> 3 years	278	Inputs	Oat hay (kg/year)	6000
	8 months–3 years	84		Gasoline (L/year)	2354
	< 8 months	163		Diesel (L/year)	3012
Females	> 2 years	684		Electricity (MW/year)	14.42
	8 months–2 years	113	Outputs	Alpacas < 3 years (units)	136
	< 8 months	170		Alpacas > 7 years (units)	211
				White greasy fiber (kg)	343
Total population		1492		Colored greasy fiber (kg)	681

Table 4 Total greenhouse gas emissions from the production of 1 kg of LW of alpaca at the Quimsachata Research and Production Center in 2018

	Sources of greenhouse gas emissions		
	kg CO_2-e/year	%	kg CO_2-e/kg LW
Emissions inside the system			
CH_4 from enteric fermentation	371,964	66.90	16.07
CH_4 from manure management	7343	1.33	0.32
N_2O from manure management	163,047	29.30	7.04
Subtotal	542,354	97.53	23.43
Emissions outside the system			
Fuel	5649	1.02	0.24
Electricity	7889	1.41	0.34
Fertilizers	209	0.04	0.01
Subtotal	13,747	2.47	0.59
Total	556,101	100.00	24.02

CH_4 methane, *CO_2-e* carbon dioxide equivalent, *LW* live weight, *N_2O* nitrous oxide.

Table 5 Carbon footprint per type of allocation

Allocation	Functional unit	Carbon footprint
Mass	kg CO_2-e[a]/kg product	29.5
Economic	kg CO_2-e/kg LW	24.0
Biophysical	kg CO_2-e/kg LW	22.6
	kg CO_2-e/kg fiber	53.0
Hectare	kg CO_2-e/ha	88.6

CO_2-e carbon dioxide equivalent, *LW* live weight.

sanitary, and reproductive management of the system under study was considered optimal, although alpacas live in challenging environmental conditions such as extremely low temperatures (Gómez-Quispe et al., 2019).

The largest source of GHG emissions came from CH_4 from enteric fermentation and represented the 67% of total GHG emissions. This proportion was greater than those reported for sheep production systems under similar conditions as ours (Jones et al., 2013 (44–49%); Dyer et al., 2014 (50%); Peri et al., 2020 (60–65%)).

These discrepancies on the proportions of CH_4 from enteric fermentation between studies might be related to the animal population, system productivity, and feed quality (LEAP (Livestock Environmental Assessment and Performance Partnership), 2014which are key primary factors required to calculate the total GHG emissions.

The second greatest source of GHG emission was N_2O emissions from manure management. This was expected because most of the N_2O emissions come from soils (Signor and Pellegrino, 2013) and rangelands are considered the largest source of N_2O because of the presence of manure (Luo et al., 2010).

In terms of economic allocation, our results were in range to those reported by Batalla et al. (2014; 11.5–44.9 kg of CO_2-e/kg LW), but greater than Jones et al. (2013; 10.85–17.86 kg of CO_2-e/kg LW) and Dyer et al. (2014; 13.9 kg CO_2-e/kg LW). A possible reason for the differences between studies may be that alpacas in extensive alpaca production systems fed in natural grasslands frequently exhibit low productivity because of the low quality and scarcity of feed resources, resulting in increased GHG emissions per unit of product. Furthermore, the interpretation of the economic allocation between studies may not be fair due to differences in prices of products and changes in market prices and price regulation throughout the years.

In terms of mass allocation, results were in range to those reported by Dougherty et al. (2019; from 13.9 to 30.6 kg of CO_2-e/kg LW). Likewise, the results on biophysical allocation were in range to those reported by Peri et al. (2020) for meat production (from 12.15 to 38.45 kg of CO_2-e/kg LW produced), but not for wool production (from 7.83 to 16.92 kg CO_2-e/kg of greasy wool). The greater biophysical allocation obtained in this study compared with that by Peri et al. (2020) might be related to the low fiber production of alpacas in an extensive production system.

It is possible to evaluate strategies for reducing the CF of a system by understanding its life cycle assessment, as well as its sources of GHG emissions. For example,

Table 6 Change in total carbon footprint resulting from the variation of the individual parameters

Parameters	Parameter increase (%)	Carbon footprint (kg CO_2-e/kg LW)	Carbon footprint increase (%)
EF fuel	10	24.05	0.12
EF electricity	10	24.06	0.17
EF fertilizer direct N_2O	100	24.03	0.04
EF fertilizer indirect N_2O	100	24.03	0.04
EF fertilizer indirect N_2O leaching	100	24.03	0.04
EF enteric CH_4 young	20	24.39	1.54
EF enteric CH_4 tuis	20	24.35	1.37
EF enteric CH_4 adults	20	26.55	10.50
EF CH_4 excreta young	25	24.03	0.04
EF CH_4 excreta tuis	25	24.03	0.04
EF CH_4 excreta adults	25	24.08	0.25
EF N_2O direct excreta	100	30.31	26.20
EF N_2O indirect excreta	100	24.77	3.10

EF emission factor, *N_2O* nitrous oxide, *CH_4* methane.

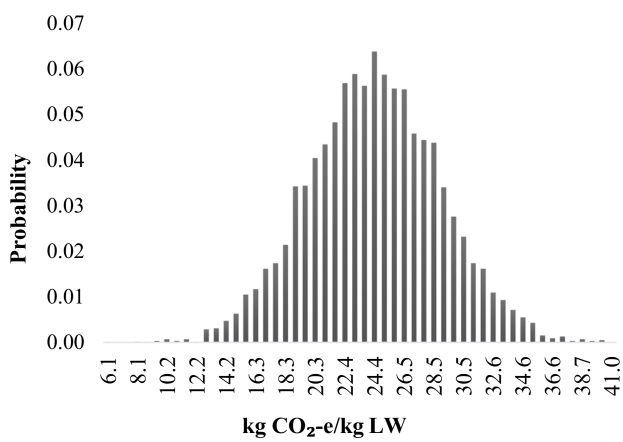

Fig. 1 Probability distribution of GHG emissions of 1 kg of alpaca LW produced based on the Monte Carlo simulation

increasing lamb growth rates and improving the nutrition of gestating ewes to increase lamb survival are effective and practical measures to mitigate GHG emissions in sheep farms (Jones et al., 2013). Also, increasing the offtake rate due to higher selection pressure and/or reproductive parameters, through improved feeding and genetics, can significantly affect GHG emissions for meat and fiber production systems according to the FAO (2013).

As manner of exercise, this present study evaluated changes in CF with changes in offtake rates. The results of the CF estimations under various offtake rates indicate that an increase in offtake rates can reduce the CF because the total GHG emissions are distributed between the increased amount of kg of LW destined for sale (i.e., biophysical allocation CF per kg LW) and fiber produced (i.e., biophysical allocation CF per kg fiber).

In summary, this study is the first to estimate the CF of an extensive alpaca production system in the Peruvian Andes. In addition, it provides a basis for designing strategies to reduce GHG emissions from extensive alpaca production systems, and thus its CF per unit of product.

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Author contribution G. Gómez Oquendo: methodology, formal analysis, writing—original draft, visualization; K. Salazar-Cubillas: writing—review and editing; V. Alvarado: formal analysis; C. A. Gómez-Bravo: conceptualization, methodology, resources, supervision, project administration, funding acquisition. All authors have read and agreed to the published version of the manuscript.

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Data availability The datasets generated during the current study will be available in the repository from Universidad Nacional Agraria La Molina (https://repositorio.lamolina.edu.pe/). Doctoral thesis: Cuantificación del metano entérico de alpacas y ovinos en pastos naturales altoandinos y huella de carbono de la producción alpaquera.

Declarations

Ethics approval This is an observational study; therefore, no ethical approval is required.

Competing interests The authors declare no competing interests.

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