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PLOS CLIMATE

RESEARCH ARTICLE

Status and opportunities for improvement in greenhouse gas emission inventories for the cattle production in Latin America and the Caribbean region: A perspective

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Abstract

The Intergovernmental Panel on Climate Change (IPCC) provides the reference for national greenhouse gas emission (GHG) inventories towards standardized, accurate, measurable, and comparable National Inventory Reports (NIR). For compliance with the 1.5 ˚C commitments under the Paris Agreement, most countries have made efforts to improve their inventory methods to tier 2 or 3. However, some relevant activities within Latin American and the Caribbean (LAC) countries, such as enteric methane emissions and methane and nitrous oxide emissions from cattle manure management are still estimated using tier 1 methods, which leads to a high uncertainty due to the importance of livestock emissions in the national totals for these countries. In this context, reducing the uncertainty in GHG inventories would not only improve the accuracy of national reports but it would also provide solid baselines for national mitigation initiatives e.g., Nationally Determined Contributions under the Paris Agreement, and accurate tools to venture into carbon bonds or payments for ecosystem services. The aim of this study was to review the status of national GHG inventories specifically for these three cattle emission categories in 11 LAC countries. We conducted a survey of GHG inventory experts in the 11 LAC countries, to identify the potential for improvement and the main barriers to achieving this. Despite some initiatives, there is still a large potential for reducing the uncertainty in LAC national GHG emission estimates, the barriers to or solutions can be categorized as technical, policy, and institutional issues. However, improving the GHG inventories of LAC countries, specifically for cattle emissions, is feasible in the

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medium term, as long as multilateral actions are considered, coherently linked under a comparable and verifiable methodology and including a commitment by countries to invest public funds in relevant research and innovations.

Introduction

The Paris Agreement, adopted in 2015 during the 21st Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC), represents a milestone in multilateral climate negotiations and offers important implications for academic research [1, 2]. This Agreement set the obligation for all Parties to make efforts to reduce their emissions, and the basis for the construction of an agreement that allows the measures adopted to be reviewed and improved when necessary [3]. Thus, national and international climate policies such as the Paris Agreement have the potential to alter the opportunity costs of specific land uses in ways that increase opportunities to achieving climate change mitigation goals [4].

The Paris Agreement establishes a long-term goal to keep the global average temperature increase well below 2˚C, and to continue efforts to limit it to 1.5˚C above pre-industrial levels [5]. To achieve this goal, the Parties proposed in Article 4.1 to reach a global peak in GHG emissions as soon as possible and then undertake rapid reductions in accordance with the available scientific knowledge, to achieve a balance between anthropogenic GHG emissions by sources and removals by sinks in the second half of this century [6, 7].

Developed countries should continue to lead in efforts to reduce emissions while developing countries were encouraged to advance their mitigation efforts by adopting economy-wide emission reduction targets in the light of different national circumstances [5]. Therefore, the Paris Agreement calls for all Parties to report on the details; in this way, the agreement introduces a nuanced approach to differentiation, establishing less stringent requirements for developing countries, while leveling the reporting obligations of the others [3]. In the Paris Agreement, all Parties determine autonomously their contribution to the global effort to reduce emissions, according to the principles of common but differentiated responsibilities and respective capabilities; that is, each Party defines internally the actions to be taken, emissions to be reduced, adaptation actions and contributions in terms of implementation [8].

To achieving long-term emission reductions, the Parties are subject to binding behavioral obligations regarding national mitigation contributions. The most important of these is contained in Article 4.2, "Each Party shall prepare, communicate and maintain successive Nationally Determined Contributions (NDC) that it intends to make. Parties shall endeavor to take domestic mitigation actions, with the aim of achieving the objectives of those contributions" [9, 10].

All Parties are required to submit a biennial transparency report which includes the national GHG inventory, progress made in implementing and achieving NDCs, climate change impacts and adaptation and financial, technology transfer and capacity-building support needed and received by developing countries, and provided and mobilized by developed countries. It imposes extensive reporting requirements for all Parties and subjects' information on mitigation and finance to close scrutiny [5, 11]. In this way, a transparency regime is established that makes national policies internationally comparable, which creates a robust enhanced transparency framework for action and support, with built-in flexibility that considers the different capabilities of Parties.

The main way to monitor progress towards NDCs is through national GHG inventories [12]; this is the quantification of the amount of GHG emitted into the atmosphere as a product of anthropogenic sources and the removals by carbon sinks, for a country during a specific period [13]. Thus, inventories play a key role in the transparency framework through which progress towards national and global climate targets will be tracked [12]. In the UNFCCC, Parties are required to develop, periodically update and publish, national inventories of anthropogenic emissions by sources and removals by sinks of all GHG, using comparable methodologies as agreed by the Conference of the Parties [14]. The last methods were established in the 2006 and 2013 revised guidelines of the IPCC which also establishes methodological options that provide flexibility for countries [15]. However, inventories should adhere to five principles: transparency, accuracy, completeness, comparability, and consistency [16].

In Latin America and the Caribbean (LAC), climate change policies are predominantly related to the agriculture, forestry and other land use (AFOLU) sector [17] as most of the GHG emissions in LAC derive from this sector and not from the energy sector as in other parts of the world such as North America and Europe; in fact, more than 20% of exports in almost all countries in the region come from AFOLU sector [17]. In addition, activities in the agriculture sector may be substantially affected by climate change given the dependence on climatic conditions. This sector is also unique in that, in addition to being a source of GHG emissions, it represents an opportunity for carbon sequestration, making it a key sector in the GHG contributions and inventories of LAC countries [4]; however, due to the lack of a universally accepted accounting framework, research is needed to develop standards for metrics and monitoring towards carbon bonds markets [18]. Meanwhile, associated risks with carbon projects such as leaking emissions and "greenwashing" of corporations with high emissions is evident.

The agriculture sector, and specifically livestock production represents an important contributor to GDP and to GHG emissions (S1 Table) and removals for LAC countries. For the last reported year, cattle production was responsible for between 6 and 43% of annual emissions (Fig 1), as estimated using the current national inventory methods.

These emissions are mainly represented by enteric methane (CH_4), methane arising from manure management and nitrous oxide (N_2O) from urine patches. Methane is a short-lived GHG which has a global warming potential of 28 on a CO_2 equivalent basis [19], and developing countries contribute about 70% of livestock anthropogenic methane emissions globally of which 25% originates from LAC [20]. Nitrous oxide is a long-lived GHG with a global warming potential of 265 [19].

In addition to these, there are also associated emissions from the livestock industry, including from transportation and energy consumption, among others, increasing the relevance of the cattle industry from a mitigation perspective. Despite efforts to set significant mitigation commitments [32], most LAC countries use default IPCC tier 1 methods and parameters for these emission categories, with few using more detailed country-specific tier 2 methods, resulting in a high uncertainty and lack of robust information with which to develop and track progress of climate policy actions.

There are currently several initiatives funded by international organizations aimed at improving national and sub-regional GHG inventories; one of these is the FAO course on new MRV concepts, UNFCCC reporting requirements for national GHG inventories and the implications of the Enhanced Transparency Framework (ETF); UNDP, on the other hand, has a training program that, together with the government of Ecuador, created a national GHG inventory system which aims to manage information to mitigate emissions and report them to the UNFCCC; however, these initiatives are still scattered and are not applied in all the countries in the region.

The aim of this study was, therefore, to review the current status of national GHG inventories within 3 relevant livestock GHG sources: enteric methane, manure management methane,

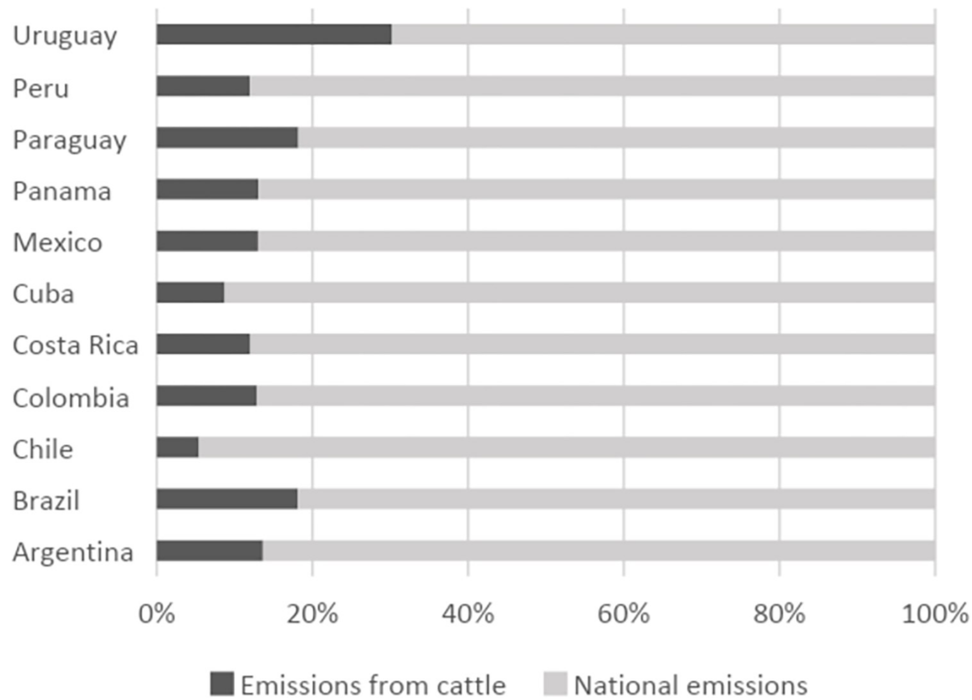

Fig 1. National emissions vs cattle emissions in percentage from eleven LAC countries. Argentina (16%) [21], measured in 2018; Brazil (22%) [22], measured in 2016, Chile (6%) [23], measured in 2018, Colombia (15%) [24], measured in 2018; Costa Rica (14%) [25], measured in 2017, Cuba (10%) [26], measured in 2020; Mexico (15%) [27], measured in 2019, Panama (15%) [28], measured in 2017; Paraguay (22%) [29], measured in 2017; Uruguay (43%) [30], measured in 2017; and Peru (14%) [31], measured in 2014).

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and manure management nitrous oxide in 11 LAC countries (S1 Fig). A survey of national GHG inventory experts was conducted to identify the potential for inventory improvement and the main barriers to this in the context of the current policy, technical and global climate.

Current status of GHG inventories in LAC countries

An expert consultation approach was used to assess the current status of the GHG inventories in LAC countries. One expert on GHG inventories from each of the 11 countries was chosen based on the fulfillment of 5 of the following 7 selection criteria: 1) being an active or recent past member of the national GHG inventory group and the most recent national BUR; 2) being part of the livestock emissions category calculation group; 3) being part of an active association, organization, government, university or national entity; 4) being actively involved in research regarding emission factors (EF), activity data and/or GHG inventories; 5) having the ability to share, discuss and to improve livestock emission calculations in its country of origin; 6) availability to intervene in future BUR from their home country; and 7) knowledge of IPCC 2019 improved EF.

A remote and standardized online questionnaire (S2 Table) was sent to each expert which included: 1) share of the cattle sector in the national GHG inventory; 2) current tier method for each cattle emission category, as reported in the most recent BUR; 3) improvement plans for tier methods; 4) existence of projections and mitigation plans for the cattle sector; 5) improvement needs/plans for the national GHG inventory (techniques, methods, governance); 6) main challenges for scaling up at the methodological level; 7) existence of funds to overcome

Table 1. Definition of tiers 1, 2 and 3 (IPCC) [34] for each category.

Category	Tier 1	Tier 2	Tier 3
CH_4 Emissions from enteric fermentation	A simplified approach that relies on default EF established in IPCC guidelines that were either drawn from the literature or calculated using regional data taken from the literature and derived using the tier 2 method	A more complex approach that requires detailed country-specific data on gross energy intake and methane conversion factors for specific livestock categories. The tier 2 method should be used if enteric fermentation is a key source category for the animal category that represents a large portion of the country's total emissions	This approach employs the development of sophisticated models that consider diet composition in detail, concentration of products arising from ruminant fermentation, seasonal variation in animal population or feed quality and availability, and possible mitigation strategies. Many of these estimates would be derived from direct experimental measurements.
CH_4 emissions from manure management	The tier 1 method entails multiplying the total amount of volatile solids (VS) excreted in each type of manure management system in the specified climate zone. The tier 1 method is applied using IPCC default VS excretion factors, default typical animal mass, default CH_4 EF, and default animal manure management systems. Emissions from manure management systems are highly temperature-dependent.	A more complex method for estimating CH_4 emissions from manure management should be used where a particular livestock species/ category represents a significant share of a country's emissions. This method requires detailed information on animal characteristics and manure management practices, which is used to develop EF specific to the conditions of the country. The main differences between the tier 1 and tier 2 calculations are whether default information or country-specific information is used in the calculation of emissions from manure management systems. The tier 2 system provides a much wider group of options for estimating emissions from different manure management systems	Some countries for which livestock emissions are particularly important may wish to go beyond the tier 2 method and develop models for country-specific methodologies or use measurement–based approaches to quantify EF. The method chosen will depend on data availability and national circumstances. Good practice in estimating CH_4 emissions from manure management systems entails making every effort to use the tier 2 method, including calculating EF using country-specific information. The tier 1 method should only be used if all possible avenues to use the tier 2 method have been exhausted and/or it is determined that the source is not a key category or subcategory.
N_2O emissions from manure management	The tier 1 method entails multiplying the total amount of N excretion in each type of manure management system by an EF for that type of manure management system. Emissions are then summed over all manure management systems. The tier 1 method is applied using IPCC default N_2O EF, default nitrogen excretion data, and default manure management system data.	A tier 2 method follows the same calculation equation as tier 1 but would include the use of country-specific data for some or all of these variables. For example, the use of country-specific nitrogen excretion rates for livestock categories would constitute a tier 2 methodology.	A tier 3 method utilizes alternative estimation procedures based on a country-specific methodology. For example, a process-based, mass balance approach which tracks nitrogen throughout the system in detail starting with feed input through final use/disposal could be utilized as a tier 3 procedure. tier 3 methods should be well documented to clearly describe estimation procedures.

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challenges; and 8) institutional view of the national GHG inventory over 5 to 10 years and current actions to achieve it.

Given the relative importance of the emissions of enteric methane, and methane and nitrous oxide emissions from manure management in cattle which share between 6 and 43% national inventories in LAC, the focus of the survey was on these three emission categories.

Current status of the national inventory methods and EF was categorized according to the IPCC [33] tier classifications (Table 1).

Countries were classified according to the effort required to improve the national GHG inventory methods for the selected emission sources. High input requirement countries (HIRC) comprise those using tier 1 across all selected categories; Medium input requirement countries (MIRC) comprise those with 1 or 2 cattle categories using tier 1; and Low input requirement countries (LIRC) comprise those using tier 2 across all selected categories (Table 2). None of the surveyed countries were using tier 3 methods or EF for any of the relevant cattle production categories; this means that despite efforts to move to tier 2, further work is still needed to reduce inventory uncertainty.

Enteric methane from cattle is the category where most countries have made progress, with 7 of the 11 surveyed countries currently using tier 2 methods. For cattle manure management methane and cattle-associated nitrous oxide emissions, only 3 of the 11 countries surveyed have progressed to tier 2.

Table 2. Classification of 11 countries in the LAC region based on the methodological tiers used for three cattle GHG-emitting categories.

	Last report	Inventory	CH_4 emissions from enteric fermentation	CH_4 emissions from manure management	N_2O emissions from manure management	Classification
Mexico	2022	2019	1	1	1	HIRC (three tier 1 EF)
Panama	2021	2017	1	1	1	
Paraguay	2020	2017	1	1	1	
Peru	2019	2014	1	1	1	
Uruguay	2019	2017	2	1	1	MIRC (one or two tier 1 EF)
Chile	2020	2018	2	1	1	
Colombia	2021	2018	2	1	1	
Cuba	2020	2020	2	1	1	
Argentina	2021	2018	2	2	2	LIRC (three tier 2 EF)
Brazil	2020	2016	2	2	2	
Costa Rica	2019	2017	2	2	2	

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In view of the importance of cattle emissions in the national GHG totals, all HIRC and MIRC countries surveyed, with the exception of Mexico, have included in their improvement plans that they will estimate country-specific EF for the next official report. None of the LIRC have included any plans to move to tier 3 methods, although some do include plans to reinforce their current tier 2 methodology e.g., where they currently use tier 2 for only dairy cattle, to extend this to other cattle. It should be noted that, for nitrous oxide from manure management, tier 2 is not necessarily associated with a country-specific EF, it is sufficient to have country-specific activity data, such as nitrogen excretion rates or animal population fractions associated with the different manure management systems.

Challenges for improving GHG inventories

Continuous improvement is an issue that cuts across all sectors of the economy for LAC countries, not only to quantify their GHG emissions but also to be competitive in potential business models such as carbon credit markets and zero deforestation agreements. Despite delays in refining inventories and specifically methods and EF for the livestock sector, all the surveyed LAC countries were committed to improve their GHG inventories. A common response from the interviewed countries was the importance and weakness of uniform and periodic activity data collection since it has a crucial impact on the GHG emissions calculations. There should, therefore, be a strong focus on development of systemized and standardized activity data collection methodologies.

The HIRC improvement plans include development of country-specific methods and EF for enteric methane; however, this is subject to particular national circumstances and institutional arrangements that will allow them to make such improvements. For Mexico, where there was a strong emphasis on development of country-specific EF for cattle enteric methane emissions from national research projects, it was reported that there was a lack of administrative management to incorporate such information into Mexico's national GHG inventory.

The MIRC have improvement plans that seek to refine the present tier 2 methodological level for enteric methane emissions by obtaining more accurate parametric data, as well as greater precision and disaggregation of its activity data by edaphoclimatic region. Currently, the MIRC are working on improving the quality of activity data in terms of accuracy and frequency of reporting. In addition, MIRC intend to achieve country-specific EF for methane and direct nitrous oxide emissions measurements from cattle manure management.

Technical support and trained human resources

Improvement to inventories to reflect local conditions and production systems in the emission calculation methods used requires the technical capacity, including appropriately skilled staff, within a country to conduct the required research in addition to an administrative framework that enables translation and incorporation of the research results into the national GHG inventory; it is evident the need for more interaction between inventory officers and researchers.

The HIRC specifically commented on the requirement for administrative management by the respective regulatory bodies in order to incorporate new data and methods officially in the country's inventories and reports. They also noted the need for sufficient financial resources to enhance the availability and collation of national data related to emissions in the agricultural sector, as well as to determine potential and actual carbon sequestration by soil.

For HIRC, support for training and ensuring continuity of the personnel involved in the preparation of national GHG inventories was highlighted, as several countries commented that the personnel do not have appropriate technical competence. For example, Panama needs methodological support focused on the Agricultural Research Institute of Panama (IDIAP) and the research centers of the University of Panama, which are key to generating country-specific EF.

The MIRC highlighted the need to learn from the experience and progress at the international level, i.e., knowledge and technical support are required both nationally and internationally; forming a group of experts at the regional level could advise on inventory improvement, specifically the development of higher tier methods and EF for cattle-associated GHG emissions, across several countries; the same as other initiatives, the value of horizontal cooperation is important.

Uruguay, as one of the MIRC, requires improved technical capacity related to the development of a tier 2 method for enteric methane emissions by type of production system rather than as a national average, for the development of tier 2 EF for manure management systems, to develop and improve EF for nitrous oxide emissions from soils, and to determine the potential for carbon sequestration in soils, including model calibration.

Paraguay also needs to increase technical resources related to infrastructure, laboratory and computing equipment, among others, to develop improved EF and collate and manage other data required for tier 2 methodology. It also seeks to strengthen existing arrangements and agreements between institutions to improve data collection and fill information gaps, as well as to increase transparency of data sources, thus increasing the reliability of data used in the national inventory, reducing uncertainty and instances of apparently incorrect outcomes. Likewise, improvements are needed in the quality, disaggregation and dissemination of the national inventory estimates, promoting the opportunities to use them for decision making and the development of public policies for mitigation and adaptation to climate change.

Nationally determined contributions and mitigation actions relating to cattle production

Mitigation measures for cattle are included by some of the countries from each of the three improvement classification groupings in their NDC. However, not all countries have specific mitigation recommendations for the cattle sector. Mexico [34, 35] proposes a 22% reduction in total GHG emissions by 2030, but with no specific projections for GHG mitigation from cattle production. Likewise, Argentina's NDC [36, 37] has an absolute goal, but no specific goals for each sector are contemplated. However, the country's National Action Plan for Agriculture and Climate Change, which is being updated as part of the National Adaptation and Mitigation to Climate Change Plan, details mitigation measures related to the agricultural sector, with only one measure related to the livestock sector ("efficiency in livestock production"). Similarly, most of the actions proposed in Cuba's NDC [38] relate to the energy sector and, to a lesser extent, to the agriculture sector, where some actions are included e.g., reducing enteric methane emissions in cattle by optimizing the diet and reducing nitrogen fertilizer application rates in forage and feed production systems for cattle.

Costa Rica [39–41] and Colombia [42] have Nationally Appropriate Mitigation Actions (NAMAs) for livestock; additionally, Costa Rica has a National Low Carbon Livestock Strategy, which includes pasture management, diets and optimization of nitrogen fertilization included as mitigation options. For Colombia, the mitigation measures for beef cattle are included within the framework of the livestock NAMA and in the NDC the country provided a projection to 2050 which considered 10 livestock regions each with 7 beef cattle age groups [43]. The government of Paraguay, together with FAO, is supporting the planning of a NAMA for sustainable Livestock.

Chile's NDC [44], proposed direct actions in the forestry sector and includes potential actions in the livestock sector; in addition, projections for the sector are being prepared, focused on reducing enteric methane emissions in cattle by optimizing diets and reducing nitrogen fertilization rates including forage and feed production systems for cattle. Peru is in the process of formulating its livestock NAMA.

Uruguay has explicit mitigation targets in its NDC [45, 46], expressed in terms of emission intensity i.e., total non-CO_2 gas emissions (as CO_2 equivalent) per kg of meat produced; in addition, the country is currently preparing a NAMA for beef cattle.

Panama is currently working on updating its NDC [47, 48]; a specific NDC for agriculture is a possibility, but there are no details as to whether it will specify measures for the cattle sector. Likewise, the country's National Association of Cattle Breeders (ANAGAN) proposes to develop a livestock NAMA with the support of CATIE, but the project has been suspended due to lack of funds and the need to collect additional data from the country.

For Brazil, the main strategy for the sustainable development of agriculture is to strengthen the Low Carbon Agriculture Plan (ABC Plan), including through the additional restoration of 15 million hectares of degraded pastures by 2030 and an increase of 5 million hectares of integrated agroforestry systems by 2030 [49, 50].

International cooperation

Several important initiatives have been developed in recent years addressing the needs for interaction and knowledge exchange, to improve consistency in technical capacity and the lack of institutional arrangements around national GHG inventory compilation and reporting. The first south-south cooperation initiative was the Latin American Network on National Greenhouse Gas Inventories (RedINGEI), created in 2013 by the Government of Chile [51]. This initiative has promoted multilateral cooperation between Spanish-speaking countries to exchange experiences, lessons learned and the adoption of good practices among its member countries. This was mainly aimed at facilitating sustainable development of technical and institutional capacity relating to national GHG inventories, resulting in increases in overall inventory quality and transparency, more timely reporting of national inventory reports, and supporting the implementation of national inventory systems, monitoring, reporting and verification (MRV) systems, inventory libraries and awareness, and as well as the implementation of the modalities, procedures and guidelines of the enhanced transparency framework fleshed out by the Katowice conference (COP24) to all countries.

The Global Research Alliance on Agricultural GHG [52] is an initiative launched in 2009 that gathers GHG inventory experts, practitioners and policy-makers from member countries and partners to produce a range of resources to help strengthen MRV systems for agricultural GHG emissions and mitigation actions. The GRA Charter provides a framework for voluntary action to increase cooperation and investment in research activities to help reduce the emissions intensity of agricultural production systems and increase their potential for soil carbon sequestration, and to improve their efficiency, productivity, resilience and adaptive capacity, thereby contributing in a sustainable way to mitigation efforts, while still helping meet food security objectives. The GRA has coordinated grants (e.g., CLIFF-GRADS) for capacity building in different research groups within LAC.

Another example of international cooperation is the CYTED network: Low-Carbon Livestock, created in 2020 to improve the quantification and estimation of GHG emissions and carbon capture in livestock systems, to identify mitigation options for a sustainable livestock and to improve the national GHG inventories in Argentina, Brazil, Chile, Colombia, France, Mexico, Peru, Spain and Uruguay. Although this is a recent initiative, it has on-going projects focused on collecting regional data and developing improved methodologies for estimating GHG inventories in the livestock sector of the country members. In the last months of 2022, two face to face meetings were held with LAC country experts (in Chile for nitrous oxide and Mexico for methane) to review the status of GHG inventories and design a road map for improvement. Conclusions and commitments from both meetings included: 1) seeking funding for research related to nitrous oxide and methane measurements; 2) writing scientific articles based on national research to improve EF; 3) creation of a regional repository and a tool for the dissemination of research on GHG inventories; and 4) a researcher exchange program.

Finally, the global One CGIAR initiative on Livestock and Climate [53] is committed to promote scientific research and exchange to improve national GHG inventories in developing countries of the global south including African countries.

Concluding remarks

In the current context of LAC countries, consideration of the refinement and methodological improvement of national GHG inventories necessarily includes a specific focus on the livestock sector, as a major contributor to national emission totals for these countries. New research findings on livestock GHG emissions could lead to a special interest in the mitigation potential of enteric methane in comparison with other sectors where the major radiative forcing is coming from carbon dioxide emissions. However, GHG emission measurement in the LAC region is still low [54, 55] in comparison with developed countries (i.e., North America, Europe, Oceania); MRV systems are still scarce and activity data, which is not regularly updated, is of poor quality. Our survey of GHG inventory experts across 11 LAC countries confirms the awareness of the importance of national initiatives to improve national GHG inventories in the livestock category, which includes improvements in activity data and EF. There is a generalized will and capacity to improve the accuracy of EF from the interviewed actors; they require that agents responsible for the inventory decide to do so, including funds and reinforcements from external collaborators who are interested in it.

Initiatives and the implementation of strategies to improve the estimation of the cattle GHG balance should be integrated across the entire chain of actors: producers, research centers, national institutions and the private sector are key players in their areas of influence to increase the accuracy of the GHG inventories, while the remaining IPCC principles (transparency, completeness, comparability, and consistency) are being partially or fully complied with by several countries.

Despite the existence of relevant stakeholder associations, there is a large gap among national EF tiers at the regional level. The private sector is inherently focused on beef and milk markets, whilst it was common to find policy makers with a high level of international commitments although their fulfillment is still scarce; there is a need for a link between these two stakeholder groups to improve GHG inventories.

In the medium and long term, reducing the uncertainty in national GHG inventories could lead to a regional initiative on carbon bonds and payments for ecosystem services: public and private initiatives led by organizations such as Climate Focus in Colombia to develop nature-based solutions through voluntary carbon markets are interesting to the industry. Similarly, divided positions at COP 27 highlight the importance of accurate measurements for implementing carbon markets, with some Parties claiming that carbon markets are the best way to increase investments in ecosystem conservation for climate benefits; others are concerned that emissions trading will encourage dubious accounting and offsetting.

These can be achieved if efforts are made towards a universal accounting framework; meanwhile, geographically and methodologically dispersed improvement initiatives can lead to erroneous inventories, leaking emissions, weak carbon markets with bias, unscientific accounting and finally "greenwashing".

The analysis presented here shows the importance of generating tools for rapid and accurate assessment of national GHG inventories. An uncertainty calculator would be ideal for countries to identify weak points for improvement regarding both activity data and EF.

From our perspective, improving the GHG inventories of LAC countries, in the cattle category, is feasible in the short and medium term, as long as multilateral actions are considered, coherently meshed under a comparable and verifiable methodology. Technical support, internal and external financing, institutional cooperation are alternatives that can help to overcome the main barriers found: diversity of production systems in the countries interviewed, low financing from internal and external sources and a lack of knowledge of suppressive and additive factors of native ecosystems.

Supporting information

S1 Table. Emissions data from national GHG inventories for category 3A (GHG emissions from livestock) and for subcategories 3A1 (GHG emissions from enteric fermentation) and 3A2 (GHG emissions from manure management) considering the latest Biennial Update Reports submitted.
(DOCX)

S2 Table. Questionnaire applied to the actors from the national GHG inventories in 11 LAC countries.
(DOCX)

S1 Fig. Map of LAC countries which highlights those whose stakeholders shared their status and opportunities for improvement in GHG inventories on cattle production for the present perspective. Source of Administrative boundaries: The Global Administrative Unit Layers (GAUL) dataset, implemented by FAO within the CountrySTAT and Agricultural Market Information System (AMIS) projects. Link to the layer of the map: https://developers.google.com/earth-engine/datasets/catalog/FAO_GAUL_SIMPLIFIED_500m_2015_level0. Link to the terms of use for the layer: https://developers.google.com/earth-engine/datasets/catalog/FAO_GAUL_SIMPLIFIED_500m_2015_level0#terms-of-use.
(DOCX)

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