frontiers in Sustainable Food Systems

ORIGINAL RESEARCH
published: 06 August 2019
doi: 10.3389/fsufs.2019.00061

The Livestock Sector in Colombia: Toward a Program to Facilitate Large-Scale Adoption of Mitigation and Adaptation Practices

Jeimar Tapasco[1]*, *Jean Françoi LeCoq*[1,2], *Alejandro Ruden*[1], *Juan Sebastián Rivas*[1] and *Javier Ortiz*[3]

[1] The Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT), Cali, Colombia, [2] Agricultural Research for Development – CIRAD, Montpellier, France, [3] Global Green Growth Institute, Bogotá, Colombia

Livestock raising is an important sector of the Colombian economy, which will face serious challenges in the next decade, including adaptation to and mitigation of climate change. Colombia must change the model of livestock production in a very short time by freeing up areas of pasture for other uses and focusing intensified livestock production in suitable zones. Despite the urgency and the magnitude of the required changes, only isolated small-scale initiatives exist. Colombia therefore has the challenge to scale-up these initiatives[1], but at present it has no program designed to achieve this objective. We started by analyzing the policies, actors, and existing initiatives in Colombia. We then sought to understand the potential for and the limitations to scaling-up promising initiatives to face the challenges of climate change in the livestock sector. We identified the key elements from previous initiatives and classified them into the conceptual spaces identified in the theory of scaling-up. These are the spaces in matters of: policy, fiscal and financial matters, institutional capacity, learning, partnerships, and technical matters, emphasizing the importance of the technical dimension. Finally, we propose some elements for the design of Colombia's national program of livestock raising.

Keywords: scaling-up, climate change, sustainability, livestock, policy, GHG emissions

OPEN ACCESS

Edited by:
Mario Herrero, Agriculture & Food, Commonwealth Scientific and Industrial Research Organisation, Australia

Reviewed by:
Eduardo Aguilera, Centro de Estudios e Investigación para la Gestión de Riesgos Agrarios y Medioambientales (CEIGRAM), Spain
Polly Joanna Ericksen, International Livestock Research Institute, Kenya

***Correspondence:**
Jeimar Tapasco
j.tapasco@cgiar.org

Specialty section:
This article was submitted to Climate-Smart Food Systems, a section of the journal Frontiers in Sustainable Food Systems

Received: *12 February 2019*
Accepted: *16 July 2019*
Published: *06 August 2019*

Citation:
Tapasco J, LeCoq JF, Ruden A, Rivas JS and Ortiz J (2019) The Livestock Sector in Colombia: Toward a Program to Facilitate Large-Scale Adoption of Mitigation and Adaptation Practices. Front. Sustain. Food Syst. 3:61. doi: 10.3389/fsufs.2019.00061

INTRODUCTION

The impacts of climate change on cattle raising are difficult to estimate because of the complexity of the relationships among climate, animals, pastures, water, and soils. Nevertheless, we know that these impacts will be related to animal well-being, the availability of food and water, and the occurrence of pests and diseases (Porter et al., 2014). High temperatures reduce animal intake and growth rates (André et al., 2011; Renaudeau et al., 2011) and heat stress in dairy cows increases mortality and economic losses (Vitali et al., 2009). The impacts of climate change on livestock diseases are uncertain and therefore difficult to predict (Mills et al., 2010; Tabachnick, 2010).

[1]Understood as the actions that generate technological changes and/or behavior agents' changes that lead to modifications in the functioning of a system through the introduction of products, goods, services, processes, and new methods in the transformation or adequacy of administrative, organizational, financial and credit, computational, and marketing systems, leading to improvements in the performance of production systems.

But there is high confidence that the geographic ranges of livestock pathogens will change and that some pathogen species in the lowland tropics may become less diverse (Mills et al., 2010).

The livestock sector worldwide supports about 1.3 billion producers and retailers and contributes 40–50% of agricultural GDP (Herrero et al., 2016b). Between 1995 and 2005, the livestock sector was responsible for greenhouse gas emissions of 5.6–7.5 $GtCO_2e$/yr. Livestock accounts for up to half of the technical mitigation potential of the agriculture, forestry, and land-use (AFOLU) sectors through management options. These options include sustainable intensification of production, promoting carbon sequestration in rangelands and reducing emissions from manure as well as reducing the demand for livestock products.

Colombia has 514,800 sites where livestock are raised, with 23.4 million head of cattle (ICA, 2017). Livestock raising contributed 1.4% of Colombia's gross national product (GNP) in 2017 and 21.8% of the agricultural GNP (FEDEGAN, 2018). It generates 6% of national employment and 19% of agricultural employment (FEDEGAN, 2018). Colombia has 34.4 Mha of pasture of which 27.9% are classified as unmanaged (DANE, 2014).

Adapting to climate change is a major challenge. By 2100, climate change will reduce pasture growth thus reducing annual production of meat and milk, averaged over various scenarios, reaching in some regions values up to 24.9% compared with the base period, 1970–2010 (Tapasco et al., 2015). Considering mitigation, the livestock sector produced 26% of Colombia's total GHG emissions (258.8 $MtCO_2e$/yr) in 2012 (IDEAM et al., 2016). This was 42% of the emissions of the AFOLU sector (158.6 $MtCO_2e$/yr), with cattle producing 95% of the livestock sector's emissions. Cattle therefore offer the greatest potential for mitigation in the agricultural sector, estimated at 83% of the proposed national goal of emissions reduction of 13.46 $MtCO_2e$/yr by 2030.

Colombia has developed a series of initiatives, programs, strategies, and projects to address mitigation and adaptation to climate change. These include:

- The National Strategy for Reduction of Emissions by Deforestation and Forest Degradation (Spanish acronym ENREDD+) (2009);
- The Colombian Strategy for Low Carbon Development (Spanish acronym ECDBC) (2011);
- The Financial Strategy to Reduce the Fiscal Vulnerability of the State in the Event of a Natural Disaster (2012);
- The National Plan of Adaptation to Climate Change (PNACC) (2012), and
- The National Policy of Climate Change (PNCC) (2016).

In 2018, the Colombian government released a policy document on Green Growth (*Crecimiento Verde*) formulated by the National Economic and Social Policy Council (CONPES[2]). The policy seeks to increase the country's productivity and economic competitiveness over a 13-year timeframe to 2030. The policy emphasizes sustainable use of natural capital and social inclusion, consistent with Colombia's commitment to the Paris accord on climate change. It proposes to improve productivity of the agricultural sector by:

- Strengthening capacity for productive agricultural structuring and sustainable agricultural production;
- Managing and transferring technology for sustainable agricultural production;
- Developing strategy to finance sustainable agricultural products; and
- Strengthening the market to stimulae enterprises and products that leverage green growth.

A major problem is that Colombia does not have an inventory of its initiatives on climate change and sustainable livestock production on which to prioritize actions under this policy. For example, Colombia made a formal commitment to the United Nations Framework Convention on Climate Change (UNFCCC) with its Intended Nationally Determined Contribution (INDC)[3], accepted in July 2018. But we do not know which adaptation and mitigation measures in the livestock sector have the greatest potential for scaling-up. Nor do we know what barriers and limitations there might be in implementing them.

We address these issues in this paper with a study on policies, value chain actors, and documents of relevant projects. We seek to identify the bottlenecks to scaling-up relevant measures and any gaps there might be in facing the challenges of climate change in the livestock sector of Colombia. We identify the key elements that a program should consider in scaling-up measures of adaptation and mitigation for the livestock sector in Colombia. In the analysis we include institutional and political aspects, financing, and capacity.

CONTEXT OF THE LIVESTOCK SECTOR AND CLIMATE CHANGE IN COLOMBIA: OPPORTUNITIES AND CHALLENGES OF MITIGATION AND ADAPTATION IN THE LIVESTOCK SECTOR

Emissions from livestock come from several sources. In Colombia, deforestation for planting of pastures produces 45% of the total, enteric fermentation 32%, urine and manure of grazing animals 20%, and 4% from manure management (IDEAM et al., 2016). One-third of the departments produce three-quarters of the country's cattle emissions with Meta (14%), Caquetá (12%), and Guaviare (9%) departments producing the most. These departments have the largest areas of natural forest converted into pastures (deforestation).

Colombia's goal for 2030 in its NDC, is to reduce GHG emissions by 66 $MtCO_2e$/year, of which 13.46 $MtCO_2e$/year will come from the agricultural sector. In the ECDBC,

[2]The National Council for Economic and Social Policy (CONPES) is the highest national authority for planning and it serves as an advisory body to the government in all aspects related to the study of and recommendations regarding general policies in economic and social development of the country.

[3]http://www.minambiente.gov.co/images/cambioclimatico/pdf/colombia_hacia_la_COP21/iNDC_espanol.pdf

the government identified intensifying livestock raising and converting pastures to other uses as large-scale actions with potential for mitigation (UNIANDES et al., 2013). This has focused on intensifying livestock production in suitable zones through appropriate management of grasslands and silvopastoral systems.

The El Niño-Southern Oscillation (ENSO) phenomenon in the last decade caused losses of US$1.8 billion in the livestock sector (FEDEGAN, 2018), killing 377,000 head of cattle, displacing another 5.6 million head, and damaging 16.1 Mha of pasture. Climate change predicts that ENSO will become more frequent and more severe (IPCC, 2014). The changes in temperature and precipitation predicted by the business-as-usual scenarios (A2 for milk and B2 for meat) will reduce milk and beef production in Colombia by 7.6 and 2.2%, respectively (Tapasco et al., 2015). Nariño, Caquetá, Casanare, Cundinamarca, and Córdoba departments will be affected most. The eastern plains (Arauca, Casanare, Meta, and Vichada departments) are one of Colombia's main regions of livestock production. Higher temperatures in this region will increase heat stress on cattle and decrease beef and milk production. A business-as-usual scenario (8.5 W m^{-2} more solar radiation by 2100, RCP 8.5) predicts 2.7% less beef and 2.1% less milk by 2040 (CIAT and CORMACARENA, 2018).

Measures to address these issues improve indicators of Green Growth such as yield, system carbon balance, and land-use conflict (**Table 1**). Appropriate pasture management and silvopastoral systems are two large-scale measures that offer synergies in both mitigation and adaptation (UNIANDES et al., 2013; World Bank and DNP, 2014).

Mitigation measures include increasing carbon contents in livestock systems, planting trees, and increasing carbon stocks in soil and biomass in pastures and shrubs. They also include reducing emissions by increasing productive efficiency by eliminating the large differences in feeding efficiency and emission intensity in livestock systems (Herrero et al., 2013). Restoring degraded pastures as well as including trees offers great mitigation potential throughout Latin America (de Moraes et al., 2017).

Adaptation includes measures to deal with higher temperatures by reducing exposure to and increasing tolerance to heat stress, to excess water, and to drought. Silvopastoral systems provide shade and can reduce body temperatures of grazing cattle up to 4°C compared with pasture-only systems (Broom et al., 2013). Sustainable intensification with improved forages that are tolerant to drought and excess water can be achieved throughout the tropics (Rao et al., 2015). These systems provide improved soil management and microclimate, together with better soil protection by providing permanent cover. Producers can diversify into cropping systems, with improved management of soil, water, and climatic resources and improved soil fertility (Rao et al., 2007).

Incorporating trees and shrubs in integrated silvopastoral systems (iSPSs) further increases carbon stocks. Moreover, iSPSs have better soil water balance and lower ambient temperatures, increasing forage production and quality (Murgueitio et al., 2014). In Colombia's dry Caribbean region, iSPSs reduce the mean annual temperature by 2–3°C and soil surface temperatures as much as 13°C. Relative humidity within the iSPS can be 10–20% higher and evapotranspiration up to 1.8 mm/day less than in systems without trees.

The Colombian livestock sector faces challenges from international free-trade agreements, which eliminate current protective tariffs on dairy and meat products. At the same time the sector also faces the environmental risks of climate change. Markets will also consider the carbon footprint and general environmental performance of these products. Colombia must therefore improve the productivity and sustainability of the livestock sector to be competitive in international markets. In most regions, forage production is low and seasonal droughts are severe with little supplementary irrigation available. Cattle are managed with set stocking at constant low rates in large-sized paddocks (FEDEGAN, 2014). The average carrying capacity in Colombia is 0.86 head/ha (0.62 if grazed crop residues are included; DANE, 2014). Sustainable intensified production in suitable areas regions can increase substantially the amount of milk or meat produced and have lower environmental impacts (Calle et al., 2013; Lerner et al., 2017; Marin et al., 2017).

Both the Colombian government and the National Livestock Federation (FEDEGAN) know that the livestock sector needs to become more efficient and sustainable within the next decade. Intensification must focus on suitable lands and areas unsuitable for intensification converted to other uses such as forestry. Although preliminary work has identified some possibilities in mitigation (UNIANDES et al., 2013), there is no overall inventory of the feasible initiatives nor of their scopes.

DEFINITION AND ELEMENTS FOR SCALING-UP

Scaling-up is a process that explores different pathways to expand, adapt, and maintain policies, programs, or successful projects to reach a greater number of people (Linn, 2012). It is part of a wider process of innovation and learning. It makes it possible for more producers and a larger area of land to adopt a technology. Scaling-up usually starts from a pilot project, which, after being validated and evaluated, is replicated by other producers and regions. In doing so it generates greater impact, often by adapting technical and social elements to each context. During the scaling-up process, it is possible to make adjustments according to experiences and lessons learned. The scaling-up process also considers the long-term risks of reversion[4] of the technology.

There are seven components (called spaces) of the environment necessary to enable scaling-up (Linn, 2012): (1) policy; (2) fiscal and financial; (3) institutional capacity; (4) learning; (5) partnership; (6) political; and (7) others (markets, environmental, and cultural).

[4]"Reversion" as we use it here is when producers who adopted the technological innovation abandoned it in less than 5 years and returned to the conventional form of production (adapted from Teshome et al., 2016).

TABLE 1 | Green Growth indicators for the livestock sector in Colombia, 2014–2030.

Indicator	Yield		GHG emissions		Surface in conflict for use of soil*	
			tCO_2e/ha/year			
	Baseline (2014)	2030	Baseline (2014)	2030	Baseline (2014)	2030
Milk	7.35 (liters/cow/day)	7.91 (liters/cow/day)	2.20	1.36	73.0%	72.8%
Dual purpose	2.63 (liters/cow/day)	2.82 (liters/cow/day)				
Meat	500 (grams of meat/day)	605 (grams of meat/day)				

**Land use conflict refers to an inappropriate use of soil according to its suitability, which can be due to under- or overuse.*
Source: CIAT et al. (2018). The baseline established (year 2014) for some of the indicators of Green Growth in the livestock sector of Colombia and changes expected to 2030.

METHODOLOGY

We carried out the study in stages. We first compiled secondary information of Colombian policy on livestock and climate change and the role of institutions in national initiatives in these areas. We interviewed some key actors to obtain their perception about the challenges and barriers to adaptation and mitigation to climate change in the livestock sector. We included Linn's (2012) seven spaces in an analysis of the strengths, weaknesses, opportunities, and threats (SWOT analysis) to scaling-up the projects.

Map of Policies, Plans, and Other Initiatives Regarding to the Livestock Sector and Climate Change Mitigation and Adaptation in Colombia

We carried out a desk review to identify the policies, plans, programs, and projects related to livestock activity and climate change issues in Colombia. We reviewed their content to capture interactions among the existing policies (Flanagan et al., 2011). We summarized the results in a timeline and a map of governmental policies and plans.

Map of Actors in the Livestock Sector and in Climate Change in Colombia

We then used a bibliographic review to identify the actors who work in livestock and climate change issues in Colombia. We classified them according to their role in the various initiatives of policy design, project implementation, research, technical assistance, guild representation, and livestock business. We classified actors into eight categories: (1) public institutions, (2) private companies, (3) trade unions and producer associations, (4) financing institutions, (5) research centers, (6) non-government organizations (NGOs), (7) international bodies, and (8) enterprises and companies that sell supplies. We created a map of the actors according to their classification.

Key Actors' Perspective About Barriers to Adaptation and Mitigation of Climate Change in the Livestock Sector in Colombia

We conducted 13 semistructured interviews October–November 2017 with the key actors identified in the map of actors from section Map of Actors in the Livestock Sector and in Climate Change in Colombia above. They were distributed as follows: Public institutions (1); Trade unions and producer associations (2); financing institutions (1); research centers (3); NGOs (3); international organizations (2); and private enterprises (1). We did not include merchants that sell agricultural supplies because they have not played any relevant role in developing the initiatives. The questions we asked sought to learn the emphasis within each group on what producers and institutions within the livestock sector should do to adapt to and to mitigate the effects of climate change. They also sought to identify the obstacles to implementation and the key policy elements needed to ensure success at a local level.

Learned Lessons From Scaling-Up Potential Projects

Identification of Projects and Initiatives With Scaling-Up Potential

We consulted the key actors about both completed and ongoing projects with a scaling-up potential in the livestock sector that they considered to be successful. In all, we identified 17 projects. We applied five criteria to identify which projects are more suitable to scale-up. The five criteria were:

1. That the project implemented measures to adapt to or mitigate climate change;
2. That the projects covered at least 2,000 ha;
3. That the project was implemented for more than 3 years;
4. That the project included a minimum of 20 producers who have implemented the measures; and
5. That at least 25% of the producers involved had herds fewer than 50 head [in Colombia, 81.3% of the livestock sites have fewer than 50 head (FEDEGAN, 2017)].

For three projects that met the five criteria, we made an in-depth review of the technical documents and reports to generate a general description of each project. We identified the technologies proposed in of them, and reviewed their scalability potential taking account of the biophysical conditions (MADR, 2018).

SWOT Analysis

We carried out a SWOT analysis (Weihrich, 1982) based on semistructured interviews with the leaders of these three

projects ("champion interviews") November 2017–March 2018. Each interview contained 23 questions addressing the project's technical component, its financing, its partners, the policy instruments on which it relied, the institutional capacity, its training strategies, and other barriers to scaling-up. We asked each champion to identify the three main strengths, weaknesses, opportunities, and threats that they considered most relevant to the design of a program to scale-up mitigation and adaptation measures. We considered the identified strengths and weaknesses to be most relevant lessons learned in implementing each project. Opportunities and threats include situations or activities that were not foreseen at the design stage and that may enhance or weaken implementation of the measures or cause reversion. We related the SWOT components identified through the champion interviews to Linn's (2012) spaces described above.

Our Institution's guidelines and national regulations did not require a written ethics approval. We did inform all interviewees about the aims of the research and all gave us verbal consent to use of the data collected.

RESULTS

Policies, Plans, Initiatives, and Actors in the Livestock Sector and in Climate Change in Colombia

We used the data from the bibliographic review of policies, plans, programs, and projects regarding climate change, to construct a timeline of the livestock sector in Colombia 1991–2017 (**Figure 1**). The timeline shows how the country has developed diverse initiatives and how it has started a series of policy instruments to achieve the coordination and structuring of climate change initiatives.

In 2011, CONPES sought to consolidate institutional strategy to articulate policies and actions in climate change matters (CONPES #37000 of 2011). In 2016, the National System of Climate Change (SISCLIMA) was established by decree, as a coordinating and management platform for adaptation to and mitigation of climate change matters (Decree 1298 of February 24, 2016). Decree 1931 in 2017 established guidelines for the management of climate change, incorporating climate change into public and private decision making. Decree 1931 postulates a development path resilient to climate change and progress toward a low carbon economy. It seeks to reduce the risks of climate change and allow creation of new opportunities linked to it. In this new political environment, there are a series of plans and strategies, some of which are already in place, that provide guidelines adaptation to and mitigation of climate change in Colombia. These include the PNACC, the ECDBC, and the ENREDD+, detailed in the Introduction.

Policy on climate change with attention to the livestock sector in Colombia had already begun to grow in relevance and appeared explicitly in 2011 with the formulation of the ECDBC. Subsequent interest in the sector grew among academic, public and private institutions, although most policy documents are related to the mitigation of climate change (**Figure 2**). In the period 1991–2017, ten laws related to climate change (CC) were passed, along with six policies, seven policy instruments (decrees, resolutions, CONPES), three programs, and 21 strategic plans and strategies.

Actors, Multi-Stakeholder Initiatives and Projects in the Livestock Sector and in Climate Change in Colombia

We identified 70 institutional actors with either direct or indirect relation to climate change and the livestock sector in Colombia (**Figure 3**). We also found that three major initiatives brought most of the actors together, although the nature and thematic agendas of the three are quite different. Briefly the three initiatives are:

- *MGS-Col is a multistakeholder (public-private) initiative with 47 members compromising the production and dissemination of technical knowledge and actions that support projects, programs and policies design, and implementation around sustainable livestock activity.*
- *SLP is an initiative implemented by a strategic alliance between the Colombian Federation of Cattlemen and the National Cattle Fund (FEDEGAN-FNG), the Center for Research in Sustainable Systems of Agricultural Production (CIPAV), the Fund for Environmental Action and Childhood (Fondo Acción), and The Nature Conservancy (TNC, cofinanced by the Global Environment Fund (GEF), administered by the World Bank (WB) and the British Embassy. This projects seeks to improve livestock productivity in an environmentally friendly manner; integrating different types of technologies such as silvopastoral systems in livestock production, and the conservation of native forests and natural ecosystems on farms.*
- *NAMA SL is an initiative led by the Ministry of Agriculture and Rural Development (MADR) with support from the Ministry of Environment and Sustainable Development (MADS), which seeks to identify mitigation activities to be implemented in the Colombian livestock sector as a contribution to reduce emission of GHG, according to the particular conditions of each region in the country. This initiative have not ended in a NAMA document yet but there is a NAMAs Information Note of Sustainable Bovine Livestock document which one was registered to united nations framework convention on climate change (UNFCCC).*

MGS-Col counts on 27% of the identified institutional actors, followed by SLP (17%) and NAMA-SL (11%). Public institutions are most involved in all three initiatives compared with private companies, which are involved only in the MGS-Col. MGS-Col has a good representation of actors and is open to others who may be interested. It is recognized nationally and has influenced policy despite limited participation by the private sector. It is slow to make decisions because it represents such broad interests. The SLP is technically strong and experienced in the field, partly because of FEDEGAN's involvement. While it can finance technological change and provide technical assistance, it covers just 0.4% of cattle farms. NAMA-SL aligns with the government's international commitments in the NDC process of the UNFCCC.

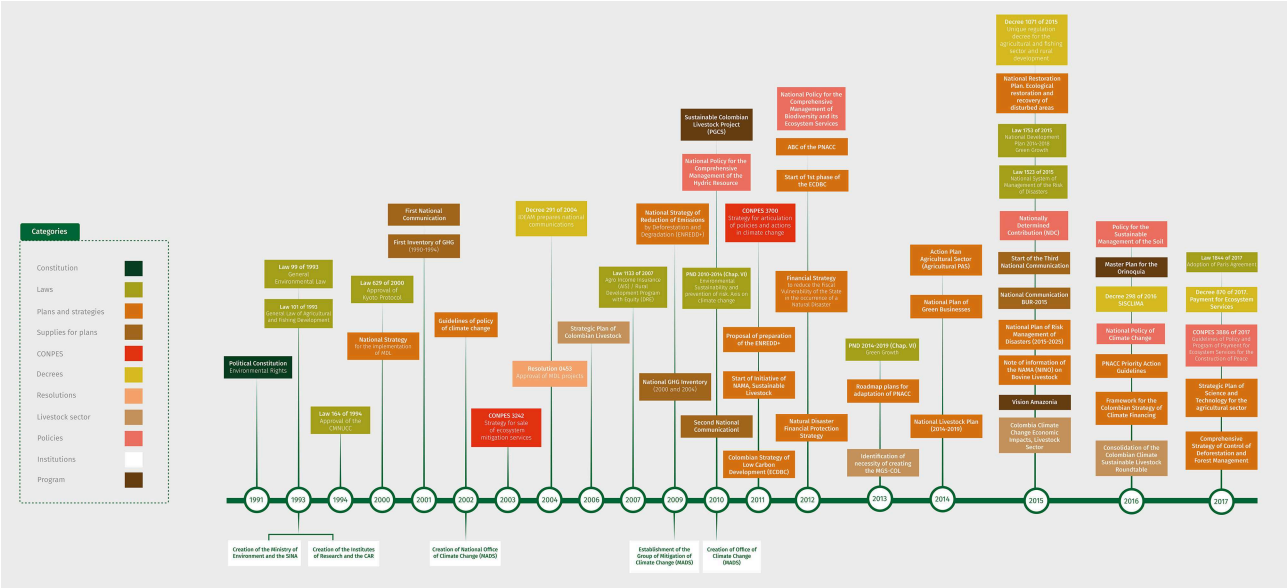

FIGURE 1 | Timeline of relevant activities in the livestock sector and climate change in Colombia.

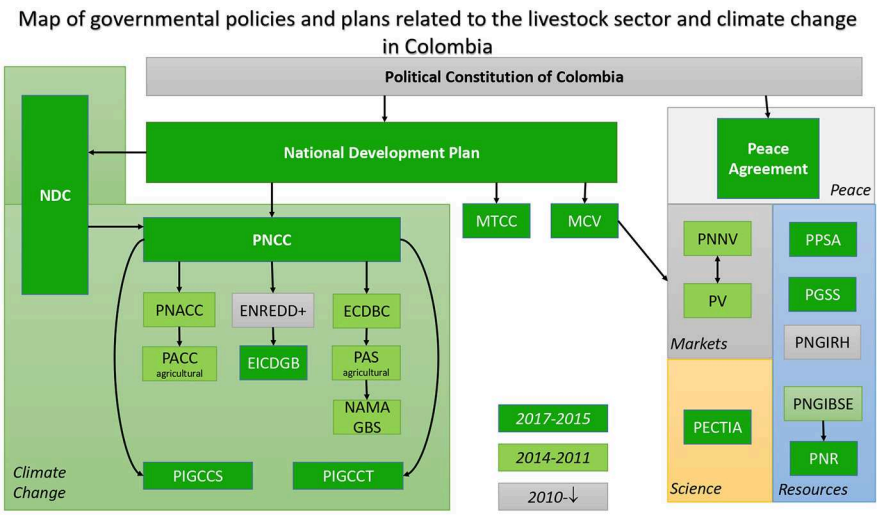

FIGURE 2 | Map of governmental policies and plans related to the livestock sector and climate change in Colombia. NDC, Determined Contribution at National Level; PNCC, National Policy of Climate Change; PNACC, National Plan of Adaptation to Climate Change; PACC A., Plan of Adaptation to Climate Change of the Agricultural sector; ENREDD+, National Strategy for Reduction of Emissions by Deforestation and Forest Degradation; EICDGB, Comprehensive Strategy of Control of Deforestation and Management of the Forests; ECDBC, Colombian Strategy of Low Carbon Development; PAS A., Action Plan of the Agricultural Sector; NAMA GBS, Nationally Appropriate Mitigation Action for Sustainable Bovine Livestock sector; PIGCCS, Comprehensive Sectorial Plans for Management of Climate Change; PIGCCT, Comprehensive Territorial Plans for Management of Climate Change; MTCC, Mission for the Transformation of the Colombian Countryside; MCV, Mission of Green Growth; PNNV, National Plan of Green Businesses; PV, Green Protocol; PECTIA, Strategic Plan of Science, Technology, and Innovation of the Colombian Agricultural Sector; PPSA, Policy of Payment for Ecosystem Services (PES) (Decree 870 of 2017); PGSS, Policy for the Sustainable Management of the Soil; PNGIRH, National Policy for the Comprehensive Management of the Hydric Resource; PNGIBSE, National Policy for the Comprehensive Management of the Biodiversity and its Ecosystem Services; PNR, National Restoration Plan.

It is focused on the implementation of silvopastoral systems, but at present has no financing, and there is no involvement by the private sector.

Commercial enterprises are not directly linked to climate change initiatives by the livestock sector in Colombia. Nevertheless, they are linked indirectly through the initiative

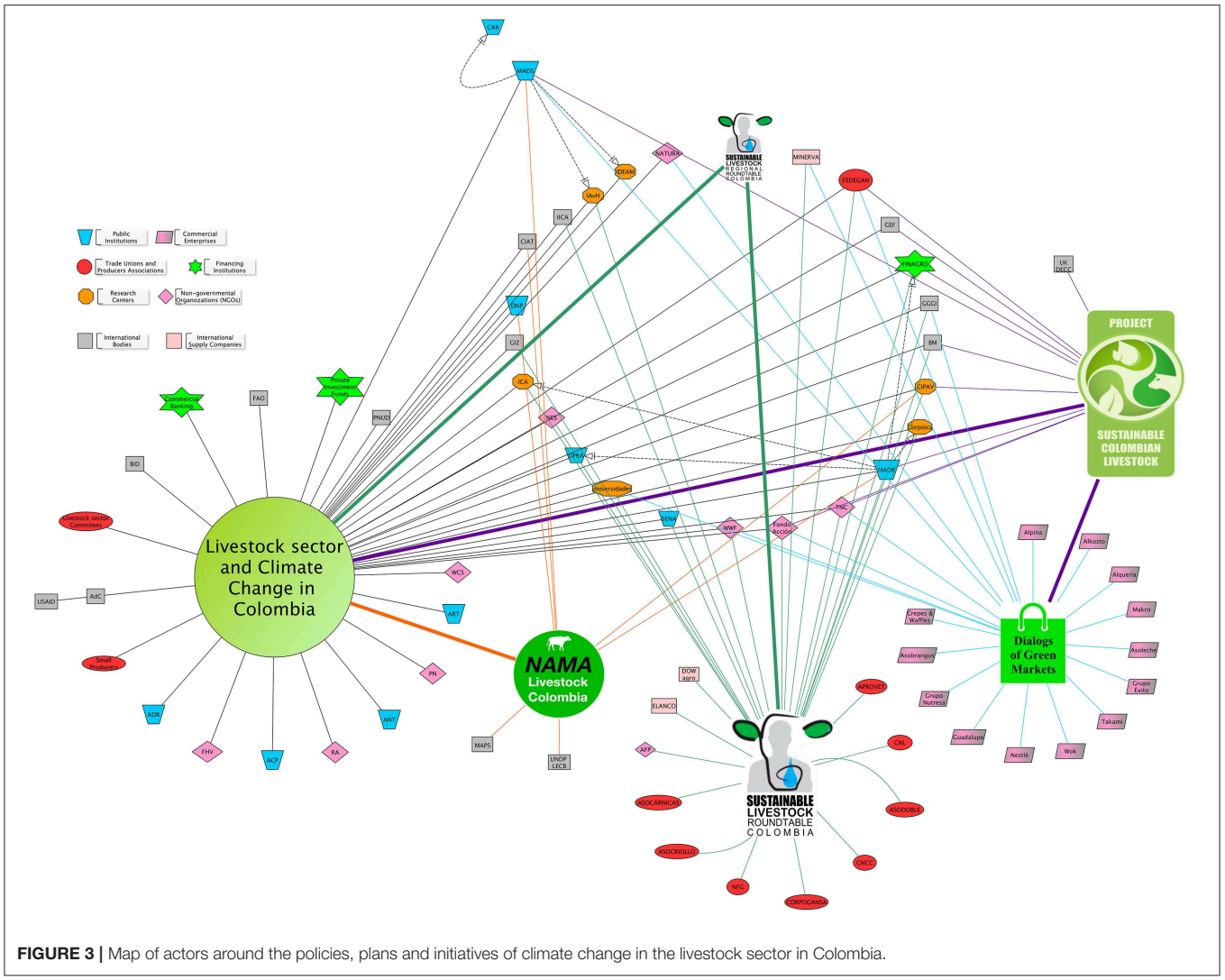

FIGURE 3 | Map of actors around the policies, plans and initiatives of climate change in the livestock sector in Colombia.

of dialogues of green markets and two companies that supply inputs to livestock do participate sporadically in MGS-Col.

Colombia was the first country in the region to join The Tropical Forest Alliance (TFA), which is affiliated with the UNFCCC and was formed after its 2012 Conference. Colombia identified beef production as one of its prioritized value chains. New initiatives have emerged since the signature in May 2019 of the zero deforestation agreements for dairy and beef value chains. Private actors have shown greater interest in these initiatives and they are involved to a greater degree than in the others detailed above.

Barriers to the Adoption of Adaptation and Mitigation of Climate Change Actions in the Livestock Sector in Colombia

The "key actors" interviewed considered that the most relevant technologies to address climate change in the livestock sector are either silvopastoral systems (38%) or division of paddocks (as opposed to traditional set-stocking of large areas) (31%). But there is only low level adoption of these technologies, for which 85% of interviewees fault the producers. Many interviewees (30%) also fault institutions for a lack of technical assistance and financial incentives, and 30% point to poor communication and coordination between producers and institutions. However, only 23% of the responders identified producer resistance to changing the traditional grazing practice as the major limiting factor. The other obstacles that responders identified were institutional, such as scant spelling out of relevant policies (54%), lack of data on which to formulate policy (31%), and poor coordination between the national and local governments (31%).

For successful implementation of national initiatives in the field, interviewees considered that they must be formulated with the participation of regional and local actors (46%) and with a holistic vision (38%). Local projects must have enough regulatory and sanctioning authority so that they can enforce environmental legislation on deforestation (38%). Other elements that interviewees identified, but with less unanimity were:

(i) Greater education of consumers and producers about responsible consumption and production;
(ii) Greater leadership of MADR in clear definition of the goals and the initiatives to achieve them;
(iii) Better identification of market niches for differentiated products and ways to meet them; and
(iv) Strengthening technical assistance; and incorporating the focus of landscape management in planning cattle production.

Lessons Learned for Scaling-Up

Projects and Initiatives With Lessons Learned for Scaling-Up

Three projects satisfied the five criteria listed in section Identification of Projects and Initiatives With Scaling-Up Potential that our consultations identified as essential components on which to evaluate scaling-up (**Table 2**). The projects were:

(1) The Sustainable Colombian Livestock Project (SLP);
(2) The Caquetá Connected Landscapes Project (Caquetá CLP); and
(3) The Orinoquia Sustainable Bovine Production (Orinoquia SBP).

There is a complete list of the projects that we identified and the selection criteria we applied in **Supplementary Table 1**.

The Orinoquia SBP is the longest running (13 years), while the project that has been running the shortest time is the Caquetá CLP (5 years). The project with the largest coverage is SLP, with 87 municipalities, while the project with the least coverage is the Caquetá CLP, which covers only four municipalities. The project that has had the largest area intervened is SLP, with more than 40,000 ha, and the one with the least intervention is the Caquetá CLP, which covers a little more than 2,000 ha. See **Supplementary Figure 1** for a map of the location of the interventions in each.

SLP has received the most finance (US$24 M over 10 yr or US$3 M/yr), while Orinoquia SBP has received the least (US$4.4 M) or less than US$0.35 M/yr. On an area basis, Orinoquia SBP has cost US$637/ha compared with SLP US$475/ha, which is US$162/ha less even allowing for the different technologies promoted in each case.

Because FEDEGAN is the implementing agency, SLP has specialized knowledge of different technologies, with strengths in the financial and economic impact of sustainable livestock production. It also brings partners like CIPAV and TNC, which have expertise in the incorporating arboreal systems in pastures and in site planning. Caquetá CLP provides comprehensive technical assistance from multidisciplinary team (social workers, anthropologists, and economists), which provides data on the socioeconomic aspects of producers' decisions to adopt technologies. Orinoquia SBP's technical strength is its flexibility to provide technologies that are easy to implement for different types of producers.

The three selected projects promote the management of pastures, dispersed trees in pastures, and both intensive and extensive silvopastoral systems. There is considerable potential in Colombia to implement these alternatives (**Table 3**). For the alternative of dispersed trees in pastures[5], there is no estimate of its potential for scaling-up in Colombia, largely because of the difficulty of establishing a baseline.

Three iSPS have been studied and validated in association with the CIPAV Foundation in three regions of Colombia where they were compared with conventional cattle ranches (Giraldo and Uribe, 2007; Murgueitio and Ibrahim, 2008; Murgueitio and Solorio, 2008; Aguilar, 2009). The first iSPS is an alternative for the tropical lowlands oriented to milk production. It consists of a system with high density (>10,000 shrubs/ha) of *Leucaena leucocephala* with star grass (*Cynodon plectostachyus,*) and *Megathyrsus maximus* cv. Tanzania or Mombaza. The second iSPS is for dairy production in the tropical highlands. It consists of high density (1,000–4,000 shrubs/ha) of tree marigold (*Tithonia diversifolia*) planted in strips associated with kikuyu grass (*Pennisetum clandestinum*) and dispersed trees of *Alnus acuminata, Pinus* spp., or *Eucalyptus* spp. at 100–300 trees/ha. The third iSPS is for the production of beef in the tropical lowlands. It consists of high density (>5,000 shrubs/ha) of forage shrubs of *Tithonia diversifolia* planted in strips, associated with improved *Brachiaria* pastures (*B. decumbens* and *B. brizantha*) and rows of timber trees such as *Gmelina arborea* and *Tectona grandis* (100 trees/ha).

Good pasture management and the implementation of intensive and non-intensive silvopastoral systems could provide up to 77% of the national goal of the NDC for the agricultural sector. But it would be necessary to intervene on 3.82 Mha. In contrast, the conversion of pastures to perennial systems such as oil palm or rubber. would provide 38% by transforming only 0.554 Mha. There are no estimates of the potential of mitigation based on the regeneration or reversion of pastures to natural ecosystems. The areas intervened so far in the three selected projects represent only 1.3% of the potential area detailed in **Table 3** (MADR, 2018). They barely reach 0.5% of the reduced emissions goal of the agricultural sector committed in Colombia's NDC.

SWOT Analysis

In the champion interviews, project leaders identified strengths, weaknesses, opportunities, and threats related to their project. We classified the SWOT items to the spaces (Linn, 2012): policy, fiscal and financial, institutional capacity, learning and knowledge, partnerships, and technology (**Table 4**). We found that none of their answers were related to the policy, markets, environmental or cultural spaces, but that we needed an additional one to account for technical capacity. This was because livestock systems such as iSPSs demand specialized knowledge (Calle et al., 2013).

The SLP has emphasized strengthening technical capacity in the region by training local technicians, which contributes in the long run to the scaling-up of the measures. Technicians' selection is fundamental, since technical capacity, experience, and regional knowledge are required. SLP underscores the importance of having personnel who know the cattle business, but who also

[5]Dispersed trees, generally native species, are randomly distributed within the grazed paddocks at densities 25–100 trees/ha. The pastures are different species which often require different management.

TABLE 2 | General description of the three projects selected.

Project/characteristics	The Colombian sustainable livestock project (SLP)	Caquetá connected landscapes project	Orinoquia sustainable bovine production
Responsible entity	FEDEGAN	Fondo Acción	Fundación Amanecer
Project objective	Promote the adoption of silvopastoral systems on livestock farms in the project areas to improve the management of natural resources, increase the environmental services provided (biodiversity, soil, water, and carbon retention), and increase productivity on the participating farms.	Reduce deforestation of the Amazon region by implementing sustainable rural development, strengthening local and regional governance, and improving the living conditions of the people in the strategically biodiverse and highly vulnerable areas in the department of Caquetá.	Improve the socio-environmental conditions and productive capacity in livestock-raising areas of the Orinoquia region.
Start/Finish	2010/Early 2020.	June 2013/June 2020 (projected)	2005/Ongoing (no end specified)
Promoted measures	Silvopastoral systems (intensive and non-intensive), planting trees in dispersed plots and grass/pasture management.	Silvopastoral systems.	Grass/pasture management.
Coverage† (see **Supplementary Figure 1**)	Eighty-seven municipalities with an area of 1,661,300 ha in pasture.	Developed in four municipalities with an area of 394,200 ha in pasture.	Twenty-eight municipalities with an area of 1,280,700 ha in pasture.
Area of pasture intervened (as of March 2018)	Goal is 50,500 ha, of which 40,600 ha have been implemented	2,040 ha implemented	6,900 ha transformed
Funding and implementation partners (partnership)	From international sources (Global Environment Facility and the UK administered by the World Bank). Links to other institutions in the implementation: CIPAV, Fondo Acción, and the Nature Conservancy.	The financing has come from international cooperation (USAID). Has an alliance with Amazon Conservation Team of Caquetá government as implementing partners.	The financing has come from national cooperation (oil companies with operations in Orinoquia: Ecopetrol S.A., Equion Energía Limited, Santiago Oil Company, and Emerald Energy).
Financing (total amount, US$ M)	24.0	8.4	4.4
Evaluation of the environmental impacts	The project has contemplated the evaluation of impacts on biodiversity, carbon capture, water resources, and soil.	Does not have a monitoring system	Does not have a monitoring system
Achievements	FEDEGAN brings support at the regional level and gives technical credibility. Has obtained international financing and built strategic alliances with environmental entities (CIPAV and TNC). Activities are aligned with the Mission of Green Growth (MCV) and the NAMA SL.	Iinteracts with local governments and has influenced the formulation of local territorial development plans. Has fostered dialogue among producers and local government in the search for joint solutions that will be reflected as measures of territorial plans.	Combined low-cost technology with microfinancing that small producers find attractive. Generated knowledge through lessons learned with different livestock-raising landscapes in one of the priority regions in matters of productive systems and agricultural development.

† *The area of pasture does not include native savannas or natural pastures. Sources: Web pages, project documents and reports.*

know how to manage pastures and silvopastoral systems and can provide a comprehensive approach for the farm. One limitation is that appropriate selection of personnel takes time and requires competitive salaries, which can be a limitation in scaling-up these measures through public institutions, with their legal restrictions on salaries.

Financing is one of the barriers to the adoption of technology. Caquetá CLP opted to strengthen the ability of producers to carry out the paperwork for special lines of credit granted through public resources. Orinoquia SBP created specialized private lines of microcredit for the livestock sector, focusing on low-cost technologies as a strategy for the scaling-upprocess. All three projects are part-financed by international and national institutions (US$36.8 million in total). Providing simple financing to implement the particular technology is a key part of the strategy to stimulate adoption of the measure. All three projects concur that the financing must arrive in kind rather than money to the producers.

All three projects undertook participatory farm planning to ensure that the proposed measures are in line with the capacity and needs of the producers. Likewise, the technology is implemented on the farm by the project technicians, who coach the producers. Producers are trained during the implementation process and receive technical assistance, which strengthens their skills to manage the new technology.

Only SLP is recognized as one of the three large institutional initiatives (**Figure 3**). In this sense, it has broad institutional recognition, which, in the medium-term, can lead closer articulation with other policy instruments. SLP also has strong links to MGS-Col, which enables direct communication with many other institutional actors in the livestock sector. Caquetá CLP emphasized institutional integration at the regional level for scaling-up, using capacity building of local government institutions and influencing the regional development plans.

Both Caquetá CLP and Orinoquia SBP recognized the lack of integration of their projects with the public policy on climate

TABLE 3 | Alternatives of low-carbon development in the livestock sector, their contributions to the reduction of emissions, and their economic characteristics (MADR, 2018).

Alternative of low-carbon development	Potential area (M ha)	Contribution to the goal in 2030 (Mt CO_2eq/yr)	Contribution to the NDC: 2030 goal of the agricultural sector (%)	Investment required (US$M)	Benefit/cost ratio	Analysis of cost effectiveness (US$/ton CO_2eq)
Pasture management[a]	2.200	1.94	15	1,840	2.3	−247
Non-intensive silvopastoral systems[b]	1.250	4.00	31	1,100	3.4	−102
Intensive silvopastoral systems (iSPS)[c]	0.370	3.99	31	618	3.7	−67
Conversion of pastures to perennial crops	0.554	5.00	38	808	1.5	−13.2
Total	4.374	14.93		4,366		

[a] *Includes both good and bad pasture management. Good management consists of renewing the pastures as necessary with soil cultivation, fertilizer, and fencing for rotational management. Paddocks with poor management are those that are not renewed and not fertilized, and the grazing is continuous or deferred. The grasses are brachiaria decumbens, prairie grass (B. humidicola), koronivia grass (B. humidicola), B. braquipara, Mombaza (Panicum máximum), star grass (Cynodon plectostachius). The reference baseline is set-stocked native pasture.*

[b] *This consists of arrays of well-managed paddocks with trees in arrays and densities 100–600 trees/ha and may be accompanied by fodder shrubs with densities of fewer than 1,000 shrubs/ha.*

[c] *The three intensive silvopastoral systems selected are those described above.*

change (i.e., ECDBC, PNACC, NDC). We emphasize that a small portfolio of technologies limits the options available to implement the measures, as is the case with Orinoquia SBP. Integration between institutions and local actors is a weaknesses in all three projects, which must be strengthened because of its importance to coordinated activities in the field.

The timeline (**Figure 1**) demonstrates the government's growing interest in strengthening the livestock sector and its approach to climate change. Climate funds and other international aid continue to provide opportunities for scaling-up, but differentiated markets are also giving opportunities. The MGS-Col initiative is another opportunity to coordinate inter-institutional activities, although not all actors are involved (**Figure 3**).

Long-term prices of meat and milk are a continuing concern with free-trade treaties with U.S. and the EU (both since 2013) and with MERCOSUR (since 2005) especially worrying to livestock farmers. Paradoxically, the Law of the National System of Agricultural Innovation (SNIA), which creates an agricultural extension service, is seen as a threat[6]. This is because it disadvantages the specialized technical assistance that the producers' guilds provide. Other threats are more regional, such as public order, illicit crops, oil-drilling zones, and regional priorities. In areas with high incidence of illicit crops areas there is a risk of reversion of grazing land because illicit crops give much higher returns than meat or milk. The bonanzas that oil-drilling brings distort the local economies, especially the cost of labor. It is noteworthy that the actors did not identify either opportunities or threats related to learning or education.

Project champions emphasized that less complex systems such as better pasture management by rotational grazing are most demanded by producers. More complex systems such as iSPS have less demand because they require more knowledge, investment and labor. They also recognize that implementing technological change on farms is a gradual process. The champion interviews indicate that all three projects have intensified production thus freeing up pasture land for restoration and conservation. The interviews also indicate that although planning is carried out at the site level, planning a landscape scale is more difficult and was largely ignored.

[6]Especially from the livestock raisers' guild, FEDEGAN (www.contextoganadero.com/columna/ley-1876-la-llave-para-la-innovacion-agropecuaria).

DISCUSSION AND RECOMMENDATIONS

Each of the three projects relied on different strategies: strengthening technical knowledge (SLP), credit access (Orinoquia SBP), and strengthening local institutions through capacity building (Caquetá CLP). All three strategies are valid and have been successful, but raise the question, might they have been more successful with the union of all three components? An analysis of projects, including SLP, concludes that scaling-up of iSPS in Colombia required combining five elements (Calle et al., 2013):

(i) Two decades of participatory research on pilot farms;
(ii) Strengthening the capacity of different stakeholders;
(iii) Pilot projects based on incentives such as payment for ecosystem services (PES), soft credits, technical assistance, and differentiated markets;
(iv) Involvement of producer organizations in innovation and technology transfer and influence on the political agenda; and
(v) Implementing large-scale projects (i.e., SLP).

SLP is the largest project to be implemented in the agricultural sector in Colombia, but its goal covers only 0.13% of the area under pasture in the municipalities where it operates. Nevertheless, the lessons learned from SLP and other initiatives provide the basis to develop a scaling-up strategy, together with the knowledge and lessons from pilot projects.

TABLE 4 | SWOT matrix of the selected projects.

Project	Strengths	Weaknesses
SLP	Specialized technical knowledge of different options of livestock systems, the incorporation of the arboreal system incorporated in paddocks, and site planning (technical space) Links with MGS-Col (institutional capacity space) Training processes strengthen technical capacity in the region (learning space)	Does not have professionals from social areas (technical space) Is not connected with the current financing systems in effect (fiscal and financial space) Has no alliances with local partners in implementation (partnership space)
Caquetá Connected Landscapes	Professionals from different disciplines, which provides comprehensive technical assistance and incorporates site planning (technical space) Integrates strengthening into the planning to access public credit instruments that are in operation (fiscal and financial space) Has an alliance with the regional government and involves local governments (institutional capacity space)	Does not have an integrated vision of the policy instruments (policy space) Limited technical portfolio of livestock technology options (technical space) No consolidated financing strategy for the conservation component despite having a strong orientation toward the restoration of natural ecosystems (fiscal and financial space)
Orinoquia Sustainable Bovine Production	Is centered on technologies with ease of implementation for different sizes of livestock sites (technical space) Specialized lines of microcredit for livestock (fiscal and financial space) Focused on low-cost technologies (fiscal and financial space)	Does not have a vision of articulation with the policy instruments (policy space) Limited technical team (technical space) Does not have alliances with other institutions in the region (partnership space)
	Opportunities	**Threats**
SLP	The consolidation of the MGS-Col as a space for inter-institutional articulation and coordination (institutional capacity space) The Colombian government is prioritizing sustainable cattle production in its policies, programs, plans, and projects (policy space) Growth of differentiated markets for products that are environmentally friendly (fiscal and financial space)	The coming Law of the National System of Agricultural Innovation (SNIA) may disadvantage the offer of specialized technical assistance (technical space) Price of meat and milk in the medium and long term may be a threat to the cattle business, especially with the coming free trade treaties (fiscal and financial space) Deepening of disagreements within the livestock sector representatives (institutional capacity space)
Caquetá Connected Landscapes	Growth of differentiated markets of products that are friendly to the environment (fiscal and financial space) International cooperation for mitigation and adaptation to climate change in the livestock sector (fiscal and financial space) International cooperation to slow deforestation (fiscal and financial space)	Increase in the areas of illicit crops (fiscal and financial space) Regional governments give low priority to restoration of natural ecosystems (institutional capacity space) Deterioration in public order (institutional capacity space)
Orinoquia Sustainable Bovine Production	The Colombian government has been prioritizing sustainable livestock production in its policies, programs, plans, and projects (policy space) Start-up of CONPES in the high plains (policy space) International cooperation for mitigation and adaptation to climate change in the livestock sector (fiscal and financial space)	Price of meat and milk in the medium and long term may threaten the livestock business, especially with the coming free trade treaties (fiscal and financial space) The volatility of the prices of petroleum may affect the profitability of the livestock business in zones with petroleum influence (fiscal and financial space) Deterioration in public order (institutional capacity space)

Interviews with project leaders (champion interviews).

Pastoral systems face serious complications in the coming decades because of climate change (Herrero et al., 2016a). They will need combinations of policies, institutional arrangements, and new technologies but that also consider the particular conditions of each region. Based on our results, we discuss below the various potentialities and limitations of scaling-up of measures based on the national situation, and of the lessons learned from the initiatives in progress.

Policy Space

Cattle production and climate change have become important in Colombia, which is reflected in national policy documents, especially those related to mitigation. The country has a firm mitigation target for 2030 specified in the NDC and has identified beef production as a key subsector to achieve it. The ECDBC has identified that intensifying livestock raising and converting pasture land to other uses are key components. We identified projects that have the best potential for scaling-up ECDBC technologies, but these were completely isolated from national policy-makers and implementers. This shows that national policy is unaware of local initiatives, which is a barrier to scaling-up any successes. An analysis of 16 case studies concluded that large-scale implementation of adaptation and mitigation in agriculture requires strong government support to achieve large-scale success (Cooper et al., 2013). Success requires support in policy and by providing frameworks that utilize the comparative advantages of the local partners involved.

A barrier to formulating policy at national level is the very coarse scale of much of the available information, which implies that large areas are homogeneous by concealing local variability. There are technological tools, such as satellite images, that can

help improve the detail of the planning and mapping that considers the local specificities in greater detail.

In Latin America countries such Colombia, Costa Rica, Guatemala, Honduras, México, Nicaragua, Perú, and Uruguay have identified the SSP as an alternative to mitigation. They have also identified policy strategies for scaling, which they have verified through NAMA (Suber et al., 2019).

Although we did not encounter the issue, land tenure is often a fundamental barrier to intensification of land use. It is a structural issue that makes it difficult for producers without clear title to their holding to access credit from government programs or to be the beneficiaries of projects with international finance. Three types of policy are required to deal with this problem (Balcázar and Rodríguez, 2013):

(i) Regularize and formalize the property rights of the land;
(ii) Implement policies and instruments to allow trade in land markets and democratize access; and
(iii) Promote sustainable intensification of land use with specific policies and instruments of planning, regulation and control.

Fiscal and Financial Space

Economic problems can limit implementation of viable technical mitigation options to <10% the potential (Herrero et al., 2016b). In the three projects in this study, international and national technical cooperation delivered short-term impact. Nevertheless, it is also a barrier to achieving progress in the longer term, because producers expect further non-reimbursable aid to finance further new technology.

Financing agricultural technology by public institutions is very attractive for producers, but making agricultural credit available to them can be difficult. In many areas in Colombia, producers, especially smallholders, lack title to the land. Without title to serve as a guarantee of any debt, financial institutions are unwilling to provide finance (Perfetti et al., 2013). Inefficient livestock production is not very profitable, so that many producers have few resources. Moreover, the agricultural sector faces high climate risk, often leading to credit default, poor credit histories, and a culture unused to credit. Financial institutions charge high fees to execute transactions and high rates of interest as well. Public promotions can offer loans at low interest rates and other incentives, but the amounts allocated isare often insufficient and are quickly depleted (DNP, 2014).

Other mechanisms such as microcredit, financial cooperatives, and financing by agricultural supply houses seek to overcome some of these limitations (Misión para la transformación del campo, 2015). Land tenure is not an issue, there are only minor formal procedures and disbursement is timely. In most cases, however, microcredit for agriculture charges rates of interest close to the formal level of usury (55% in 2018, SFC, 2018). Users of microcredit cite high interest rates and the low amounts available as the main problems (Banco de la República, 2018), Small loan caps are a major problem for technologies that require high investments, such as iSPS, which can cost up to US$2,330/ha (FEDEGAN, 2017). It often means that the larger areas of medium- and large-sized livestock producers are excluded[7].

Institutional Capacity Space

It is often difficult to work with local and regional public institutions because of technical, financial, and operational weaknesses, and their eagerness for immediate results. Installing sustainable livestock systems, however, demands long-term strategy, which is inconsistent with the short-term agendas of high-rotation public servants that staff these institutions. It is therefore often prudent to consider strengthening the non-public institutions in a region if they are able to assume a determining role in the long term and reduce the risks of failure (Teshome et al., 2016). Westermann et al. (2015) and Aggarwal et al. (2018) consider that multistakeholder platforms and policy-making networks are key to effective upscaling.

Not one of the three projects has achieved a good connection between the strategies designed by the central government and the activities implemented at the local level. In this context, the OCDE recommended *"Reinforcing the interaction between the parties responsible for the adoption of policies and the different parties interested in all the phases of the process of adoption, both at the central level and at the regional level"* (OCDE, 2015). Indeed, one of the key challenges to scaling-up agricultural interventions, is to integrate knowledge across multiple levels by devolving action from the national to the local level. This ensures that interventions are put in the local context and are therefore locally viable (Westermanna et al., 2018). The importance of the local context is well-known in other studies (van Doren et al., 2016).

Learning Space

Training producers to manage the new technology is an important strategy that has been included in each project. This is an essential component to guarantee that producers can manage the new technology in the long term. The concept of technicians training local technicians to become trainers within the region will promote implementation of the technologies outside the project. It will be important to evaluate in the future the outcomes of this strategy. Diffusion of expertise to regional and local public institutions can strengthen implementation of the government's plans and activities. There is no strategy in the projects to link with the universities in the regions, although they could be valuable actors in strengthening the learning spaces. MGS-Col could contribute here.

Large-scale implementation of adaptation and mitigation activities in agriculture does require an iterative learning process as part of strengthening the capacity of the partners involved (Cooper et al., 2013). Young producers in Africa are being trained to use climate-smart agriculture to manage global warming (Mungai et al., 2018), but there is no mention of it in these projects.

Partnership Space

Participation by private individuals is important, but so far only SLP has direct links with FEDEGAN, the producers' guild.

[7]Medium- and large-sized farms have more than 50 ha in paddocks.

Indeed, FEDEGAN administers the project. Private business, marketers and local producer associations, however, remain disconnected as shown in the map of actors in the livestock sector (**Figure 3**). Agreements on zero deforestation for meat and dairy value chains were ratified in May, 2019 as a separate initiative, but one that links directly with the private sector. In addition, Colombia subscribed to the Tropical Forest Alliance 2020[8] in 2017. Moreover, MGS-Col and the MADR have the opportunity to coordinate better to take advantage of the strengths that the various initiatives bring. It is also important to have thematic partners. For example, FEDEGAN brings its knowledge of the livestock industry, while other partners can provide input in environmental and social issues. The incorporation of local partners who understand both the territory and the producers needs and potentials is also a key issue when implementing large-scale programs.

Technical Space

Specialized knowledge is required to achieve credibility among producers and ensure adequate implementation. This is the main reason why recent policies, such as the SNIA, are perceived more as threats than opportunities. It is also important to have a wide array of technical options amongst which producers can choose to select those that best fit their particular conditions. Implementation requires a multidisciplinary technical team to provide a holistic approach that takes account of social, economic, cultural, and other issues as well as the technical components. Although not identified by the champions, monitoring, report, and verification (MRV) is an important technical aspect related to mitigation, especially in silvopastoral systems where it is difficult to do. This is because it is costly, but is required to qualify for international payment for the mitigation service (Suber et al., 2019).

Other Lessons

We learned other lessons from the three projects relevant to scaling-up.

Farm planning contributes to a better sense of the needs of producers and their connection with the immediate environment. It is more complex to coordinate farm planning with planning at larger scales (national and regional); however. We now understand better planning at landscape scales, which allows us to understand the conflicts and needs at larger scales. Landscape planning ensures that the productive systems are planned in coherence with the natural ecosystems that predominate in many regions. This maintains evolutionary and ecological processes, as well as preserving ecosystem services that are key for the success of the productive activities themselves.

Scaling technological adoption needs to consider the current technological level of each farm and the steps required to move it gradually toward a sustainable intensive system. In addition, it is important to be familiar with the biophysical and socioeconomic conditions to understand the technological limits of a site at the time that the technological process is adopted. We recommend seven steps that correspond to different levels of intensification and investment (**Figure 4**)[9]:

(i) Divide paddocks, provide water points and cattle alleyways;
(ii) Improve and recuperate pastures;
(iii) Provide shade areas;
(iv) Plant dispersed trees in paddocks;
(v) Establish living fences;
(vi) Implement non-intensive silvopastoral systems; and
(vii) Implement of intensive silvopastoral systems.

Step (vii) *demands specialized knowledge about rotational grazing, cattle management practices, and forestry* (Calle et al., 2013). Although it is not a straitjacket, it is a reference for taking into account in any initiative what one wants to undertake for the purpose of avoiding the risks of reversion.

There are many similarities between this analysis for Colombia and other cases, such as Sustainable Livestock of the Amazon- PECSA in Brazil[10]. Both recognize the importance of the makeup of the technical team and the initial financing using international funding. PECSA differs in using a business model in which private enterprise provides the technical assistance, negotiating interventions directly with the producers. The technical provider operates as a concession, in which it invests in technological transformation of the farm. In return, it captures the farm profits for an agreed time, after which the farm is returned to the producer operating at a higher technological level. The technical business unit invests, using soft credit provided by international sources, and is directly responsible for the debt. This is an innovative model, whose success will depend on the medium- and long-term outcomes, yet unknown. One unanswered question is how well the original producers will manage the new technology when they resume control of their farms. The program does not include a component to strengthen the original producers' technical capacity to manage the new technology. Moreover, PECSA will require a solid exit strategy to be able to build capacity in producers when the project ends.

CONCLUSIONS

Colombia has been evolving its climate change policies and the livestock sector has been gaining greater relevance, especially in climate change mitigation and general sustainability. Improvement of pastures and silvopastoral systems can contribute to attaining a large part of the goal proposed in the NDC for the agricultural sector. However, to do so, the area to be intervened would be almost 4 Mha. Scaling-up appropriate technologies to this extent is a major challenge.

Our analysis identified key elements for potential scaling-up. The political space already exists with Colombian livestock institutions already showing encouraging interest in issues

[8]https://www.tfa2020.org/en/

[9]We make this recommendation for zones with introduced grasses since a considerable area exists in this type of pastures in Colombia that can be intervened. We recommend better understanding of the environmental implications of intervening in native savanna or natural grasslands.

[10]Personal interview with Renato Farias, executive director of the Instituto Centro de Vida [Center of Life Institute, ICV]. Sustainable Agriculture in Amazonia (PECSA), is an outcome of the Novo Campo program of the ICV.

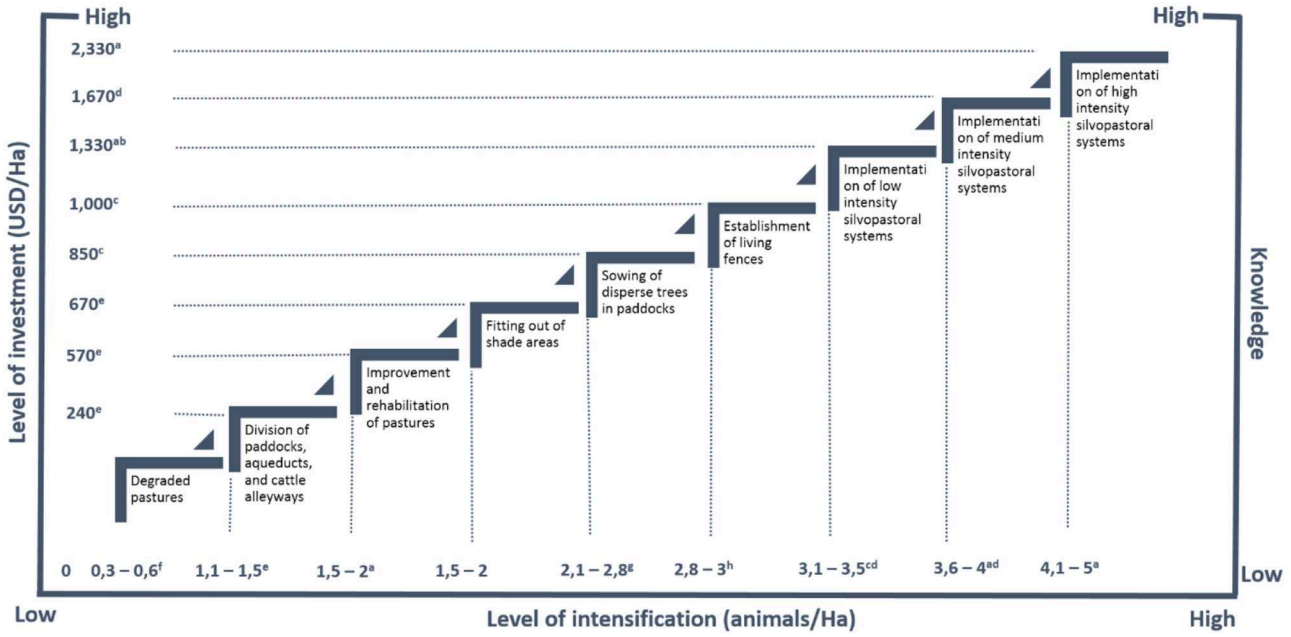

FIGURE 4 | Scale of technologies for implementation in productive livestock systems[11].

related to climate change. Institutional and partnership space also exists with mechanism of broad integration among actors of the sector (MGS-Col) although there are some limitations. Moreover, Colombia has suitable experiences for scaling-up. Within the 17 existing sustainable livestock production projects and initiatives, 16 of them point directly at adaptation to and mitigation of climate change. Of these, three show important potential for scaling-up and offer lessons that can be applied elsewhere. The SLP in particular has become the insignia project of FEDEGAN, the national cattlemen's guild. These projects provide encouraging learning space, but are not connected nationally.

Financial spaces already exist; but there are limitations in the availability of private and public funding in relation the magnitude of that required. While political, learning, and partnership spaces are sufficient for scaling-up at the national level, the link between scales continues to be a problem. The alignment between projects and policy tools continues to be a limiting factor and there is little connection between learning spaces in the different regions of the country. Local partner spaces are only incipient, although we recognize that local partners are key for reaching producers at the farm level.

The internal strengths and weaknesses identified in the SWOT analysis need to be considered in the design of any national scaling-up initiative. We highlight the importance of the technical space where there is a large gap in investment and knowledge between livestock systems of low and high intensity. We therefore recommend creating support tools to accompany a process of gradual technological transformation at the farm level. This is because the large investment of cash, labor and knowledge required to move from a low- to a high-intensity system makes intensification difficult to achieve and risks reversion.

We consider that strengthening regional institutional capacity, including producer organizations, is a key long-term strategy for scaling-up. The three projects that we analyzed used different strategies, which confirms that there is not just one path to success (Linn, 2012). Nevertheless, we believe that it would be worthwhile to test strategies that integrate the strengths of the various initiatives. Poor connection with policy instruments is a consistent weakness in all three of the projects we evaluated. A key challenge in future initiatives will be to design a strategy that make it possible to link these instruments from the start of any project. Linking local actors to the projects has not been a limitation for the success of the projects that we analyzed, but we recognize it as a weakness when it comes to scaling-up.

The external opportunities and threats of the SWOT analysis identify that international support is a key component for success. Institutional capacity is a major concern in achieving a scaling-up, and it is necessary to take into account that strengthening institutional capacity is a slow and complex process. The profitability of livestock in Colombia continues to be a major worry due to the low efficiency of production, and is threatened by the new free trade treaties. Technology can improve the sector's productivity and reduce its environmental impacts in the near term. A green growth policy will be a key component to achieving these goals.

Some structural problems in Colombia that affect the scaling-up will process change only with difficulty in the coming years, but they are critical to designing measures to minimize the risk of reversion. The most important of these are the conditions of

[11] a. FEDEGAN (2017), b. Rocha et al. (2013), c. CATIE (2008), d. Suarez Cerquera (2013), e. FEDEGAN, FNG and SENA (2012), f. DANE (2014), g. Esquivel et al. (2009), h. Uribe et al. (2011).

safety, especially in marginalized zones, land tenure, illicit crops, and the volatility of petroleum prices.

The Colombian government is currently considering a Comprehensive Program of Productive and Environmental Reconversion of the Livestock Sector (PIRPAG). The program will focus on the productive redirection of the livestock sector toward more intensive and sustainable systems in areas that are appropriate for the activity. It is also occurring in zones with conflicting land uses as livestock activity on páramos and national parks. The program aims to cover 10% of the area in pastures in the country over a period of 30 years. It is an opportunity for scaling-up of measures of sustainable livestock raising and of a low carbon footprint to reach the goals of the NDC.

The analysis allows us to identify some key elements for the process of design of PIRPAG:

(i) Carry out land-use planning process to ensure that livestock raising will be carried out on suitable land and define suitable practices according to local conditions;
(ii) Include the leadership of MADR in the formulation of public policy and design of instruments that facilitate the implementation and scaling-up of the identified activities;
(iii) Involve MGS-Col as a space of interinstitutional collaboration;
(iv) Involve FEDEGAN and the Colombian Corporation of Agricultural Research (AGROSAVIA), which have the capacity to come to the field at the level of the producer. They bring the technical knowledge necessary to build models and develop training centers at the local level in synergy with SNIA;
(v) Ensure access to financial resources from international cooperation directed from the institutions that preside over the National System of Climate Change (Spanish acronym SISCLIMA), the MADS, and the National Planning Department (Spanish acronym DNP); and
(vi) Strengthen local capabilities, in both public institutions (governments, offices of the mayor, and Regional Autonomous Corporations) and non-public organizations (NGOs, producer associations, universities).

Conditions in Colombian are similar to those of various countries of Latin America and the Caribbean (LAC). For example, many LAC countries confront deforestation, low productivity of meat and milk, and poor management of pastures. They also have environmental conflicts linked to livestock production, institutional weakness at the local level, and low access to financing. Many of the recommendations and conclusions we reach here can be used elsewhere in LAC to help design of strategies to scale-up measures of adaptation and mitigation in the livestock sector.

DATA AVAILABILITY

The raw data supporting the conclusions of this manuscript will be made available by the authors, without undue reservation, to any qualified researcher.

AUTHOR CONTRIBUTIONS

JT and JL conceived of the presented idea and wrote the manuscript with input from AR and JR. JR designed and performed the methods in sections Map of policies, plans, and other initiatives regarding to the livestock sector, and climate change mitigation and adaptation in Colombia and Map of actors in the livestock sector and in climate change in Colombia under supervision from JL. AR designed and performed the methods in sections Key actors' perspective about barriers to adaptation and mitigation of climate change in the livestock sector in Colombia and Learned lessons from scaling-up potential projects under supervision from JT. JO was involved in planning and supervised the sections Key actors' perspective about barriers to adaptation and mitigation of climate change in the livestock sector in Colombia, Learned lessons from scaling-up potential projects, and contributed to the final version of the manuscript.

FUNDING

This work was implemented as part of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), which is carried out with support from the CGIAR Trust Fund and through bilateral funding agreements and with the financial and technical contributions of the Global Green Growth Institute. For details, please visit https://ccafs.cgiar.org/donors and http://gggi.org/. The views expressed in this document cannot be taken to reflect the official opinions of these organizations.

ACKNOWLEDGMENTS

The authors would like to express their gratitude to Myles Fisher for his support in editing the text.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2019.00061/full#supplementary-material

REFERENCES

Aggarwal, P. K., Jarvis, A., Campbell, B. M., Zougmoré, R. B., Khatri-Chhetri, A., Vermeulen, S. J. et al. (2018). The climate-smart village approach: framework of an integrative strategy for scaling up adaptation options in agriculture. *Ecol. Soc.* 23:14. doi: 10.5751/ES-09844-230114

Aguilar, C. (2009). *Producción y Calidad de Leche y Carne en Sistemas Silvopastoriles. II Congreso Sobre Sistemas Silvopastoriles Intensivos*. Available online at: http://producemich.comli.com/ (accessed September 14, 2018).

André, G., Engel, B., Berentsen, P., Vellinga, T. V., and Oude Lansink, A. G. (2011). Quantifying the effect of heat stress on daily milk yield and monitoring

dynamic changes using an adaptive dynamic model. *J. Dairy Sci.* 94, 4502–4513. doi: 10.3168/jds.2010-4139

Balcázar, Á., and Rodríguez, C. (2013). "Tierra para uso agropecuaria," in *2013 Políticas Para el Desarrollo de la Agricultura en Colombia.* eds J. J. Perfetti, A. Balcázar, A. Hernández, and J. Leibovich (Bogotá: SAC and Fedesarrollo), 65–115.

Banco de la República (2018). *Reporte de la Situación Actual Del Microcrédito en Colombia–Junio de 2018*. Bogotá: Banco de la República. Available online at: www.banrep.gov.co/sites/default/files/publicaciones/archivos/encuesta_microcredito_junio_2018.pdf (Consulted on September 24, 2018).

Broom, D. M., Galindo, F. A., and Murgueitio, E. (2013). Sustainable, efficient livestock production with high biodiversity and good welfare for animals. *Proc. R. Soc.* 280:20132025. doi: 10.1098/rspb.2013.2025

Calle, Z., Murgueitio, E., Chará, J., Molina, C. H., Zuluaga, A. F., and Calle, A. (2013). A strategy for scaling-up intensive silvopastoral systems in Colombia. *J. Sustain. For.* 32, 677–693. doi: 10.1080/10549811.2013.817338

CATIE [Centro Agronómico Tropical de Investigación y Enseñanza] (2008). "Valor económico y ecológico de las cercas vivas," in *Serie Técnica; Informe Técnico No. 372 en Fincas y Paisajes Ganaderos*, eds C. Villanueva, M. Ibrahim, and F. Casasola (Turrialba: Centro Agronómico Tropical de Investigación y Enseñanza), 36.

CIAT [Centro Internacional de Agricultura Tropical], CCAFS [Research Program on Climate Change, Agriculture and Food Security], CRECE [Centro de Estudios Regionales Cafeteros y Empresariales], DNP [Departamento Nacional de Planeación], GGGI [Global Green Growth Institute] (2018). *Informe 4: "Recomendaciones técnicas y de política para la misión de crecimiento verde en Colombia" consultoría "Productividad de la tierra y rendimiento del sector agropecuario medido a través de los indicadores de crecimiento verde en el marco de la misión de crecimiento verde en Colombia."* Available online at: https://www.dnp.gov.co/Crecimiento-Verde/Documents/ejes-tematicos/Suelo/Productos%20finales/Informe%204%20-%20Productividad%20Suelo%20Final.pdf (consulted on October 9, 2018).

CIAT [Centro Internacional de Agricultura Tropical] and CORMACARENA [Corporación para el Desarrollo Sostenible del Área de Manejo Especial La Macarena] (2018). *Plan Regional Integral de Cambio Climático para la Orinoquía*. CIAT Publicación No. 438. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia.

Cooper, P. J. M., Cappiello, S., Vermeulen, S. J., Campbell, B. M., Zougmoré, R., and Kinyangi, J. (2013). *Largescale Implementation of Adaptation and Mitigation Actions in Agriculture*. CCAFS Working Paper no. 50. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available online at: www.ccafs.cgiar.org

DANE [Departamento Nacional de Estadística] (2014). *Censo Nacional Agropecuario 2014*. Bogotá: Departamento Administrativo Nacional de Estadística.

de Moraes Sá, J. C., Lal, R., Cerri, C. C., Hungriad, K. M. Cesarde, P., and Carvalhoe, F. (2017). Low-carbon agriculture in South America to mitigate global climate change and advance food security. *Environ. Int.* 98, 102–112. doi: 10.1016/j.envint.2016.10.020

DNP [Departamento Nacional de Planeación] (2014). *Sistema Nacional de Crédito Agropecuario: Propuesta de Reforma*. Bogotá: Misión para la transformación del campo.

Esquivel, M. J., Harvey, C., Finegan, B., Casanoves, F., Skarpe, C., and Nieuwenhuyse, A. (2009). "Regeneración natural de árboles y arbustos en potreros activos de Nicaragua," in *Agroforestería en las Américas* (CATIE), 76–84. Available online at: http://repositorio.bibliotecaorton.catie.ac.cr/bitstream/handle/11554/6769/Regeneracion_natural_de_arboles.pdf?sequence=1&isAllowed=y

FEDEGAN [Federación Colombiana de Ganaderos] (2014). *Plan de Desarrollo Ganadero 2014–2019: Por una Ganadería Moderna, Sostenible y Solidaria*. Federación Colombiana de Ganaderos. Retrieved from https://goo.gl/9dq1qS (consulted on September 24, 2018).

FEDEGAN [Federación Colombiana de Ganaderos] (2017). *Ganadería Colombiana Sostenible. Principios Agroecológicos SSPi*. Manizales: Curso de ganadería sostenible.

FEDEGAN [Federación Colombiana de Ganaderos] (2018). *Cifras de Referencia del Sector Ganadero Colombiano*. Available online at: http://estadisticas.fedegan.org.co/DOC/download.jsp?pRealName=Cifras_Referencia_2017.pdf&iIdFiles=641 (consulted on September 5, 2018).

FEDEGAN [Federación Colombiana de Ganaderos], FNG [Fondo Nacional del Ganado], SENA [Servicio Nacional de Aprendizaje] (2012). *Estudio de Costos Modales en Ganadería Bovina*. Oficina de Investigaciones Económicas.

Flanagan, K., Uyarra, E., and Laranja, M. (2011). Reconceptualising the "policy mix" for innovation. *Res. Policy* 40, 702–713. doi: 10.1016/j.respol.2011.02.005

Giraldo, C., and Uribe, F. (2007). Manejo integrado de garrapatas en sistemas sostenibles de producción ganadera. *Carta Fedegan* 101, 66–74. Available online at: http://biblioteca.colanta.com.co/pmb/opac_css/index.php?lvl=notice_display&id=14732 (accessed September 13, 2018).

Herrero, M., Addison, J., Bedelian, C., Carabine, E., Havlík, P., Henderson, B., et al. (2016a). Climate change and pastoralism: impacts, consequences and adaptation. *Sci. Tech. Rev.* 35, 417–433. doi: 10.20506/rst.35.2.2533

Herrero, M., Havlík, P., Valin, H., Notenbaert, A., Rufino, M. C., Thornton, P. K., et al. (2013). Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *Proc. Natl. Acad. Sci. U.S.A.* 110, 20888–20893. doi: 10.1073/pnas.1308149110

Herrero, M., Henderson, B., Havlík, P., Thornton, P. K., Conant, R. T., Smith, P., et al. (2016b). Greenhouse gas mitigation potentials in the livestock sector. *Nat. Clim. Change* 6, 452–461. doi: 10.1038/nclimate2925

ICA [Instituto Colombiano Agropecuario] (2017). *Censo Pecuario Nacional.* Available online at: https://www.ica.gov.co/Areas/Pecuaria/Servicios/Epidemiologia-Veterinaria/Censos-2016/Censo-2017.aspx (consulted on November 27, 2018).

IDEAM [Instituto de Hidrología, Meteorología y Estudios Ambientales], PNUD [Programa de las Naciones Unidas para el Desarrollo], MADS [Ministerio de Ambiente y Desarrollo Sostenible], DNP [Departamento Nacional de Planeación], and CANCILLERÍA. (2016). *Inventario Nacional y Departamental de Gases de Efecto Invernadero (GEI) de Colombia. Tercera Comunicación Nacional de Cambio Climático de Colombia*. Bogotá: IDEAM, PNUD, MADS, DNP, CANCILLERÍA, FMAM.

IPCC (2014). *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Core Writing Team, eds R. K. Pachauri and L. A. Meyer (Geneva: IPCC), 151.

Lerner, A. M., Zuluaga, A. F., Chará, J., Etter, A., and Searchinger, T. (2017). Sustainable cattle ranching in practice: moving from theory to planning in Colombia's livestock sector. *Environ. Manag.* 60, 176–184. doi: 10.1007/s00267-017-0902-8

Linn, J. F. (2012). *Scaling-up in Agriculture, Rural Development and Nutrition*. Washington, DC: International Food Policy Research Institute (IFPRI). Available online at: www.ifpri.org/publication/scaling-agriculture-rural-development-and-nutrition (consulted on September 24, 2018).

MADR [Ministerio de Agricultura y Desarrollo Rural] (2018). *Documento Soporte Construcción Contribución Del Sector Agropecuario y Desarrollo Rural*. Bogotá: MADR.

Marin, A., Baldissera, T., Pinto, C., Garagorry, F., Zubieta, A., Giraldo, L. A., et al. (2017). *Grazing Management Innovation as a Strategy to Improve Animal Production and Reduce GHG Emissions*. CCAFS Info Note. Wageningen: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Mills, J. N., Gage, K. L., and Khan, A. S. (2010). Potential influence of climate change on vector-borne and zoonotic diseases: a review and proposed research plan. *Environ. Health Perspect.* 118, 1507–1514. doi: 10.1289/ehp.0901389

Misión para la transformación del campo (2015). *El Campo Colombiano: un Camino Hacia el Bienestar y la Paz. Informe Detallado de la Misión Para la Transformación del Campo*. Bogotá: Departamento Nacional de Planeación.

Mungai, C., Muchaba, T., Szilagyi, L., Radeny, M., Atakos, V., and Ntiokam, D. (2018). *Youth Engagement In Climate-Smart Agriculture in Africa: Opportunities and Challenges*. Wageningen: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available online at: www.ccafs.cgiar.org

Murgueitio, E., Chará, J., Barahona Rosales, R., Cardona, C., and Naranjo R. (2014). Los sistemas silvopastoriles intensivos (SSPi), herramienta de mitigación y adaptación al cambio climático. *Trop. Subtrop. Agroecosyst.* 17, 501–507. Available online at: http://www.redalyc.org/articulo.oa?id=93935728001 (accessed September 13, 2018).

Murgueitio, E., and Ibrahim, M. (2008). "Ganadería y medio ambiente en América Latina," in *Ganadería del Futuro: Investigación para el Desarrollo*, eds E. Murgueitio, C. Cuartas, and J. Naranjo (Cali: Fundación CIPAV), 19–40.

Murgueitio, E., and Solorio, B. (2008). "El Sistema Silvopastoril Intensivo, un modelo exitoso para la competitividad ganadera en Colombia y México," in *V Congreso Latinoamericano de Agroforestería para la Producción Pecuaria Sostenible*, 15. Available online at: www.danac.org.ve (accessed September 27, 2018).

OCDE [Organización para la Cooperación y el Desarrollo Económico] (2015). *Revisión de la OCDE de las Políticas Agrícolas: Colombia 2015 Evaluación y Recomendaciones de Política*. Publicaciones OCDE. Available online at: https://www.oecd.org/countries/colombia/Colombia-Revision-OCDE-Politicas-Agricolas-2015.pdf (accessed September 27, 2018).

Perfetti, J. J., Balcázar, A., Hernández, A., and Leibovich, J. (2013). *Políticas Para El Desarrollo De La Agricultura En Colombia*. Bogotá: SAC and Fedesarrollo.

Porter, J. R., Xie, L., Challinor, A. J., Cochrane, K., Howden, S. M., Iqbal, M. M., et al. (2014). "Food security and food production systems," in *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* eds C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L. White (Cambridge; New York, NY: Cambridge University Press), 485–533.

Rao, I. M., Peters, M., Castro, A., Schultze-Kraft, R., White, D., Fisher, M. J., et al. (2015). LivestockPlus–the sustainable intensification of forage-based agricultural systems to improve livelihoods and ecosystem services in the tropics. *Trop. Grassl. Forrajes Trop.* 3, 59–82. doi: 10.17138/TGFT(3)59-82

Rao, K. P. C., Verchot, L., and Laarman, J. (2007). Adaptation to climate change through sustainable management and development of agroforestry systems. *J. SAT Agric. Res.* 4, 1–30. Available online at: http://oar.icrisat.org/2561/1/Adaptation_to_Climate_Change.pdf (accessed September 10, 2018).

Renaudeau, D., Gourdine, J., and St-Pierre, N. R. (2011). A meta-analysis of the effects of high ambient temperature on growth performance of growing-finishing pigs. *J. Anim. Sci.* 89, 2220–2230. doi: 10.2527/jas.2010-3329

Rocha, C., Cárdenas, C. A., and Mora Delgado, J. (2013). Costos de Establecimiento de un Sistema Silvopastoril de Sauco (Sambucus nigra) y Kikuyo (*Pennisetum clandestinum*) en Roncesvalles (Tolima). *Agroforestaría Neotropical* 3, 70–76. Available online at: http://revistas.ut.edu.co/index.php/agroforesteria/article/view/323/287 (accessed September 10, 2018).

SFC [Superintendencia Financiera de Colombia] (2018). *Certificación del Interés Bancario Corriente para la modalidad de Crédito de Consumo y Ordinario*. Available online at: https://www.superfinanciera.gov.co/publicacion/10097727 (consulted on September 24, 2018).

Suarez Cerquera, E. (2013). *Diseño de programa silvopastoril, para la recuperación del suelo en la finca "La Esperanza" en la vereda Nilo del municipio de Palermo, Huila* (Thesis). Bogotá: Universidad Libre.

Suber, M., Gutiérrez Beltrán, N., Torres, C. F., Turriago, J. D., Arango, J., Banegas, N. R., et al. (2019). *Mitigación con Sistemas Silvopastoriles en Latinoamérica. Aportes para la incorporación en los sistemas de Medición Reporte y Verificación bajo la CMUNCC*. CCAFS Working Paper no. 254. Wageningen: Disponible en línea. Available online at: www.ccafs.cgiar.org

Tabachnick, W. J. (2010). Challenges in predicting climate and environmental effects on vector-borne disease episystems in a changing world. *J. Exp. Biol.* 213, 946–954. doi: 10.1242/jeb.037564

Tapasco, J., Martínez, J., Calderón, S., Romero, G., Ordóñez, D. A., Álvarez, A., et al. (2015). *Impactos Económicos del Cambio Climático en Colombia: Sector Ganadero*. Banco Interamericano de Desarrollo. Monografía No. 254 (Washington, DC).

Teshome, A., de Graaff, J., and Kassie, M. (2016). Household-level determinants of soil and water conservation adoption phases: evidence from north-western Ethiopian highlands. *Environ. Manag.* 57, 620–636. doi: 10.1007/s00267-015-0635-5

UNIANDES [Universidad de los Andes, Colombia], MADS [Ministerio de Ambiente y Desarrollo Sostenible], BID [Banco Interamericano de Desarrollo] (2013). *Estrategia Colombiana de Desarrollo Bajo en Carbono*. Bogotá: Informe final.

Uribe, F., Zuluaga, A. F., Valencia, L., Murgueitio, E., Zapata, A., Solarte, L., et al. (2011). *Establecimiento y Manejo de Sistemas Silvopastoriles. Manual 1, Proyecto Ganadería Colombiana Sostenible*. Bogotá: GEF, World Bank, FEDEGAN, CIPAV, FONDO ACCION, TNC, 78.

van Doren, D., Giezen, M., Driessen, P. P. J., and Runhaar, H. A. C. (2016). Scaling-up energy conservation initiatives: barriers and local strategies. *Sustainable Cities and Soc.* 26, 227–239. doi: 10.1016/j.scs.2016.06.009

Vitali, A., Segnalini, M., Bertocchi, L., Bernabucci, U., Nardone, A., and Lacetera, N. (2009). Seasonal pattern of mortality and relationships between mortality and temperature-humidity index in dairy cows. *J. Dairy Sci.* 92, 3781–3790. doi: 10.3168/jds.2009-2127

Weihrich, H. (1982). The TOWS matrix: a tool for situational analysis. *Long Range Plan.* 15, 54–66. doi: 10.1016/0024-6301(82)90120-0

Westermann, O., Thornton, P., and Förch, W. (2015). *Reaching More Farmers–Innovative Approaches to Scaling Up Climate Smart Agriculture*. CCAFS Working Paper no. 135. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available online at: www.ccafs.cgiar.org

Westermanna, O., Förchb, W., Thorntonc, P., Körnerd, J., Cramere, L., and Campbelle, B. (2018). Scaling up agricultural interventions: case studies of climate-smart agriculture. *Agric. Syst.* 165, 283–293. doi: 10.1016/j.agsy.2018.07.007

World Bank and DNP [Department of National Planning] (2014). *Low-Carbon Development for Colombia*. Washington, DC: World Bank.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.