Ecosystem services in livestock farming: Integral valuation framework and field applications

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Ecosystem services in livestock farming: Integral valuation framework and field applications

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Abstract

This document presents a framework for evaluating the environmental, economic, and social dimensions of ecosystem services in livestock systems. Livestock plays a critical role in global food security and economies but also contributes to environmental challenges, including deforestation and greenhouse gas emissions. To address these issues, the Ecosystem Services Advisory Group, established under the One CGIAR Initiative on Livestock and Climate (L&C), seeks to promote sustainable livestock practices. Key ecosystem services highlighted in this framework include food and feed production, carbon sequestration, soil fertility enhancement, microclimatic regulation, biodiversity conservation, and emission reductions. The proposed integrated valuation strategy assesses ecological benefits, economic value, and social perceptions, aiming to support sustainable livestock management. Field applications in Colombia, Kenya, and Tunisia demonstrate the advantages of silvo-pastoral systems and improved pastures in boosting productivity, mitigating greenhouse gas emissions, and enhancing ecosystem resilience. The framework emphasizes the importance of balancing livestock production with environmental sustainability through innovative practices. Looking ahead, the initiative will focus on expanding evaluations across Latin America and Africa, refining methodologies, and strengthening stakeholder engagement to advance sustainable livestock farming on a global scale.

1. Introduction

This document provides a comprehensive overview of the role livestock systems play in global food security, economic development, and ecosystem dynamics, while addressing the critical need for sustainable practices in the face of rising environmental challenges. Livestock contributes significantly to food security, poverty reduction, and agricultural development, supporting the livelihoods and nutrition of over 1.3 billion people and accounting for 40% of global agricultural output (SEBI Livestock, 2023; World Bank, 2021). However, the sector's reliance on natural resources is substantial, with pastures covering 26% of global land (Agregán et al., 2021). The environmental impacts of this extensive land use, compounded by intensive livestock practices, include deforestation, biodiversity loss, water pollution, and greenhouse gas emissions (Steinfeld et al., 2006).

As global demand for animal-source foods increases and the urgency for a carbon-neutral agricultural sector intensifies, balancing livestock production with environmental sustainability has become a pressing challenge (Flórez et al., 2023; Robinson et al., 2011). Livestock systems have a dual impact on ecosystem services: they provide provisioning services like food, fiber, and leather, and support biodiversity in natural and semi-natural landscapes through grazing (FAO, 2010; Teague et al., 2016). At the same time, they exert significant pressures on other ecosystem services, such as soil quality, water cycles, and carbon sequestration, due to overgrazing, excessive resource use, and greenhouse gas emissions (Herrero et al., 2013).

Addressing these challenges requires a transition to sustainable livestock systems that mitigate negative environmental impacts while enhancing ecosystem services. Practices such as improved grazing management, silvopastoral systems, and efficient animal feeding strategies can increase productivity, reduce greenhouse gas emissions, and promote ecosystem resilience (Teague et al., 2016).

The **CGIAR Initiative on Livestock and Climate** seeks to address the dual challenge posed by climate change for livestock systems in Africa and Latin America: the sector's vulnerability to climate impacts and its role as a greenhouse gas emitter. Researchers are collaborating with public and private stakeholders to co-create and implement innovations that help adapt livestock systems to climate change while reducing emissions (CGIAR, 2024).

Within this framework, the **Ecosystem Services Advisory Group** was established, comprising multidisciplinary experts from the International Center for Tropical Agriculture (CIAT), the International Center for Agricultural Research in the Dry Areas (ICARDA), and the International Livestock Research Institute (ILRI). Since 2022, the group has focused on understanding the relationships between livestock systems and ecosystem services, promoting sustainable interventions, and developing a comprehensive valuation methodology. This approach compares conditions before and after interventions or between systems with and without interventions to evaluate whether positive outcomes outweigh negative consequences. The methodology aims to guide sustainable livestock interventions that balance economic and environmental objectives (Flórez et al., 2023).

The document is structured as follows: Section 2 defines the socioecological system of livestock and identifies key ecosystem services and environmental benefits. Section 3 outlines the methodology for the integral valuation of ecosystem services and its application in livestock systems. Section 4 discusses the incorporation of environmental value into economic evaluations. Section 5 presents case studies conducted in Colombia and Africa. Section 6 explores research on emissions mitigation in livestock farming across Latin America. Section 7 highlights the publications and conferences where our findings have been disseminated. Finally, Section 8 outlines the planned steps for 2025.

2. Identification of ecosystem services in livestock agrifood systems

A socio-ecological system is a dynamic combination of biophysical and geological units that interact with one or more social systems, which are shaped by stakeholders and institutions (Glaser et al., 2008; Martín-López et al., 2012; Ostrom, 2009; Pallero et al., 2018). Understanding these systems requires a "human in nature" perspective, acknowledging that human societies are both shaped by and have co-evolved with the constraints and dynamics of the ecosphere. This co-evolution has resulted in integrated systems where humans and ecological processes interact and adapt together (Farhad, 2012; Flórez et al., 2023; Martín-López et al., 2009).

Socio-ecological systems are characterized by the dynamic interaction between their ecological and social components. The ecological system provides essential ecosystem services, such as food production, water regulation, and carbon sequestration, which sustain human life, economic activities, and production processes. In turn, the social system generates both positive externalities (e.g., environmental benefits) and negative externalities (e.g., pollution, overexploitation) that influence the natural conditions and functionality of the ecological system (Martín-López et al., 2012). Effective management of socio-ecological systems requires an ecosystem-based approach, along with strategies tailored to the social, economic, and ecological contexts (Flórez et al., 2023; Pallero et al., 2018).

A mixed crop-livestock farming village serves as an illustrative example of a socio-ecological system. In this context, the ecological system includes natural resources such as forests, wetlands, rangelands, rivers, and lakes, as well as crops and livestock cultivated and managed by humans. The social system comprises various interconnected actors and institutions: farming families whose livelihoods depend on agriculture and livestock; associations that facilitate cooperation among families; competition among families for limited resources; intermediaries who purchase agricultural products; final consumers of these products, both local and external; and local and national governments, which set the regulatory framework for interactions within the social system (Flórez et al., 2023). Figure 1 illustrates these complex interactions, highlighting the interconnectedness of ecological and social components.

Ecosystem services refer to the wide array of benefits that nature provides to society, enabling and enhancing human life. These services include the provision of nutritious food, feed, and clean water; the regulation of diseases and climate; support for crop pollination and soil formation; and recreational, cultural, and spiritual benefits (Millennium Ecosystem Assessment, 2005; Flórez et al., 2023; McElwee & Shapiro-Garza, 2020; Philip Robertson & Harwood, 2013; Quijas & Balvanera, 2013; WWF, 2018). The availability of ecosystem services in natural systems is deeply intertwined with biodiversity. Generally, higher biodiversity results in a greater supply of ecosystem services, making the preservation and sustainable management of biodiversity critical. Biodiversity refers to the variety of life forms within species, between species, and across ecosystems, serving as a foundational element of ecological systems.

Ecosystem services are commonly classified into four main categories: **provisioning, regulating, supporting, and sociocultural services** (Millennium Ecosystem Assessment, 2005; FAO, 2023; Flórez et al., 2023).

Livestock systems—such as those based on pastures, cultivated forages, rangelands, and agro-silvo-pastoral systems—play a dual role in generating ecosystem services and delivering environmental benefits. We have identified seven key ecosystem services and three notable environmental benefits provided by these systems (see Table 1).

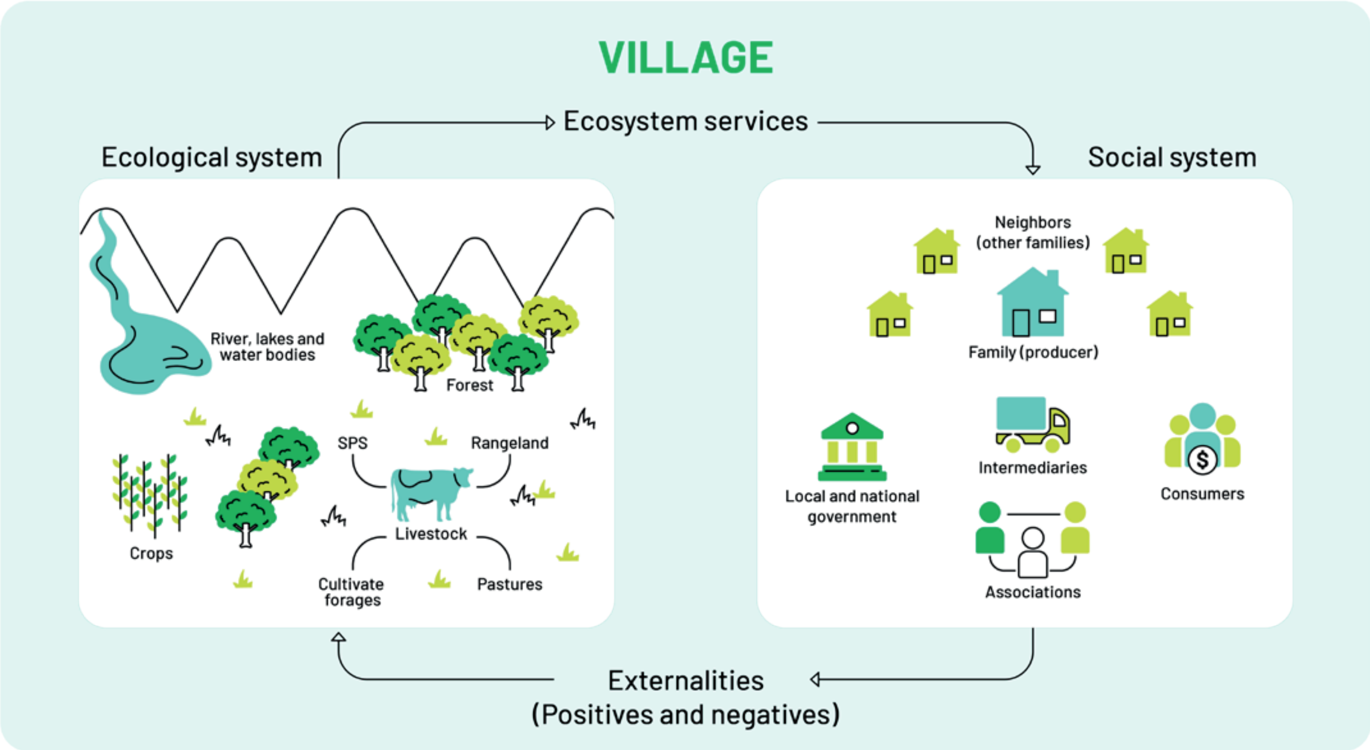


Figure 1. Socio-ecological system in the mixed farming context

Source: Flórez et al. (2023)

Table 1. Ecosystem services and environmental benefits in different livestock systems

Name	Type	Pastures	Cultivated forages	Rangelands	Agro-silvo-pastoral systems
Food	Ecosystem service	✓	✓	✓	✓
Feed	Ecosystem service	✓	✓	✓	✓
Carbon storage and sequestration	Ecosystem service		✓	✓	✓
Micro-climatic regulation	Ecosystem service			✓	✓
Soil fertility	Ecosystem service	✓	✓	✓	✓
Habitat for species	Ecosystem service		✓		✓
Aesthetic appreciation	Ecosystem service			✓	✓
Methane emissions reduction	Environmental benefit	✓	✓	✓	✓
Water use reduction	Environmental benefit			✓	✓
Land use reduction	Environmental benefit	✓	✓	✓	✓

Source: Flórez et al. (2023)

3. Integral valuation strategy

The integral valuation of ecosystem services provides a holistic framework for assessing the ecological, economic, and social dimensions of the benefits ecosystems offer. This approach facilitates a comprehensive understanding of the interactions between natural and human systems, enabling stakeholders to evaluate the impacts of interventions in socio-ecological systems, such as livestock production. By comparing conditions before and after interventions or between treated and untreated systems, this methodology offers a detailed analysis of trade-offs and synergies. Integral valuation is particularly valuable for designing sustainable policies and management practices that balance environmental conservation with economic and social objectives (Flórez et al., 2023; Villegas-Palacio et al., 2016).

Dimensions of Integral Valuation

Ecological Valuation

This dimension focuses on quantifying the physical benefits provided by ecosystem services, including carbon sequestration, soil fertility, and biodiversity support. Examples of ecological metrics include the annual rate of carbon capture, nutrient cycling efficiency, and species diversity supported by specific land-use practices. These metrics enable decision-makers to assess ecosystems' direct contributions to environmental sustainability and the impacts of human interventions. Understanding these ecological benefits is crucial for optimizing resource use and designing interventions that preserve or enhance ecosystem functionality (Flórez et al., 2023; Pascual et al., 2023).

Economic Valuation

Economic valuation translates ecological benefits into monetary terms by assigning financial value to services such as carbon storage, water purification, and nutrient cycling. Techniques such as market pricing, replacement costs, and willingness-to-pay models are commonly used to estimate these values. This dimension provides stakeholders with a tangible basis for comparing the costs and benefits of interventions, supporting informed decision-making (Pascual et al., 2023; Villegas-Palacio et al., 2016).

Social Valuation

Social valuation considers the perceptions, knowledge, and use of ecosystem services by communities. It examines factors such as how communities value biodiversity, their willingness to adopt sustainable practices, and the cultural significance of specific landscapes. By integrating these perspectives, social valuation ensures that management practices align with local needs and values, fostering broader acceptance and sustainability.

Together, these three dimensions form a robust framework for evaluating ecosystem services and implementing sustainable practices. This comprehensive approach helps balance diverse priorities, ensuring the long-term health of ecosystems and the communities that depend on them (Flórez et al., 2023).

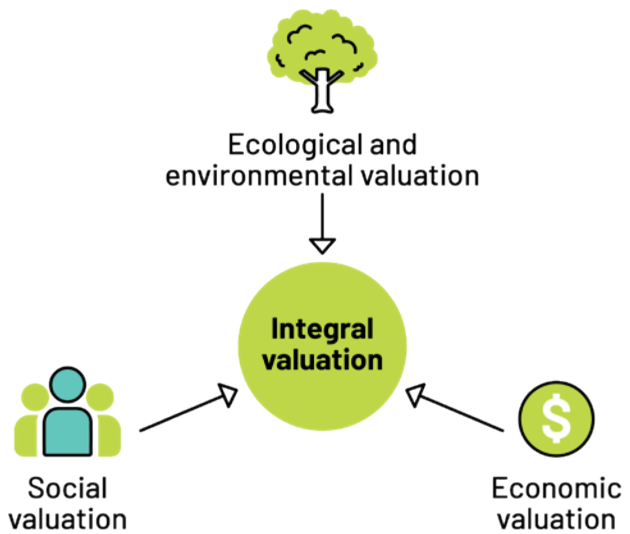


Figure 2. Integral valuation of ecosystem services and environmental benefits

Source: Flórez et al. (2023)

We have developed an integral valuation strategy to assess the key ecosystem services and environmental benefits provided by livestock systems (see Table 2). This strategy aims to provide a comprehensive framework for understanding and quantifying these contributions across ecological, economic, and social dimensions.

Table 2. Strategy for integral valuation of ecosystem services and environmental benefits in livestock systems

Ecosystem service/ Environmental benefit	Ecological and environmental valuation	Economic valuation	Social valuation
FOOD	Product: Milk and meat. Amount of milk (lts) or meat (kg) produced per animal or hectare	The value of milk, meat, leather, feather, etc. produced. Market price or milk and meat are used.	Do you think that milk and meat are important for human nutrition? Do you consume meat, milk, or both? Rate from 1 to 5 how important you think milk and meat is for human nutrition?
FEED	Quantity of feed accessible per animal or hectare Quality of feed Seasonal availability	Market price of Forage Feed cost (60-70% of total cost)	Do you know what the feed service in livestock systems is? Rate from 1 to 5 how important you think the feed service is?
CARBON STORAGE AND SEQUESTRATION	Storage: Amount of carbon stored to date Sequestration: Annual rate of carbon capture	Market price Carbon price in Tradable Emissions Permit Systems	Do you know what the carbon sequestration service in livestock systems is? Rate from 1 to 5 how important you think the carbon sequestration service is?
MICRO CLIMATIC REGULATION	Productivity change: Comparison of animal productivity with and without shade	Income changes Increase in income derived from increased production	Do you know what micro climatic regulation in livestock systems is? Rate from 1 to 5 how important you think the microclimatic regulation service is?
SOIL FERTILITY	Identification: Nutrients available in manure Quantification: Estimation of the amount of manure in the livestock system	Replacement cost Cost of soil fertilizers that we would have to use if we did not have available manure	Do you know what the soil fertility service in livestock systems is? Rate from 1 to 5 how important you think the soil fertility service is?
HABITAT FOR SPECIES	Identification: What species inhabit the livestock system? Quantification: Estimation of the number of individuals and reproduction and death rate of each species	Willingness to pay to conserve the species Experimental approach, Discrete Choice Experiment (DCE)	Do you know what species live in your livestock system? Do you consider that this species are goods or bads for your livestock system? Do you want these species to continue living in your livestock system or do you want to eradicate them?
AESTHETIC APPRECIATION	Identification: The livestock system has a landscape that may be of tourist interest	Travel costs Cost incurred by a person who wishes to visit this livestock landscape	Do you think the livestock landscape is attractive enough to visit? Rate your experience visiting the livestock landscape from 1 to 5? Did visiting the livestock landscape generate feelings in you such as tranquility, inspiration, joy, amazement or similar? Would you recommend other people visit the livestock landscape?
METHANE EMISSIONS REDUCTION	Quantification: Estimate of the reduction of methane emissions per animal and in units of CO2 eq	Market price Carbon price in Tradable Emissions Permit Systems	Do you know what methane emissions in livestock systems is? Are you interested in reducing methane emissions in your production system? Rate from 1 to 5 how important you think it is to reduce methane emissions?
WATER DEMAND REDUCTION	Quantification: Estimation of the reduction of the water requirement of the forage. Evo transpiration is applied. Estimation of the reduction of water consumption by animals. What type of water does the requirement cover: How much green water (rain) and how much blue water (superficial)?	Market price Water price	Do you know what the water demand in livestock systems is? Are you interested in reducing water demand in your production system? Rate from 1 to 5 how important you think it is to reduce the water demand?
LAND USE REDUCTION	Quantification: Estimation of the area needed to feed an animal	Opportunity cost Opportunity cost of using land in another activity than livestock, for example for conservation, afforestation, crop production, or infrastructure	Do you know what land use in livestock systems is? Are you interested in reducing land use in your production system? Rate from 1 to 5 how important you think it is to reduce land use?

4. Economic evaluation of sustainable interventions

In livestock systems, the decision to implement an intervention involves weighing its costs—primarily the investment required—against its benefits, which include increased income and the estimated monetary value of improved ecosystem services. Incorporating both production value and the value of ecosystem services and environmental benefits facilitates more comprehensive economic evaluations and enhances decision-making processes in livestock management.

The economic evaluation process includes six interconnected methods:

1. **Free cash flow:** Analyzes cash inflows and outflows over time, capturing operational costs, revenues from livestock products (e.g., meat, milk, live animals), and expenses for livestock care and infrastructure. Detailed cash flow analysis highlights critical liquidity periods and supports effective financial planning, ensuring project viability (Leal et al., 2023; Sandoval et al., 2023).
2. **Net Present Value (NPV):** Assesses whether a livestock project adds value in current terms by discounting future cash flows at a specific rate.
3. **Internal Rate of Return (IRR):** Evaluates the expected profitability of a project, aiding in comparison with alternative investments.
4. **Benefit/Cost Ratio (B/C):** Measures economic efficiency by comparing the present value of benefits to total costs.
5. **Repayment period (RP):** Determines the time required to recover the initial investment, a key metric for planning in both intensive and extensive livestock systems (FAO, 2017).
6. **Risk analysis:** Addresses uncertainties such as climate, market fluctuations, and productivity variations. Tools like Monte Carlo simulations estimate the likelihood of success and quantify the impact of variables, enabling more informed decisions (Sandoval et al., 2023).

The evaluation of sustainable interventions in livestock systems occurs in two stages:

1. **Economic evaluation:** In this initial stage, economic indicators (NPV, IRR, RP, B/C ratio, and risk) are calculated and used to compare outcomes with and without the intervention.
2. **Economic and environmental evaluation:** This phase integrates the valuation of ecosystem services and environmental benefits as potential income in the free cash flow. Economic indicators are then recalculated (NPV, IRR, RP, B/C ratio, and risk), allowing comparisons between purely economic outcomes and combined economic-environmental results, both with and without the intervention.

This two-step evaluation framework enables a thorough analysis of the economic and environmental impacts of livestock interventions, providing valuable insights for sustainable livestock management.

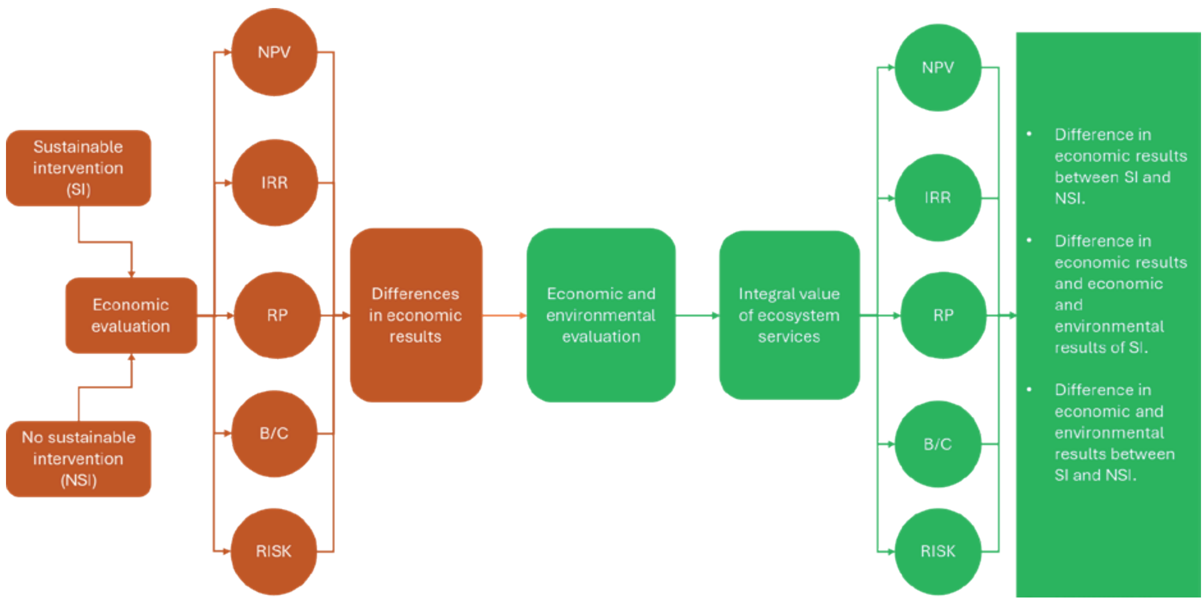


Figure 3. Framework for economic and environmental evaluation

5. Development of analytical tools for benefit:cost analysis

The primary goal of the Ecosystem Services Advisory Group has been to evaluate the various benefit/cost analysis tools used by participating CGIAR institutions and develop a more robust, user-friendly tool. This involves harmonizing key assumptions, definitions, parameters, and outputs to create a standardized tool that generates consistent and comparable results. A successful harmonized tool would allow results to be aggregated for global estimates, providing valuable guidance for investment decisions by national and regional leaders, as well as international development and climate financing institutions. If developed in collaboration with these institutions, such a tool could also support transactions in the voluntary carbon market.

To achieve this goal, the advisory group has focused on two key areas:

Establishing a global ecosystem services database

Significant progress has been made in building a database on ecosystem services in livestock agrifood systems for the Latin American, Central and West Asian, North African (CWANA), and East and West African regions. In Latin America, studies on carbon storage, sequestration, and emissions reduction have been compiled (CIAT livestock latin america quantification ecosystem services.xlsx). The focus for 2025 will shift to collecting studies from Africa.

Developing a comprehensive, harmonized valuation tool

The advisory group is working to enhance existing benefit/cost analysis tools by adopting an integral valuation approach. The Alliance team has been leading efforts to conceptualize and develop a comprehensive model for valuing ecosystem services and environmental benefits in livestock systems. This includes defining the socio-ecological framework for livestock farming, identifying key variables for ecological evaluation, and establishing economic and social valuation methods. These concepts are detailed in earlier sections of this document and the policy brief Ecosystem Services and Environmental Benefits in Livestock Systems: Definition of Terms and Valuation Methods (Flórez et al., 2023).

Field studies applying this method have been conducted in Colombia (Gonzalez Quintero et al., 2024; González-Quintero et al., 2023; Sandoval et al., 2023), with ongoing research in Kenya. Results from these studies indicate both economic and environmental benefits from sustainable interventions that enhance the supply of ecosystem services in dairy and beef livestock systems.

These initiatives represent important steps toward achieving a global standard for assessing the economic and environmental impacts of livestock interventions, ultimately contributing to sustainable development and climate resilience.

Previous and on-going efforts of the involved CGIAR centers

The **ILRI team** has developed an analytical framework to explore the trade-offs and synergies between livestock and ecosystem services. This multifaceted relationship is characterized by interdependencies that include trade-offs, synergies, and bundles. This essay examines these dynamics within Senegal, contributing to the broader discourse on livestock's role in ecosystem service provision.

The interaction between livestock and ecosystem services is best understood through a social-ecological systems lens, which acknowledges the intertwined nature of human activities, such as livestock production, with natural ecosystems. Within this framework, livestock both depends on and impacts various ecosystem services, creating a dynamic relationship that is spatially and temporally variable. Three primary interaction types are identified:

1. **Trade-offs:** Gains in one ecosystem service at the expense of another.
2. **Synergies:** Mutual enhancement of multiple services.
3. **Bundles:** Groups of co-occurring ecosystem services.

A multidimensional approach is crucial to fully capture livestock's economic contributions to ecosystem services. The Total Economic Valuation (TEV) framework offers a robust methodology, encompassing both use values (direct, indirect, and option values) and non-use values (bequest and existence values). This approach extends the analysis beyond market transactions, offering a comprehensive perspective on livestock's economic significance.

In Senegal, agro-pastoralism is integral to the socio-economic structure but operates within a fragile context vulnerable to environmental shocks, including climate variability, health crises, economic fluctuations, political instability, and social challenges. These factors contribute to fluctuations in livestock quantity, quality, and value, exacerbating systemic vulnerabilities.

Key research areas to advance this discourse include:

- Value chain analyses for cattle and small ruminants in agropastoral zones such as the Ferlo region and major livestock markets like Dahra and Toubatoul.
- Comparative studies on pastoral and non-pastoral units to evaluate the effects of organized resource management.
- Analysis of variables such as climate gradients, inequality, seasonality, and the shock-prone environment.

The **Livestock Sector Investment and Policy Toolkit (LSIPT)** offers valuable methodologies to analyze trade-offs and synergies between pastoralism and ecosystem services. Two approaches are suggested:

1. **Dominant Livestock System (DLS):** Focuses on operational and fixed costs to define net income from agricultural and off-farm activities.
2. **Household-level analysis:** Examines physical assets and activity-specific costs.

Future research should emphasize the multifunctionality of livestock at the household level, particularly its roles in poverty alleviation and vulnerability reduction. Collaborative efforts between local experts and international organizations are essential to advancing this research agenda.

The **ICARDA team** has been refining its Analysis Pack for Economics of Land Degradation (APELD), an innovation initially funded by the World Bank for projects in Uzbekistan and Tajikistan and later enhanced under the LCSR Initiative. APELD now represents a key advancement in evaluating the costs and benefits of combating land degradation (LD).

APELD consists of three modules:

1. **Quantifying losses from inaction:** Estimates the quantities and monetary values of ecosystem services (ESS) lost due to insufficient efforts to address LD.
2. **Assessing benefits of action:** Evaluates the potential ESS gains and their monetary values from implementing suitable policy, institutional, and technological interventions.
3. **Calculating investment returns:** Determines the implementation costs of interventions over a planning period (10-20 years) and calculates the total discounted benefits, including benefit-cost ratios, to show monetary returns per dollar invested.

These modules provide disaggregated estimates across combinations of provinces, biomes, and LD classes, as well as aggregate values at regional and national levels. The outputs further distinguish ESS values into use (direct and indirect) and non-use categories.

Despite its strengths, APELD has limitations:

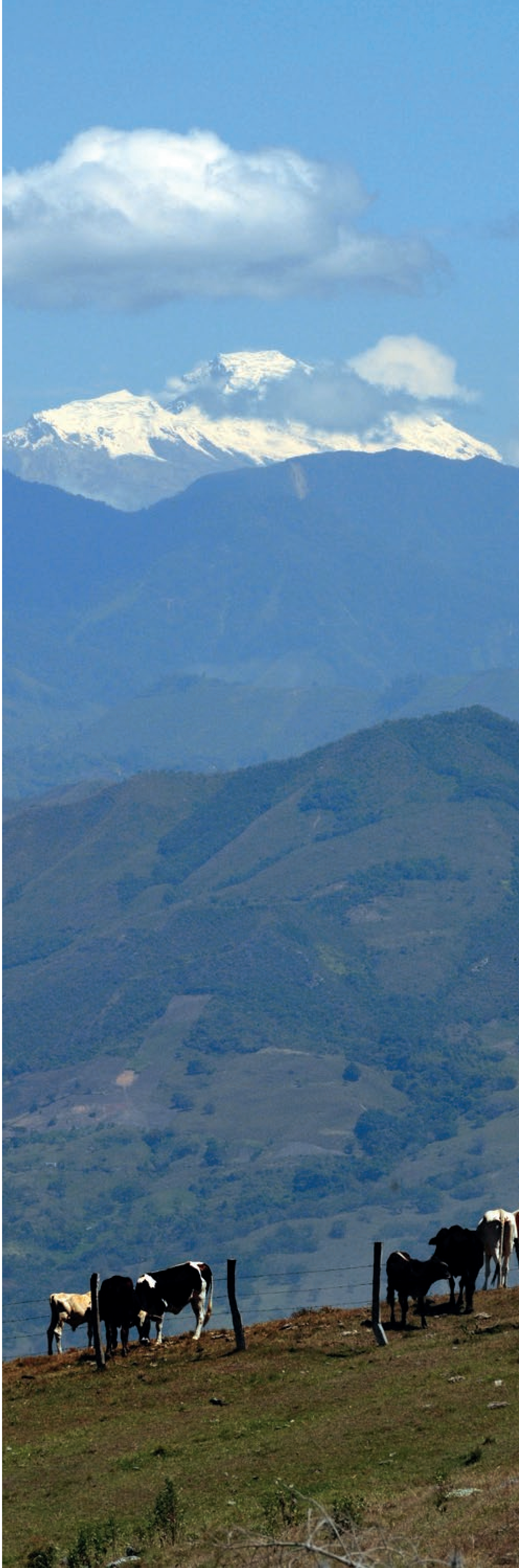
Deterministic nature: It does not account for the stochastic variability of weather and prices.

Emission estimation: Livestock emissions are indirectly estimated from forage carbon content rather than from methane emissions due to enteric fermentation, highlighting areas for future refinement.

The ongoing development of APELD underscores its potential to provide actionable insights for addressing land degradation while advancing the valuation of ecosystem services in diverse contexts.

The **CIAT team** has developed a **methodology for evaluating the economic viability of adopting forage technologies in livestock systems**, focusing on their potential to enhance productivity and sustainability (CIAT, 2017). It highlights the importance of livestock farming in the tropics, where degraded pastures and low productivity hinder economic and environmental outcomes. Improved forage systems, such as silvo-pastoral approaches, are proposed as solutions offering financial and ecological benefits. The methodology combines discounted cash flow analysis, traditional profitability indicators (e.g., NPV, IRR, and B/C ratio), and Monte Carlo simulations to incorporate risk and uncertainty. Key steps include defining objectives and challenges, collecting data, conducting cost-benefit analyses, and modeling cash flows for scenarios with and without technology adoption. Sensitivity and scenario analyses identify critical variables and assess project robustness under varying conditions. The approach provides insights into incremental benefits, guiding decision-making for primary producers. While emphasizing private economic evaluations, the document recommends incorporating social and environmental assessments to capture broader impacts. This structured framework supports the adoption of sustainable forage technologies by demonstrating their profitability and alignment with sustainability goals. This framework has been applied widely in the analysis of forage-based livestock system interventions in the global tropics, i.e., in Latin America and Africa.

In a later step, the CIAT team has made advances in incorporating environmental and social valuation methods into the above-mentioned methodology for economic evaluation and tested this in various case studies in Colombia and Africa.



6. Case studies in Latin America and Africa

Since 2022, the Ecosystem Services Advisory Group has conducted field studies and utilized various tools to perform comprehensive analyses. These analyses estimate the quantities and valuations of ecosystem services and environmental benefits lost due to inaction, as well as those that could be generated through optimal policy, institutional, and technological innovations in livestock systems.

Economic-environmental assessment of silvo-pastoral systems in Colombia: An ecosystem service perspective

This study presents an economic and environmental evaluation of implementing improved pastures and legume-based silvo-pastoral systems (SPS) in the Valle del Cauca region of Colombia. It values the ecosystem service of microclimatic regulation provided by tree shade and the environmental benefit of reduced methane emissions from improved animal diets. The financial analysis estimates potential profitability increases in beef production within SPS, while the environmental evaluation calculates the monetary values of microclimatic regulation and methane emission reductions. Incorporating the value of methane emission reductions into the combined economic-environmental evaluation, results indicate that both SPS enhance profitability indicators and lower the probability of economic loss. Methane emission reductions in SPS are valued at US$6.12 per cattle, and the economic value of microclimatic regulation is estimated at US$2,026 per hectare (Sandoval et al., 2023).

Enhancing dairy cattle sustainability: Impact of silvo-pastoral systems and improved pastures on milk carbon footprint and farm economics in Cauca, Colombia

SPS and improved pastures are effective strategies for transforming dairy systems by boosting cattle productivity, reducing climate change impacts, and increasing farm profitability. This study calculates the carbon footprint (CF) of four small dairy cattle farms in the Cauca Department. It identifies improvements in milk yields, reductions in greenhouse gas (GHG) emission intensities after implementing SPS and improved pastures (IP), and changes in profitability indicators. Baseline milk CFs ranged from 2.4 to 3.2 kg CO_2-eq per kg of fat-and-protein-corrected milk ($kgFPCM^{-1}$). In the improvement scenario, SPS and IP covered more than 48% of the total farm area on average, increasing forage availability and quality, leading to higher animal yields, and reducing milk CF by up to 40% (ranging from 1.4 to 2.7 kg CO_2-eq $kgFPCM^{-1}$). The integral valuation estimates a reduction in milk carbon footprint of 1,813 kg CO_2-eq per animal per year, valued at US$58, and 5.9% per hectare per year of shade coverage valued at US$411 (Gonzalez Quintero et al., 2024).

Carbon footprint reduction in Colombian beef fattening: The role of improved pastures

In Colombia, beef cattle production often suffers from low stocking rates, low animal productivity, and high environmental impacts. This study estimates the climate change impact of 20 beef fattening farms in the Córdoba Department, a key beef-producing region. It identifies potential beef yield improvements and GHG emission mitigations in farms with high-yielding improved pastures and assesses the profitability of implementing such technologies. The 25% of farms with the lowest CF (9.2–12.1 kg CO_2-eq kg live weight $gain^{-1}$) had an average live weight gain (LWG) of 349.2 kg LWG per animal unit per year, exclusively used high-yield improved pastures, and practiced good cattle husbandry and pasture management. The remaining 75% had a CF between 13.5 and 43.4 kg CO_2-eq kg LWG^{-1}, a meat yield of 210 kg LWG AU^{-1} yr^{-1}, low adoption of improved pastures (less than 50% of farm area), and poor management practices. The profitability analysis shows positive effects on economic performance when improved pastures and good management practices are implemented. A reduction in beef carbon footprint of 239 kg CO_2-eq per animal per year was estimated, valued at US$9 (González-Quintero et al., 2023). This study is currently under peer review for publication.

Integral valuation of GHG emission mitigation measures for Kenyan dairy cattle farmers

Ongoing research in Kenya focuses on implementing mitigation measures related to pasture improvements. This study aims to estimate the reduction of GHG emissions and assess their economic and social values. An economic and environmental evaluation will determine the financial viability of the proposed mitigation measures.

The study "Social Valuation of Climate Change Mitigation Strategies in Kenyan Dairy Farms" examines dairy farmers' awareness, perception, and willingness to adopt mitigation strategies. Conducted with 46 farmers from Nandi and Uasin Gishu counties, the study used surveys to assess three key components: knowledge, perception, and willingness to act. These were combined into a social value indicator using Principal Component Analysis.

Farmers demonstrated high awareness of climate change and its anthropogenic causes, with knowledge and perception indicators scoring 0.926 and 0.807, respectively. They recognized the risks of climate change and expressed concern about its impacts on their livelihoods. However, willingness to act scored significantly lower (0.380), primarily due to resource constraints and inadequate preparedness. Only 6.52% felt sufficiently resourced to implement strategies, though all respondents were interested in receiving training. Preferred mitigation strategies included adopting Urochloa hybrids, particularly when combined with herd management (58.7%), and replacing cows with purebred Friesians (47.8%). Manure management was the least favored strategy (8.7%). Gender and age differences influenced the social value indicator, with men and adults assigning higher values.

The findings highlight the urgent need for capacity-building initiatives, including training and financial support, to enable farmers to bridge the gap between awareness and action. By addressing structural barriers and promoting farmer-preferred practices, such as hybrid forages, interventions can enhance adoption rates and contribute to a more climate-resilient dairy sector in Kenya. Aligning mitigation efforts with farmers' preferences and needs ensures effective and sustainable outcomes in addressing climate change challenges.

Uptake of validated technologies and processes to enhance land use planning, management, governance, and restoration practices in mediterranean silvo-pastoral livestock systems

A current study in Tunisia assesses the adoption of innovative tools and technologies designed to improve land use planning, governance, and restoration in Mediterranean SPS. The study evaluates how these validated practices contribute to sustainable livestock production, improved ecosystem management, and enhanced governance frameworks. Specifically, it aims to:

1. Evaluate the effectiveness of promoting native forage legume species in restoring soil health and vegetation cover in degraded systems.
2. Assess productivity changes among pastoral farmers resulting from the use of validated tools and technologies for improved land use and management practices.
3. Analyze the socioeconomic benefits and sustainability of restoration practices applied by pastoralists, improving livestock productivity and supporting ecosystem services.
4. Examine gender and community participation in decision-making processes and their influence on the success of land management practices.

Application of APELD in Central and West Asia and North Africa (CWANA)

ICARDA scientists, in collaboration with experts from the World Bank, the University of California, and national CWANA partners, utilized the Approach for Participatory Ecosystem Land Degradation (APELD) to generate detailed analyses on the costs of land degradation (LD), benefits of implementing appropriate interventions, and returns on investment at national and landscape scales in Tajikistan and Uzbekistan (Yigezu et al., 2020; Yigezu et al., 2023a). Some results for severe LD classes in Uzbekistan were included in the World Bank's recent Country Climate and Development Report for Uzbekistan. The findings revealed that due to inaction in hotspot areas, Uzbekistan annually loses at least 1.28 million tons of potential crop production (3.38% of total national production), 9,500 tons of forest and shrub biomass stock (0.04%), and 119,000 tons of forage from natural pastures (6.8%). Additionally, the country loses at least 3.56 billion cubic meters of water (39.51% of total supply) and 658,000 tons of soil annually due to erosion. These factors contribute to the release of at least 470,000 tons of CO_2 into the atmosphere, representing 0.39% of total national emissions in CO_2 equivalents.

The multidisciplinary team recommended technological, policy, and institutional changes to help combat land degradation and promote sustainable practices. Implementing these changes could result in producing an additional 877,000 tons of food and non-food crops, 1.01 million tons of forest and shrub biomass, and 97,000 tons of forage—representing increases of 2.32%, 4.73%, and 5.52%, respectively. The interventions would also prevent the loss of 1.78 billion cubic meters of water (21.77% of total supply) and reduce soil erosion by 358,000 tons (54% of current erosion), thereby reducing carbon emissions.

The monetary value of inaction in 2021 was estimated at least at $2.83 billion, equivalent to 4.59% of GDP. The major economic costs are related to water loss ($1.10 billion or 1.79% of GDP) and yield loss in croplands ($1.10 billion or 1.78% of GDP). Other costs include biomass loss in natural pastures, health problems induced by land degradation, and infrastructure damage due to landslides and extreme weather.

The expected gains from implementing the recommended changes in the priority areas have a total annual value of $1.49 billion, equivalent to 2.42% of GDP. Over a 10-year planning horizon, considering climate change scenarios and a discount rate of 12.7%, the total benefits are estimated at $8.86 billion. The cost of implementation is estimated at $560 million over 10 years, leading to a benefit-cost ratio of 15.81.

The policy implication is clear: the costs of inaction are significantly higher than the costs of action. Left unchecked, degradation of natural capital is expected to increase, especially with climate change. Therefore, coordinated efforts are needed from the government of Uzbekistan, development partners, civil society, and citizens to invest in preventing further degradation.

APELD application in Tunisia

An application of the first module of APELD in Tunisia highlights the urgency of addressing land degradation, revealing that inaction costs the country about $2.17 billion (4.65% of GDP) in lost ecosystem services annually. Croplands, irrigation water, and rangelands are the top three sources of loss, accounting for 53.98%, 28.19%, and 12.09% of the total cost, respectively. The results have spurred discussions for potential large-scale projects to combat land degradation in CWANA through policy, institutional, and technological innovations. A joint effort among ten national research institutions, Tunisian governmental agricultural bodies, and ICARDA aims to secure funding from organizations like the World Bank, the Global Environmental Facility, and the German Technical Cooperation (GTZ), offering hope for sustainable solutions to the national threat of land degradation in Tunisia.

In Table 3 we present the principal results of our field implementations in Colombia

Table 3. Implementations in Colombia

Reference	Implementation	Country	ESS and EB	Ecological value	Economic value US$
Sandoval et al. (2023)	Silvo-pastoral system Improved pastures Beef production	Colombia	Methane emissions reduction	144 kg CO_2eq/animal/year	6
			Microclimatic regulation	Shade coverage 60.4%/ha/year	2,026
Gonzalez Quintero et al. (2024)	Silvo-pastoral system Improved pastures Dairy production	Colombia	Milk carbon footprint reduction	1,813 kg CO_2eq/animal/year	58
			Microclimatic regulation	Shade coverage 5.9%/ha/year	411
González-Quintero et al. (2023)	Improved pastures Good cattle husbandry Pasture management practices Beef production	Colombia	Beef carbon footprint reduction	239 kg CO_2eq/animal/year	9

7. Carbon storage and sequestration and GHG emissions reduction: Livestock farming in Latin America

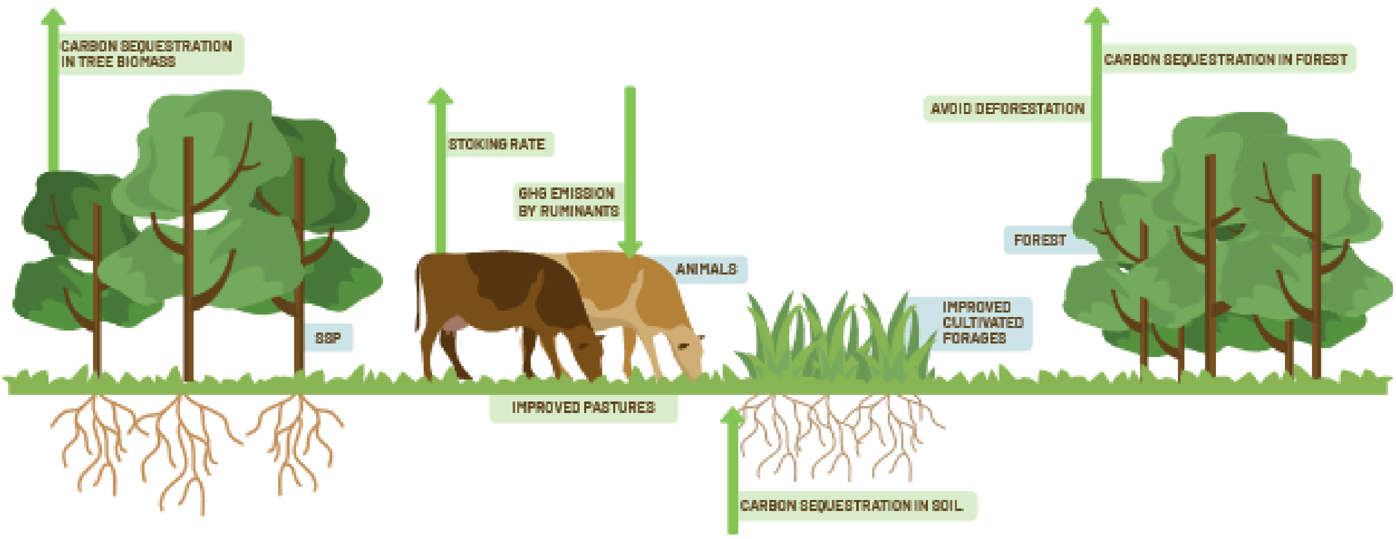


Figure 4. Improving the carbon balance in livestock systems

Implementing technologies such as improved pastures and SPS can significantly enhance the carbon balance in livestock systems. These technologies improve carbon storage and sequestration in forage biomass, trees, and soil while simultaneously reducing methane emissions through dietary improvements for livestock. Moreover, they optimize land use by increasing system carrying capacity, reducing the demand for additional space, and preventing deforestation (see Figure 4).

We are currently conducting a review of studies on climate change mitigation strategies in livestock systems across Latin America. The focus is on improving the carbon balance through enhanced carbon storage and sequestration as an ecosystem service, alongside the environmental benefit of reducing GHG emissions. Key mitigation technologies implemented in the region's livestock systems include improved pastures, SPS, living fences, protein banks, and sustainable intensification practices. Overall, the implementation of these technologies demonstrates positive outcomes, significantly enhancing carbon storage and sequestration while reducing GHG emissions (see Tables 4 and 5).

Table 4. Improving carbon storage and sequestration in livestock systems

Description of ESS	Reference	Implementation	Control (no action)	Results	Location
Carbon sequestration is an ecosystem service that involves capturing and retaining greenhouse gases within ecosystems, thereby preventing their release into the atmosphere as a strategy to mitigate climate change. Two primary forms of carbon sequestration are the storage and capture of carbon in tree biomass and soil	Nahed-Toral et al. (2013)	Pasture with living fence, scattered trees, protein bank, and *C. plectostachyus*	Pasture with *C. plectostachyus* as a monoculture	Increased carbon sequestration in 0.78 t C ha^{-1}	Mexico - Chiapas
	Nahed-Toral et al. (2013)	SPS with dispersed trees	Open pasturelands	Increased soil carbon stock of 85.78 Mg ha^{-1}	Latin America
	Montagnini et al. (2013)	SPS with dispersed trees	Open pasturelands	Increased tree carbon of 29.09 Mg ha^{-1}	Latin America
	Montagnini et al. (2013)	Forage banks	Degraded pastures	Increased soil carbon stock of 20 Mg ha^{-1}	Costa Rica
	Montagnini et al. (2013)	Improved pastures with high tree density	Degraded pastures	Increased tree carbon stock of 30.5 Mg ha^{-1}	Costa Rica
	Aryal et al. (2022)	Living fences	Open pasturelands	Increased soil carbon stock of 46.02 Mg ha^{-1}	México
	Parra et al. (2023)	SPS	Degraded pastures of *B. brizantha* (DP)	Increased carbon sequestration of 4.18 t C ha^{-1}	Colombia - Meta
	Lombo et al. (2023)	SPS with dispersed trees	Open pasturelands	Increased tree carbon stock of 26.3 Mg ha^{-1}	Colombia - Caribbean Region

Table 5. Reducing GHG emissions from livestock systems

Description of ESS	Reference	Implementation	Control (no action)	Results	Location
Carbon sequestration is an ecosystem service that involves capturing and retaining greenhouse gases within ecosystems, thereby preventing their release into the atmosphere as a strategy to mitigate climate change. Two primary forms of carbon sequestration are the storage and capture of carbon in tree biomass and soil	Montagnini et al. (2013)	*B. brizantha* + *Leucaena leucocephala*	*Hyparrhenia rufa* (Native pasture)	Reduced CH_4 emissions of 0.206 kg animal^{-1} day^{-1}	Latin America
	Montagnini et al. (2013)	Intensive and improved system	Extensive system	Reduced emission of 2.5 kg CO_2eq kg carcass^{-1} year^{-1}	Brazil
	Gaviria-Uribe et al. (2020)	Improved pastures and SPS	Hay of *Dichantium aristatum* used for comparison as one of the most common feed resources in the region	Reduced CH_4 emissions of 0.33 g CH_4g of LW gain^{-1}	Colombia - Valle del Cauca
	Gaviria-Uribe et al. (2020)	Rumen manipulation: Electron receptors (i.e. nitrate)	No dietary and rumen manipulation	Reduced CH_4 emissions of 20%	Latin América, Brazil, Mexico, Colombia, Costa Rica, Argentina, Peru, Chile, Uruguay
	Sandoval et al. (2023)	SPS	Grass monoculture	Reduced emissions of 0.63g CO_2eq. g liveweight gain^{-1}	Colombia - Valle del Cauca
	González-Quintero et al. (2023)	Improved pastures and Good Cattle Management	Natural pastures	Reduced beef carbon footprint of 6.3 kgCO_2eq kg liveweight gain^{-1}	Colombia - Córdoba
	Sarabia-Salgado et al. (2023)	SPS with woody legumes (*Leucaena leucocephala*) that is associated with stargrass (*Cynodon nlemfuensis*) – dry season	Monoculture system with stargrass (*Cynodon nlemfuensis*) – dry season	Reduced CH_4 emissions of 0.0.3 kg CH_4 AU^{-1} year^{-1}	México
	Sarabia-Salgado et al. (2023)	SPS with woody legumes (*Leucaena leucocephala*) that is associated with stargrass (*Cynodon nlemfuensis*) – rainy season	Monoculture system with stargrass (*Cynodon nlemfuensis*) – rainy season	Reduced N_2O of 0.04% for feces and 0.35% in urine	México
	González-Quintero et al. (2023)	SPS and improved pastures	Open pasturelands	Reduced milk carbon footprint of 0.675 kg CO_2eq kgFPCM^{-1}	Colombia - Cauca

8. Publications

The outcomes of our work within the Ecosystem Services Advisory Group have been disseminated through various publications and presented at multiple conferences (see Tables 6 and 7).

Table 6. Publications by the Ecosystem Services Advisory Group

Title	Year	Journal/Data base	Type	DOI/Handle
Ecosystem services and environmental benefits in livestock systems: Definition of terms, and valuation methods	2023	CGSpace	Policy Brief	https://hdl.handle.net/10568/135852
Economic-environmental assessment of silvo-pastoral systems in Colombia: An ecosystem service perspective	2023	Heliyon	Paper	https://doi.org/10.1016/j.heliyon.2023.e19082
A case study on enhancing dairy cattle sustainability: The impact of silvopastoral systems and improved pastures on milk carbon footprint and farm economics in Cauca department, Colombia	2024	Agroforestry systems	Paper	https://doi.org/10.1007/s10457-024-01070-y
Carbon footprint reduction in Colombian beef fattening: The role of improved pastures	2024*	Heliyon	Paper	NA*

**This paper has surpassed the peer review stage and is in the process of publication.*

Table 7. Conference participation of the Ecosystem Services Advisory Group

Conference	Title	Date	Place	Type	Handle
Tropentag 2024	Integral valuation of ecosystem services and environmental benefits in livestock farming	September 2024	Vienna-Austria	Poster	https://hdl.handle.net/10568/155114
International Research Symposium on Agricultural Greenhouse Gas Mitigation: From Research to Implementation	Economic and social valuation of climate change mitigation strategies in livestock systems	October 2024	Berlin-Germany	Oral presentation	https://hdl.handle.net/10568/163407
VII International Agri-Development Convention	Servicios ecosistémicos y beneficios ambientales en sistemas ganaderos, una aproximación desde la valoración integral	October 2024	Varadero-Cuba	Oral presentation	https://hdl.handle.net/10568/158476
Global Bioeconomy Summit 2024	Integral valuation of ecosystem services and environmental benefits: Economic and environmental assessment	October 2024	Nairobi-Kenya	Oral presentation	https://hdl.handle.net/10568/163142
III International Research Symposium on Agribusiness and Agrarian Economics	Valoración integral de servicios ecosistémicos y beneficios ambientales en sistemas de producción ganaderos	October 2024	Medellín-Colombia	Oral presentation	Link in process
V Congress of Agricultural Economics and Agribusiness	Strategies of integral valuation of ecosystem services and environmental benefits in livestock farming	October 2024	San Jose-Costa Rica	Oral presentation	https://hdl.handle.net/10568/163496
XII International Rangeland Congress	Ecosystem services and environmental benefits in livestock farming: integral valuation and assessment strategies	June 2025	Adelaie-Australia	Oral presentation	To be presented in 2025
XII International Rangeland Congress	Trade-offs and synergies between pastoral activities and ecosystem services: valuation of carbon emissions mitigation strategies in livestock systems	June 2025	Adelaie-Australia	Oral presentation	To be presented in 2025

9. Next steps

In 2025, we aim to advance and validate our integrated valuation strategy for ecosystem services and environmental benefits. To achieve this, we propose the following actions:

Develop comprehensive economic and environmental evaluations: We will continue with ongoing field implementations in Kenya and Tunisia, with results expected in 2025. Additionally, we plan to initiate similar studies in Colombia and Senegal.

Expand research on ecosystem services and environmental benefits: Building on our work in Latin America, we will broaden the scope to explore additional ecosystem services beyond carbon storage, sequestration, and GHG emission reduction. A similar effort will be undertaken in Africa to identify and evaluate these services.

Integrate findings into CGIAR Science Programs: We will consolidate our work on ecosystem services and environmental benefits in livestock systems within the framework of the new CGIAR Science Program on Sustainable Animal and Aquatic Foods (SAAF), ensuring alignment with broader strategic goals.

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