Instrument Design and Economic Modeling of Pathways to Reduce Biological and Land Use Emissions from Cattle Farms in connection with the ETS in Colombia

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ACRONYMS

MADR: Ministry for Agriculture and Rural Development (Ministerio de Agricultura y Desarrollo Rural)

UPRA: Agency for Rural Planning (Unidad de Planificación Rural Agropecuaria)

CIAT: International Center for Tropical Agriculture

AFOLU: Agriculture, forestry, and other land uses

INGEI: National Greenhouse Gas Inventory (Inventario Nacional de Gases de Efecto Invernadero)

IDEAM: Institute of Hydrology, Meteorology and Environmental Studies (Instituto de Hidrología, Meteorología y Estudios Ambientales)

INDC: Intended National Determined Contribution

RUV: National Foot and Mouth Disease Vaccination Registry (Registro Único de Vacunación)

FEDEGAN: National Association of Cattle Farmers (Federación Nacional de Ganaderos)

PES: Payments for Ecosystem Services

MRV: Monitoring, Reporting and Verification

FMD: Livestock's Foot and Mouth Disease

DANE: National Administrative Department of Statistics (Departamento Administrativo Nacional de Estadísticas)

AU: Animal Unit or head of cattle

ETS: Emissions Trading System

PES: Payments for Ecosystem Services

LUC: Land Use Change

IPCC: Intergovernmental Panel on Climate Change

1. Introduction

In 2018, Colombia's congress passed Law 1931 mandating the creation of an ETS, a market-based, cost-efficient, policy instrument that complements the country's set of low-carbon development policies, including the likes of a carbon tax created in the 2016 national tax reform. All with the goal to meet its Intended Nationally Determined Contribution: a 20% reduction in CO_2e emissions compared to its business-as-usual projection for 2030. In Colombia, Biological emissions from bovine livestock contribute 14.8% of all emissions in the country (INGEI, 2016) and 36% of national emissions come from land use change (LUC), 53% of which (19% of the country's total), correspond to conversions of forests to pastures. An uncertain, yet meaningful, amount of all emissions from the conversion of forests to pastures can in turn be assigned to the cattle sector since the dominating post-deforestation land use are pastures used for cattle rearing (Armenteras et al., 2013). Additionally, out of Colombia's total surface area (114 million ha), 27.2% (31 million ha) is occupied by rangelands and pastures (UPRA, 2018), 27.9% of which are unmanaged (DANE, 2014), making policies aimed at reducing pastures a planning priority of relevant government agencies to tackle climate change, food security and agrarian development (DNP, 2018), especially after the UPRA defined limits to the agricultural frontier in 2018 following law 1776 of 2016.

Improving the emissions intensity of milk and meat production, in conjunction with reducing land use emissions from cattle farms, presents a large mitigation opportunity with the potential to meet 83% of the country's NDC (Tapasco et al., 2019). Therefore, the prospect of Colombia meeting its NDC will improve if the ETS is instrumental in driving a transition to a less emissions intensive production of milk and meat, as well as a reduction of land use emissions. Colombia's cattle sector, with an average stocking rate of only 0.86 Animal Units per hectare (AU/ha) (FEDEGAN, 2019), can improve its stocking rate by up to 550% compared to best practices observed in other tropical jurisdictions (Calle et al., 2013). Such improvement could create a land sparing effect if effectively guided by economic incentives or regulation for farmers to convert portions of their pastures to alternative land uses. Potential land uses for the spared land, such as forest restoration, can result in a net reduction of greenhouse gas (GHG) emissions from the cattle sector, while providing a range of environmental and social co-benefits. At the same time, net nitrous oxide (N_2O) and methane (CH_4) emissions from cattle's manure management and enteric fermentation could decline at "no-cost" to farmers if the emissions intensity per kg of beef and milk produced improves, while the stocking rate or the farming area falls (Kerr et al., 2019).

Currently, Law 1931 of 2018, presents a possibility to design an ad-hoc system for Colombia's ETS to be instrumental in driving a transition to a low-emissions cattle sector. The Environmental Defense Fund, one of the participating entities in the design of the ETS, is currently exploring the possibility of setting a point of regulation in slaughterhouses, which would surrender allowances for the emissions associated with the age of the incoming cattle, creating an incentive for farmers to reduce biological emissions downstream in the cattle supply chain. However, two challenges emerge with this approach. First, monitoring data on cattle age at slaughterhouses is difficult because of the high informality downstream in the Colombian cattle supply chain. The problem of informality in cattle slaughters worsened in 2016 when 284 formally registered slaughterhouses were closed for not complying with strict sanitary requirements, bringing the number of authorized facilities in the country down from 791 in July of 2016 to 507 in July of 2018. This decrease represented a 36% reduction in the number of facilities, while the number of total animals slaughtered in the country grew, suggesting that slaughtering quickly leaked to illegal facilities (INVIMA, 2018). Second, this approach would not address land use emissions, which can be over an order of magnitude higher than biological emissions when cattle is reared in deforested lands or in lands with high restoration potential (Cederberg et al., 2011). As an alternative to setting a point of regulation in slaughterhouses, this paper elaborates on four possible pathways to regulate biological emissions and land use change emissions form the sector. For biological emissions (figure 1), a biological emissions standard is considered as well as regulation of biological emissions under the ETS' cap. For land use change emissions (figure 2), two pathways are considered: (1) creating a mandatory regulation for cattle farmers to reduce increase forest cover in their properties and (2) a program to support cattle farmers to develop "carbon farming" projects in a portion of their properties' pastures.

Figure 1.

Biological Emissions Mitigation			
Pathway	**Advantages**	**Disadvantages**	**Similar Policy Instruments**
Biological Emissions Standards	Biological emissions factors can be readily used as measurement unit	Absolute emissions reduction uncertainty	Corporate Average Fuel Economy (CAFE) standards
Biological Emissions regulation under the ETS cap	Certainty of emissions reduction Trading of allowances lets the sector find the most cost-effective way to reduce emissions	Only as reliable as the data on animal numbers, which currently can only be modelled	Regulation for the livestock sector under New Zealand's Emissions Trading System

Figure 2.

Land Use Change Emissions			
Pathway	**Advantages**	**Disadvantages**	**Similar Policy Instruments**
Optional Spared Land/Reforestation	Market-based policy may increase buy-in from the cattle sector	Uncertainty of emissions reductions Dependability on uncertain carbon prices	Australia's Carbon Farming Initiative
Mandatory Spared Land/Reforestation Standards	Certainty of emissions reduction	Risk of political unfeasibility Risk of poor enforceability	Brazil's Forest Code

In sum, this paper focuses on elements of the design, and emissions and benefits modelling of policy instruments corresponding to each pathway. By modeling the economic benefit and the emissions mitigation potential of a proof-of-concept jurisdictional pilot program (hereafter called "the program"), answers to the following questions are provided: (1) for the proposed land use change mitigation pathways, how much carbon can be sequestered in the case study jurisdiction? (2) What can be the mitigation potential of the proposed pathways to regulate biological emissions? (3) What is the present value of the benefits from emissions mitigation under different carbon prices? The answers to these questions will provide the Environmental Defense Fund with (1) a sense of the magnitude of the emissions mitigation potential of such pathways, helping inform decisions on how to make the ETS instrumental in driving a transition towards a net reduction in emissions from the cattle sector, and (2) the potential economic benefits from greenhouse gas emissions reductions, helping inform decisions on how to finance the transition towards a low-emissions cattle sector.

2. Elements of the Program: Pathways for Biological and LUC Emissions Mitigation

The proposed program presents pathways to engage regional cattle associations and/or individual landowners in a combination of mandatory and voluntary emissions mitigation actions. At the center of the program are a set of targets, each corresponding to one of the pathways for land use emissions mitigation or biological emission mitigation. The proposed points of regulation for a biological emissions standard (section 3.1.) are the cattle associations that make up FEDEGAN; jurisdictional entities that cover the entirety of cattle ranching farms within the legal agricultural frontier. For the case of land use change mitigation, the program proposes mechanisms of interaction at the farm level (section 3.2.).

2.1. Emission Factors as Mandatory Emissions Intensity Standards

2.1.1. Unit of measurement

Emissions factors (equation 1) for methane and nitrous oxide from manure management and enteric fermentation, expressed in kgs of CH_4 or N_2O AU^{-1} yr^{-1}, can serve as the metric for a mandatory standard for biological emissions. An improvement in emission factors is equivalent to an improvement in the emissions intensity of one AU per year. Such improvement, do not necessarily represent absolute emissions reductions, in fact, they might lead to an increment in absolute emissions if such improvements lead to a shorter time to slaughter, leading to higher rotation, and a higher activity data (total AU per year). Exogenous factors, such as a growth in consumption or eradication of Foot and Mouth disease[1] can also increase activity data and lead to higher absolute biological emissions even with strong improvements in emission factors.

$$emission\ factor\ (EF) * activity\ data = absolute\ biological\ emissions \quad (1)$$

$Where\ (following\ IPCC\ methodologies)$:

$$EF = \frac{GE * \left(\frac{Y_m}{100}\right) * t}{55.65}$$

And:

$GE\ is\ the$ gross energy intake, MJ $AU^{-1}t^{-1}$;

$\frac{Y_m}{100}$ $is\ the$ methane conversion factor, percent of gross energy in feed converted to methane;

55.65 $is\ a\ factor, in$ MJ/kg CH4, for the energy content of methane

And:

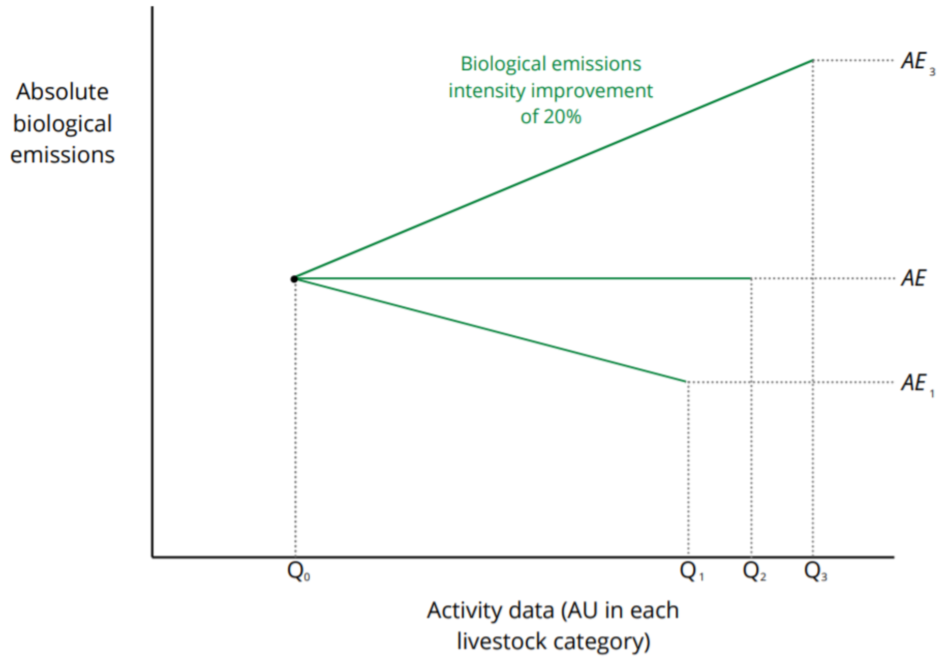
$Activity\ data = AU\ in\ each\ livestock\ category$

Emission factors, in this context, are a measure of how much of the gross energy intake ($MJ * AU^{-1} * t^{-1}$) is converted by an ruminants digestive system to methane or nitrous oxide emissions for a given period of time a period of time (t). To improve emission factors, farmers can pursue management actions, such as pasture improvements or genetic selection, decreasing emissions and augmenting protein yield per unit of feed.

[1] Exports of Colombian meat, milk and live cattle depends on the status of Foot and Mouth Disease certification by the World Organization for Animal Health. Different waves of FMD have resulted result in the country pausing all exports and resuming them only after certification is reissued.

It is important to note that (by definition of equation 1) improvements in biological emissions intensity would only lead to declines in absolute biological emissions if activity data remains constant or declines. Under such scenario, any improvements in emissions factors would necessarily lead to reductions of absolute biological emissions. However, this is unlikely given historic growth trends on the national livestock inventory, meaning that animal numbers might grow in a larger magnitude than the decline in emission factors, resulting in an increase in absolute biological emissions. Therefore, a limitation of an emissions standard would be that it could translate in a growth of the cattle sector over time and the absence of an absolute cap to emissions inherently would create uncertainty around the mitigation outcome of the program. In other words, there would be a risk that a marginal improvement in biological emissions factors smaller to a marginal increment in activity data results in higher absolute emissions (Graph 1).

Graph 1.



Where:

AE_1 Represents a growth in animal numbers smaller than 20% as compared to 2020 levels

AE_2 Represents a growth in animal numbers of 20% as compared to 2020 levels

AE_3 Represents a growth in animal numbers larger than 20% as compared to 2020 levels

2.1.2. Monitoring and Verification.

An additional benefit of using emission factors as the regulation standards is that monitoring of emissions factors is done regularly in Colombia as part of the process of updating process of IPCC emission factors[2] used to report emissions from cattle in the National Greenhouse Gases Inventory (INGEI). Furthermore, the entities leading this effort, such as IDEAM and CIAT, would not have a conflict of interest if a liability or reward is given to jurisdictions for their emissions factors' performance. Currently, jurisdiction specific emission factors (classified as Tier III per IPCC methodologies,

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[2] Tier 3 emission factors are more accurate since they are developed using jurisdiction-specific data. They follow a peer-review and IPCC validation process before they can be used in countries' GHG inventories. Colombia used in its latest inventory the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Chapter 10, sections 10.4 and 10.5).

which includes a peer review process) are only available for enteric fermentation, which is the largest single source of biological emissions. For nitrous oxide and methane from manure management and patches on pastures, default emission factors (Tier I per IPCC methodologies) are used, which prevents setting emissions standards for these emissions. Nonetheless, jurisdiction-specific emission factors for emissions from manure management are currently under development and may become available soon, according to the team leading this research at IDEAM and CIAT.

Following this approach, an incentive is created for jurisdictions to improve the emissions intensity per animal unit by placing a liability on a jurisdiction if its biological emissions factor fails to achieve a target determined in the regulation. Upon exceeding of the target, a jurisdiction would be penalized by a specified monetary amount for every unit (in kgs of CO_2e AU^{-1} yr^{-1}) that it surpasses the target at a given period. To determine the total monetary liability, the number of units over the target is multiplied by the corresponding penalty per unit, and the result multiplied by an activity coefficient that represents the contribution of the jurisdiction to the overall national cattle inventory. There are multiple ways to model activity data to create such coefficient. A possible approach could be dividing data on animal units in each jurisdiction (from a time series previous to the regulation, when the incentive to manipulate that figure is created[3]) by the total number of animal units in the country. A theoretical effect of such regulation would be a shifting of cattle inventories from jurisdictions with higher emissions factors to those with lower emissions factors. This would create a competitive advantage for jurisdictions with a lower cost of abatement or those with inherent lower emission factors due to cooler temperatures or lower precipitation[4]. Assuming that over the duration of the program the proportion of animal units in each jurisdiction to the animal units in the national

[3] A coefficient is advised in lieu of a figure of animal numbers since it is ultimately an estimate of each jurisdictions contribution and the coefficient captures better the notion that there is an inherent estimation error than using a specific figure of animal units as activity data.
[4] The effect of temperature and precipitation on biological emission factors is described in section 4

inventory would change, there would be a need for periodic reassessment of the activity coefficient. This assessment would need to be performed by an impartial entity, such as the National Statistics Department (DANE) or contracted to a non-profit organization such as CIAT. Furthermore, the cost of the penalty could be transferred from the jurisdictions, which have limited agency to spur mitigation actions at the farm level, to cattle farmers via the parafiscals[5]. This cost-efficient strategy could ultimately drive farmers to pursue the management actions necessary to reduce emissions when the marginal cost of abatement is lower than the cost of the penalty.

2.2. Integration of the Cattle Sector Under the ETS' Cap

Similar to the emissions intensity standard pathway, emission factors provide a reliable measure of emissions intensity, which multiplied by an estimate for activity data, allows to calculate the allowances to be surrendered by a chosen point of regulation. The true question, therefore, is how to define a point of regulation for which enough data is available to estimate activity data with meaningful accuracy and precision. Because EDF is preliminarily exploring a point of regulation in slaughterhouses, a different point of regulation is proposed, providing an alternative approach if the latter is ultimately deemed inconvenient. The proposed points of regulation for this pathway are, alike those for an emissions intensity standard, the jurisdictional entities that comprise FEDEGAN.

Pursuing this approach would necessitate relatively more robust estimates of activity data than an emissions intensity standard since allowances traded between the ETS and the sector would need to be fungible[6]. This is different to an emissions intensity standard, which could operate independently from the ETS, meaning that the penalty paid by each jurisdiction for surpassing the standard does not necessarily need to be equivalent to the cost of per unit of emissions in the ETS. Different to the

[5] A form of tax paid by farmers and collected by processors for every kg of meat or liter of milk sold.

[6] Meaning that if an allowance is sold by the sector into the ETS, it must closely represent the true amount of emissions than in other sectors.

standard approach, the activity data should provide more than an image of the proportional contribution of a jurisdiction to the whole sector's activity. Under the ETS integration approach, activity data must be a figure that (if multiplied by IPCC emission factors which are expressed in terms of AU) estimates the number of animal units per age group in a jurisdiction at a given time.

One benefit of placing a point of regulation on jurisdictional entities is that it bypasses the high informality of the cattle supply chain, particularly for meat products[7]. A downside is that a point of regulation in jurisdictional entities can create more friction for passing of price signals to farmers or consumers, who are ultimately making production or consumption that affect emissions. In other words, the relatively low agency of jurisdictional entities to oblige farmers to change their management actions to reduce emissions could be a problem. However, given that jurisdictional entities already collect parafiscals from farmers, it could be possible to use this mechanism in a cost-effective way to pass price signals from the cost of polluting to the supply chain of milk and meat.

2.3. A "Forest Code" for the Cattle Sector in Colombia.

A key aspect of the program is the creation of a mechanism to link improvements in emissions intensity to a land sparing effect in farms with potential for reforestation. Theoretically, in grazing cattle rearing systems, an improvement in emissions intensity can translate into a higher stocking rate because there is an overlap of the management actions that need to happen for both outcomes to occur. Improved emissions intensity could result in a land sparing effect if animal units remain constant, decline, or grow to a limited extent, and there is an accompanying regulation or economic incentive in place that leads farmers to pursue a different land use in a portion of the farm. A regulation could take the form of a mandatory minimum percentage of forest cover in each farm, in a similar fashion to Brazil's Forest Code;

[7] The milk supply chain has a stronger formality. There is a relatively small number of dairy companies in Colombia and they are mostly large highly-formal corporations. The largest ten companies in revenue have around 80% of the market (Asoleche, 2017)

while an economic incentive could be created by providing a system for farmers to "farm for carbon" in the spared land. Naturally, assuming AUs will not decrease in the future[8], land sparing can only happen in a farm when the stocking rate increases due to a fall in the pasture area.

2.4. A Voluntary Opt-in Program for Carbon Farming

In the presence of an economic incentive, a profit maximizing farmer could spare some pastures (or the entire property) to pursue "carbon farming", if by increasing the farm's stocking rate, a combination of additional revenue (compared to business-as-usual management) from cattle ranching and carbon offsets can be achieved. If the biological emissions intensity in a farm improves through either of the proposed pathways, farmers can improve their stocking rate while reducing the pasture area and maintaining or increasing the output from farms. Hence, farmers can be motivated to improve the stocking rate of farms and spare land for "carbon farming" if capacity building is provided at no cost, irrespectively of the magnitude of the additional income from carbon offsets.

Similar programs in Australia have resulted in poor adoption and the barriers have included lack of information, uncertainty, and costs (Kragt et al., 2017) [9]. In Colombia, presumably, other factors that could affect adoption are land speculation, informal land tenure or cultural attachment to cattle ranching. The proposed pathway is to provide programmatic support in the form of capacity building and financing of capital costs to small and medium holder farmers in jurisdictions with high LUC and biological emissions mitigation potential. The proposed program would emulate several components of other jurisdictional sustainable livestock experiences in

[8] In the case of Colombia, animal numbers, and production and consumption of milk and beef has increased every year since 2005 (FEDEGAN, 2019), which suggests the possibility that the trend will hold for some time into the future. However, the penetration of plant-based alternatives to dairy and beef may also reduce consumption in the future. USDA figures show that in the United States milk consumption has declined from around 21 gallons per year per capita in 2010 to around 17 in 2020.

[9] Fleming et al., 2019 suggest that framing carbon farming around the creation of co-benefits rather than the economic benefits exclusively can increase mitigation actions by farmers.

Colombia, such as the Initiative for Sustainable Forest Landscapes by the World Bank's BioCarbon Fund in the Orinoquia Region and the silvopastoral projects developed by CIPAV, The Nature Conservancy and other stakeholders. If this pathway were pursued, partnering directly with these organizations on their ongoing initiatives would be advisable. EDF could help scale up these programs to cover more farmers, improve more livelihoods and reduce more emissions on two fronts. First, by leveraging the newly created Emergent platform to provide a source of financing to farmers and, second, by suggesting provisions that the purchase of offsets from firms in the ETS must include at least a proportion of offsets from the cattle sector.

Reviews of World Bank's Regional Integrated Silvopastoral Ecosystem Management Project can help provide an insight of the potential adoption rates of this kind of programs in Colombia, and ultimately, the effect they can have on emissions reductions. For example, Pagiola et al (2016), explores the effect of PES on forest permanence after the project (and associated PES), led by the World Bank in Quindío, Colombia, ended in 2008, finding that: (1) PES had a positive and significant ($p<0.001$) impact on management and land use, with PES recipients substantially increasing the proportion of farm area devoted to improved pastures and forest cover, and (2) that 9 percent of PES recipients and 14 percent of control households changed more than half of their farm area after the payments ended.

That said, the economic case for pursuing land use emission management actions would improve if protocols are developed to issue marketable carbon offsets from soil carbon sequestration. Currently, researchers at Duke University, led by Dr. Brian Murray, are working to develop a protocol to account for these emissions reductions. This is particularly important since carbon stored in soils can be around 20 percent of that stored in above-ground biomass (Silver et al., 2001).

3. Case Study: Modelling of a Potential Pilot

By modelling a case study for a jurisdiction with high potential to reduce emissions and improve livestock stocking rates, EDF will gain insights on the economic value and climate change mitigation potential of the proposed pathways. The objective of this model is to provide estimates of the GHG mitigation potential and present value of associated carbon offsets of a jurisdictional program to reduce land use and biological emissions from the Colombian cattle sector.

Cattle farms at the edge of the agricultural frontier have a larger mitigation potential for land use change emissions compared to other farms. Restoration of secondary forests at the edge of pastures adjacent to primary forest, that exist as a result of recent deforestation, can display carbon accumulation rates higher than other pastures further within the agricultural frontier and with longer periods of time will elapsed between the deforestation event and the beginning of forest succession (Elias et al., 2019). The proximity to seed banks (Barot et al., 1999), soil fertility in recently deforested soils compared to more eroded cattle pastures (Uhl, 1997) and the elimination of the edge effect (Lan Qie et al. 2017) are factors that explain the potential of pastures at the edge of the agricultural frontier to accumulate carbon more rapidly in the form of above and below ground biomass.

Additionally, in farms in the Amazon region, where air temperature is consistently around 25°C (IDEAM, 2019), a mitigation action to reduce biological emissions from cattle, such as improved manure management, will have a larger effect on GHG emissions mitigation compared to an equivalent action in farms in regions with cooler temperature, particularly in the Colombian Andean mountain range. This is because some emission factors, such as those of methane and nitrous oxide from manure management in warmer regions, are the double of those of cooler regions (IPCC, 2006). Additionally, nitrous oxide emissions increase considerably in regions with higher precipitation (Griffis et al., 2017), such as the Amazonian region in Colombia.

In addition, there are co-benefits of pursuing forest restoration in pastures adjacent to large expanses of tropical forest. First, a buffer is created, playing a double role of reforesting areas with large forest-growth potential, while potentially avoiding further deforestation of forests standing outside the agricultural frontier (Wang et al., 2020)[10]. Second, it creates additional areas of restored forests adjacent to large expanses of forests rather than creating new "islands of green" within the agricultural frontier, this strategy provides an alternative to the "single large or several small" (SLOSS) debate (Wilson et al., 2017) and can complement a jurisdictional initiative to prevent deforestation if done at a sufficiently large scale (Seymour et al., 2018). Third, this strategy provides a cost-effective way to build a carbon stock in part of the farms since it requires little maintenance beyond the fencing of the pasture-facing sides of the restoration areas (the presence of standing forest saves the effort of fencing a side of the restoration polygons). One cost-effective fencing alternative would be to install live fences, a silvopastoral practice that enhances the provision of ecosystem services such as carbon sequestration and can improve animal performance by reducing stress in cattle (Pagiola et al., 2007).

Figure 1.

Environmental factors for deciding the location of pastures participating in the program	Cattle pastures at the edge of the agricultural frontier in the Amazon region vs. Cattle pastures with decades of use and further from primary forests
Seed recruitment	Seed banks may have been eroded, too far from forests for aerial dispersal or dispersal affected by local defaunation (Barot et al., 1999)
Edge effect	Carbon stocks around edge of forests can be 25% lower compared to mid-forest locations (Lan Qie et al. 2017). By eliminating the edge effect on existing forest edges, they can increase their carbon stocks by an equivalent amount over time.
Soils condition	Concentrations of phosphorus and nitrogen in soils is higher in lands that have been recently deforested (Uhl, 1997).

[10] The potential mitigation from avoided deforestation is not modeled, nor included in the program, since this effect is uncertain and determining additionality would require establishing deforestation baselines.

Environmental co-benefits	Buffer can help avoiding new deforestation (Wang et al., 2020) while increasing the area of already established wildlife habitat and ecosystem services providing forests.
Temperature	Nitrous oxide emissions factors double in high temperature locations (Amazon, high proportion of pastures at the edge of ag frontier) compared to low temperature ones (Andes, low proportion of pastures at edge of ag frontier).
Precipitation	High precipitation increases likelihood of anaerobic conditions which leads to higher nitrous oxide emissions factors (Lesschen et al., 2011). Precipitation is higher in Amazon region where a larger proportion of pastures are at the edge of the ag frontier.

4.1. Study Area

For the study area, a 750 km^2 polygon was drawn using Global Forest Watch, covering a mosaic of pastures and forests in the Solano municipality in the Caquetá department of Colombia (Figure 2). Solano is a municipality at the edge of the agricultural frontier with a high mitigation potential and a relatively large cattle inventory. The polygon was selected so that all pastures lie within 5 km from the edge of a large expanse of forest (80 km^2 forest fragment was selected as the threshold), and was drawn to avoid urban settlements, legal and indigenous reserves, and water bodies visible at a 25x25 mts pixel resolution. For the purposes of this model, The proportion of pastures to total area in the polygon was estimated at 68%, which represents the area of pastures that correspond to a stocking rate of 0.86 AU/ha, knowing that 46,674 heads of cattle graze in the km^2 polygon. Additional criteria for the selection of a study area were the presence of at least 30,000 heads of cattle, (verified with data provided by the Comité de Ganaderos de Caquetá), and a proportion in the area of least 70% of pastures resulting from deforestation that has happened in the last 20 years, as determined by Global Forest Watch metrics.

4.2. Model objectives

The objective of this model is to provide estimates of the GHG mitigation potential and present value of associated carbon offsets of a jurisdictional program to reduce land use and biological emissions from the Colombian cattle sector. The model provides answers to the following questions (assuming constant activity data): (1) How much carbon can be sequestered in forests in the hypothetical maximum area of spared land for the maximum improvement in stocking rates, assuming arithmetic progression at 4-year intervals for a period of 20 years? (2) What can be the mitigation potential of improvements in biological emissions intensity (equivalent to improvements in emission factors) assuming constant activity data and a biological emissions standard of 50% in 20 years? (3) What is the present value of the monetized emissions mitigation, excluding transition costs, under different carbon prices and discount rates?

4.3. Sources of information

IPCC guidelines were used to input estimates of the amount of carbon sequestered in AGB per hectare subject to natural regeneration as a reforestation management strategy. Requena-Suarez et al (2019) refined the estimates for Tier 1 IPCC emission factors based on the rate of accumulation of carbon in above ground biomass (AGB) in different tropical forests around the world. By measuring a large sample of plots, the authors determined that for tropical rainforests in South America (figure 3) like those surrounding Solano in Caquetá, the relationship between time elapsed since the start of succession and AGB (measured in Mg/ha) can be explained by the allometric equation (1): $AGB(t) = -40.87 + 53.34 * \ln(t)$. To convert AGB to carbon stored in the forest biomass, a conversion factor of 0.47 (AGB*0.47) was used as recommended by IPCC GHG inventory guidelines. Because of current scientific uncertainty, it is assumed in IPCC Tier 1 method that forest soil carbon do not change with management. For this reason, carbon sequestered in soil has not been included in the calculations. The present value of carbon mitigation for a given four year interval is calculated using the following equation:

$$PV(C) = \sum_0^4 \frac{AGB(t)*0.47p}{(1+r)^t}$$

Where $PV(C)$ is the present value of carbon offsets from reforestation, p is the price per tCO_2e, $AGB(t)$ is the amount of carbon sequestered in AGB forest biomass and r is the discount rate.

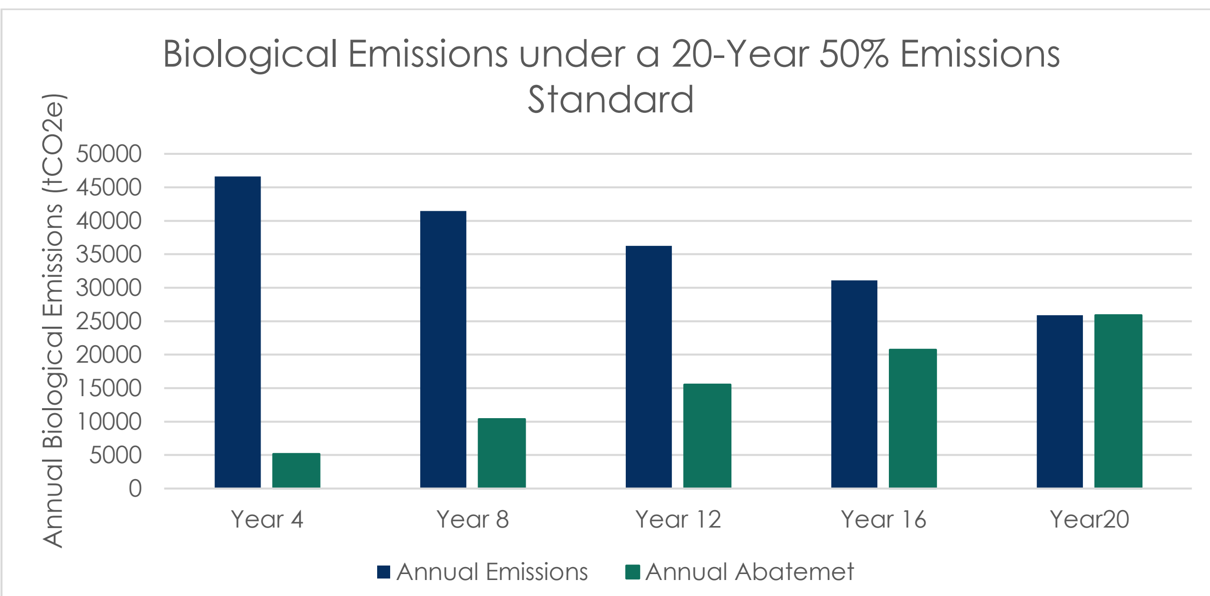
Estimates on best available stocking rates come from literature review. Ermgassen et al., (2018) show that the stocking rate in Amazonian pastures can increase fourfold from the status quo average if pasture management, silvopastoral and rotational grazing are introduced. For the purpose of the model, a transition from 0.86 AU/ha, the average in Colombia according to FEDEGAN, to 3.44 AU/ha is used to set the 4-year targets. This represents a hypothetical fourfold increment in stocking rates in year 20 as a result of the program. It is assumed that marginal improvements in stocking rates will become increasingly harder over time, hence each four-year period corresponds to a diminishing marginal gain of pastures for reforestation. In terms of permanence, the model assumes that all forests regenerating in pastures will remain intact during and after the program, and that the goals are achieved fully at each 4-year period. In other words, the calculation of the carbon benefits does not account for costs of risks buffers or potential reversals of carbo stocks.

5. Results

5.1. Biological Emissions Mitigation

Biological emissions in the jurisdiction of study decline to 26,000 tCO2e by the end of the program, and a total of 272,000 tCO2e are avoided over the 20 years by setting a biological emissions intensity standard that adjusts by 10% every four years, and assuming that the jurisdiction's farmers achieve the goal at every period and AUs remain constant (Graph 2). The results provide an estimate for avoided nitrous oxide and methane emissions from manure management and enteric fermentation and exclude emissions from manure patches on pastures[11] which, if included, could yield a result up to 33% higher. The associated value of the biological emissions reductions amounts to USD 2.7M for a carbon price of USD 10/tCO2e. These values represent an upper bound estimate for other jurisdictions with equal or less animal numbers, cooler temperatures, and lower precipitation, since these are all factors that make biological emissions lower. Different biological emissions standards were modelled and the magnitude of the emissions mitigation provided in the appendix. Similarly, sensitivity analysis of the potential economic benefits from emissions mitigations under different prices per tCO2e are included in the appendix. However, for the program to be able to monetize these emissions reductions a baseline would have to be set to determine true additionality from business as usual, since the model considered a status quo baseline of emissions in 2015, the latest data available for the construction of the 2016 national GHG inventory.

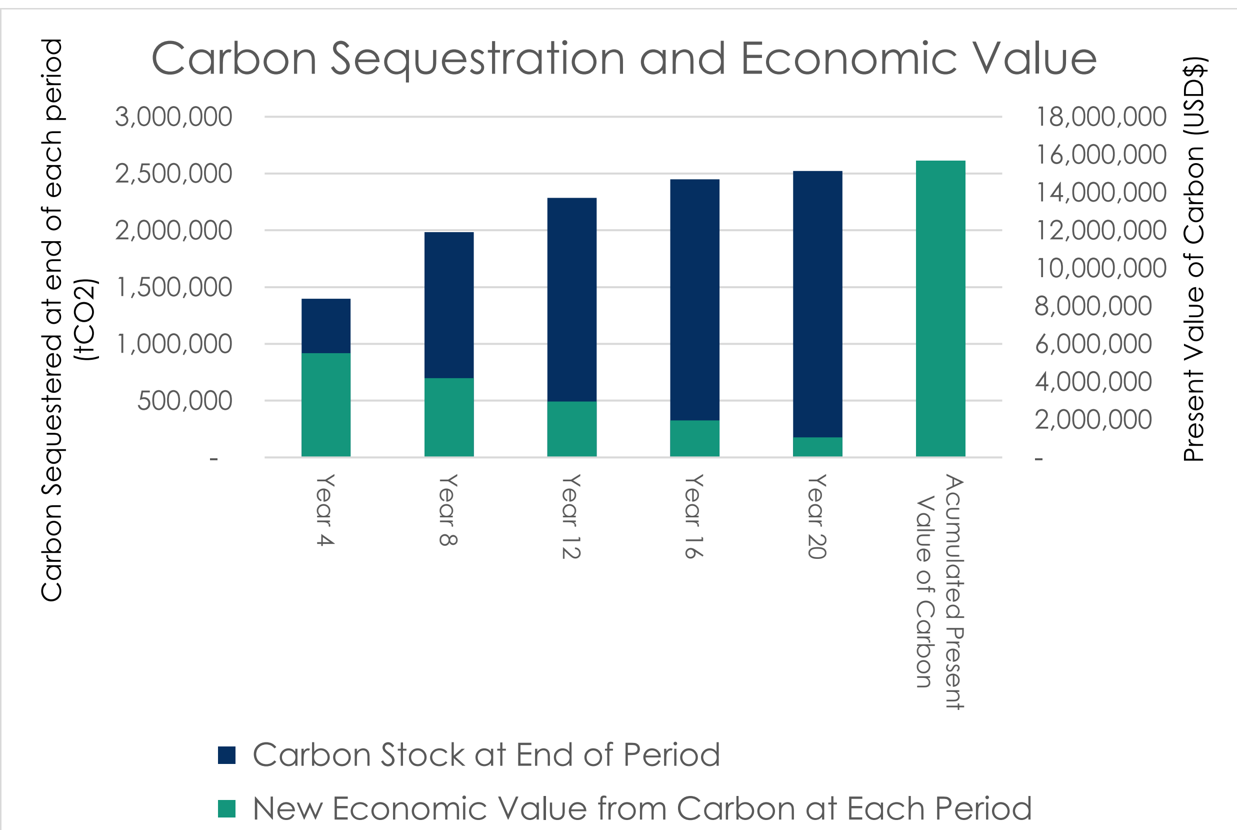
Graph 2.



[11] Nitrous oxide emissions from cattle manure patches on pastures were not included in calculations because of data limitations. In Colombia, manure patches comprise 33% of all biological emissions from bovine livestock and 5% of national emissions.

5.2. LUC Emissions Mitigation

The potential for LUC emissions mitigation is considerably higher for the studied jurisdiction as expected, and up to an order of magnitude larger than nitrous oxide and methane emissions from manure management and enteric fermentation. This is consistent with literature (Cederberg et al., 2011), showing the dominance of LUC emissions in the emissions profile of cattle reared in the Amazonian region. The annual rate of carbon sequestered in secondary forests is marginally diminishing, which can be explained by the shape of the allometric curve that describes the growth of above ground biomass in secondary forests in the American tropical rainforests. The total emissions mitigated over the extension of the 20 years are 2.6 MtCO2e which corresponds to an economic value of USD 16M. These values correspond to the upper limits for all jurisdictions in Colombia with an area in pastures with restoration potential that is equal or lower to 50,784 ha. The appendix includes sensitivity analysis of emissions mitigation for jurisdictions with a lower restoration potential and different carbon prices.



6. Discussion

The model presented was developed for purposes of providing estimates of the potential emissions reduction and economic benefits from carbon from a proposed hypothetical program to reduce biological emissions from the cattle sector in Colombia. A more accurate description of the program's economic impact would ideally include costs associated with the necessary long-term governance, capacity building requirements, capital investments and opportunity cost of the land. A full benefit cost analysis should at least include: (1) fencing costs, which Pagiola et al., (2007) estimate at around $110 to $160/km for live fencing in silvopastoral projects. (2) MRV and issuing costs of carbon offsets, which areapproximately $0.10/t$CO_2$ (Verified Carbon Standard, 2019). (3) The opportunity costs per hectare for a cattle farm in Colombia which Montagnini et al (2011), estimates at US$165 ha^{-1} $year^{-1}$ for lands fit for cattle ranching.

In the model, the 4-year goals in the program are set as aspirational targets and help provide an ex-ante estimate of the potential to generate economic benefits from carbon offsets. For those offsets, if the program was to be brought to fruition, a previously defined benefit-sharing agreement[12] could dictate how the benefits are distributed among farmers, associations, developers, financers or other entities involved. Payments to farmers, regardless of their magnitude, could take the form of capacity building programs[13], be applied as discounts on the parafiscals that FEDEGAN collects from farmers, or given as cash transfers.

In addition, the results may overestimate the mitigation potential of the program, because cattle ranching has been identified as a low-cost mechanism for land speculators to take possession of lands in Colombia, and presumably, the program would have a smaller effect in spurring mitigation actions in farms that are pursuing

[12] The ISFL from the World Bank's BioCarbon Fund has developed very interesting benefit sharing contracts for their projects that could serve as a base for this project.

[13] Capacity building and financial support to transition from livestock to horticulture would be an interesting way to pursue further mitigation.

cattle ranching as an excuse for land occupation rather than as mean to sustain a household livelihood. In a country with one of the highest GINI coefficients in the world (50.4 in 2018 according to World Bank figures), program design should safeguard low-income farmer's from being disproportionately affected by mandatory regulations, and should provide the conditions to enable enhanced access to the economic benefits from the program. Bovine livestock provides a range of societal benefits in Colombia, by acting as a savings asset for households (Herrero et al., 2016), providing employment to 810,000 people (FEDEGAN, 2019) and serving as a source of protein. 67.5% of cattle farms in Colombia have less than 25 heads of cattle and 91% have less than 100 (Add histogram to appendix) suggesting that important mitigation can happen if small and medium farmers are engaged in the program.

6.1. Permanence, Additionality and Leakage of LUC Mitigation

Standard development and verification agencies such as the Verified Carbon Standard, have defined procedures to calculate the necessary risk buffers to reach a specific emissions reduction after non-permanent forest cover is factored in (VCS VM0007, 2015). Other silvopastoral projects in Colombia, such as the those led by the World Bank's BioCarbon Fund in the Orinoquia region, have developed their own methodologies, setting aside a portion of emission reductions as a buffer reserve to match a target of permanent emission reductions (BioCarbon Fund, 2018).

If the program achieves coverage of all cattle jurisdictions in Colombia, leakage in the form of deforestation from shifting cattle inventory distributions, would be addressed at the level of the lands included in the agricultural frontier. Therefore, the model assumed that land sparing happened in a sealed system in which the push of forests into farms does not generate a displacement of cattle outside of the agricultural frontier, causing deforestation elsewhere. This, however, might not be true and a more detailed model could estimate this effect. Similarly, positive effects on avoided deforestation, from the creation of secondary forest buffers between the agricultural frontier and primary forests, could also be quantified if the larger jurisdiction develops baselines for deforestation. An additional uncertainty to develop robust estimates for permanence of new forest cover, is the effect that climate change will have on future climate stocks, especially when Amazon ecosystems may be close to reaching an ecological tipping point (Nepstad et al., 2008) and global temperature rise is accelerating at the fastest rate since the beginning of the Holocene (NOAA, 2019).

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Appendix

Figure 1.a.

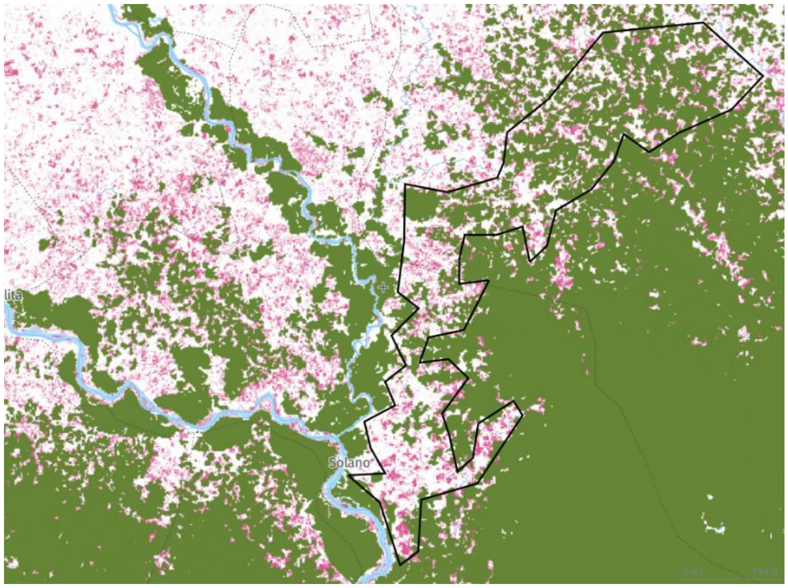

Figure 1.b.

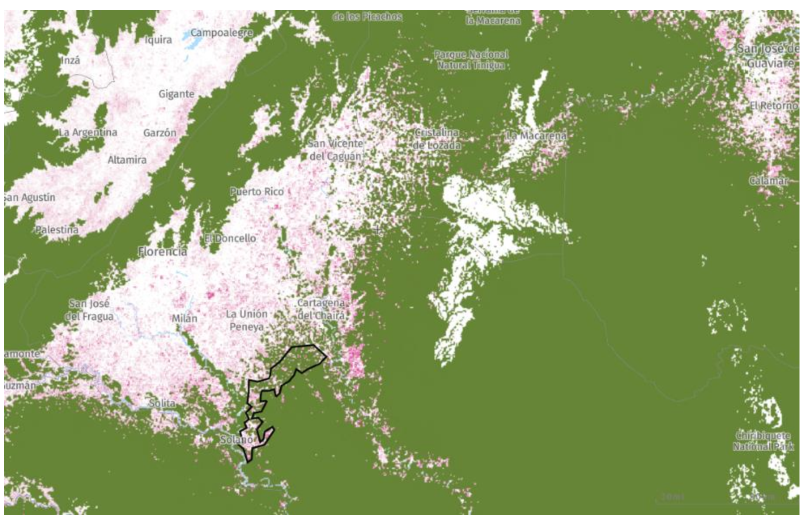

Figure 1. c.

Figure 2

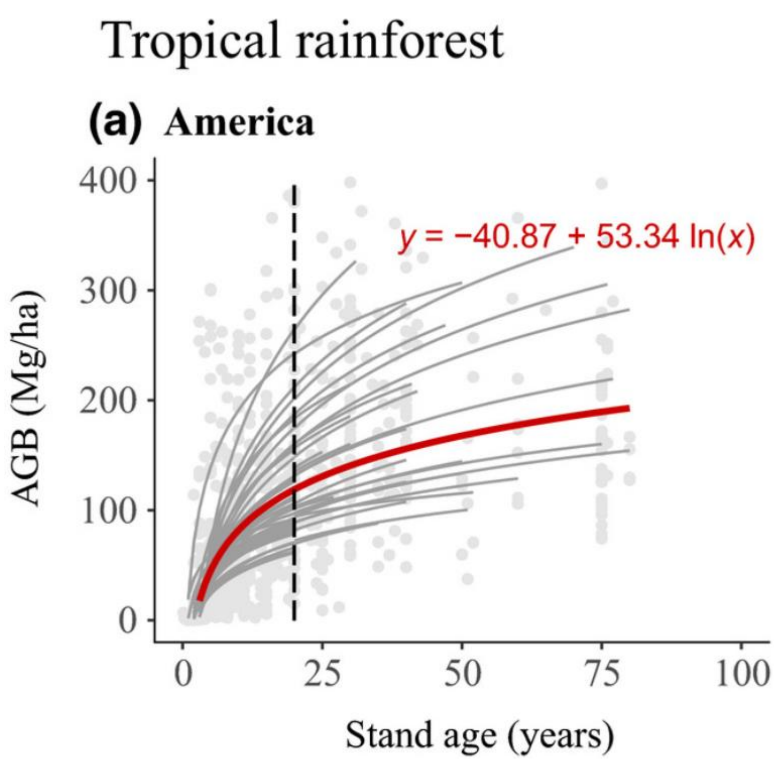

Figure 3

Unilateral and unconditional target

The Republic of Colombia commits to reduce its greenhouse gas emissions by 20% with respect to the projected Business-as-Usual Scenario (BAU) by 2030.