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Agricultural Greenhouse Gas Emissions in Latin America and the Caribbean

Current Situation, Future Trends and One Policy Experiment

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1. Executive Summary

The world demand for food and feed will increase by between 50% and 85% from 2009 to 2030, and a substantial part of the growth in demand is expected to be met by farmers in LAC by intensifying production activities on existing agricultural lands and by expanding the agricultural frontier. A rapid expansion of the agricultural frontier in the region could easily undo any progress made by REDD+ (Reduced Emissions from Deforestation and Forest Degradation) and other policies. Thus, one challenge for LAC is to increase aggregate agricultural production to meet this growing demand for food/fiber/energy without proportionally increasing greenhouse gas emissions. However, agriculture's potential contributions to reducing GHG in LAC are unclear, and the implications of policy actions (including publicly funded research on technological change) to reduce agricultural GHG emissions for food production, food prices, agricultural employment or agricultural income are not known. Some of these implications may be particularly important to the poor within and outside of LAC. This research project begins to fill some of these important gaps in knowledge.

Two existing models were enhanced to examine agriculture-GHG links in LAC; the IFPRI IMPACT model provides national, regional and global perspectives; and a CGE model of Brazil provides sub-national and national perspectives. This Discussion Paper focuses on the IMPACT model.[1]

The IMPACT model baseline scenario (run to 2030) reminds us that world food situation has recently departed from its very long-term trend of declining real food prices to one of slowly increasing real prices for major grains and livestock products, especially beef products. This new trend will pose new and perhaps serious challenges for the world's poor and food insecure, and may make the task of managing agriculture in LAC to reduce GHG emissions more contentious and more costly.

The IMPACT model baseline scenario also highlighted the very significant contribution of agriculture in LAC to GHG emissions – approximately 980 million tons of CO_2 equivalent were emitted in 2010 alone; that total is expected to decline to approximately 871 million tons by 2030. Moreover, the sub-sectoral GHG emissions varied substantially by country, e.g., in 2010, cropping activities contributed 7% of all emissions in Chile, while the cattle herd in Brazil

[1] Results of the baseline and policy scenarios associated with the CGE model of Brazil will be examined in a companion Discussion Paper.

contributed 54% of that country's total agricultural GHG emissions. Per-hectare contributions associated with land clearing were very large (in some ecological zones emitting over 700 t CO_2 eq./ha), and although area cleared is small relative to total cropped area in most LAC countries, the percentage contribution of forest clearing to total agricultural GHG is significant (e.g., in 2010, nearly 60% for Central America and the Caribbean but only 26% for Colombia). The share of GHG emissions associated with land clearing falls over time for all countries in LAC (e.g., between 2010 and 2030, land clearing's contribution to GHG emissions in Brazil fell from 40% to 26% .

An examination of the major demand drivers of agricultural change in LAC (with consequences for GHG emissions) revealed that while China, India and Brazil all play important roles in shaping the world food situation, none of these countries contributed more than 4% to demand-induced agricultural changes in LAC over the 2010-2030 period, although the influences of these large countries were predominantly felt over the next decade or so.

The IMPACT model was used to examine the effects of a hypothetical (but politically sought-after in some arenas) complete and effective *ban on the clearing of native vegetation* for agriculture in tropical areas within LAC on GHG emissions, food production, food prices, and child malnutrition at several spatial scales. Results suggest that a complete ban on land clearing for agriculture would significantly reduce GHG emissions associated with the clearing of forests and other forms of natural vegetation vis-à-vis what would have occurred in the absence of the ban. The *land 'saved'* (approximately 3.3 million hectares) is approximately equally distributed across the Amazon, northern South America and the Central America & Caribbean sub-regions that comprise the LAC tropics. The total volume of *GHG emissions avoided* due to land *not* being cleared (about 1.8 billion tons of CO_2 equivalent) is concentrated in the Amazon and Central America & Caribbean sub-regions where tropical forests cover much of the area into which agriculture would expand. The ban reduces (as expected) agricultural production within tropical areas in LAC. However, these *economic losses* (e.g., US$ 12.7 billion in 2030, compared to the baseline) are not distributed uniformly across the three sub-regions within tropical LAC – the northern South American 'rim' around the Amazon suffers approximately 45% of all losses in gross value of agricultural output attributable to the ban. At country level, though, some of the losses tended to be mitigated by agricultural gains in non-tropical areas. Brazil, for example, would likely experience net gains associated with the ban on area expansion in the tropics. Central America & Caribbean, Colombia, Ecuador, Peru, and Mexico would all suffer significant declines in gross value of agriculture, with Ecuador experiencing the largest losses, when measured as a percent of total agricultural GDP.

These losses could potentially be offset by compensating the appropriate stakeholders for the tons CO_2 equivalent retained in the native vegetation. However, the very wide range of relatively recent market prices for CO_2 emissions suggests that there is great uncertainty regarding the value of avoided GHG emissions. That said, at the average price of CO_2 equivalent OTC transactions in LAC in 2009 (roughly US$ 4.30/t CO_2 eq.), our estimates suggest such compensation schemes could cover over 1/2 of the value of the losses in agricultural output in the tropics associated with the ban.

The ban also induces some increases in area expansion and some product mix adjustments that increase agricultural production and GHG emissions in *non*-tropical areas *within* LAC; the agricultural gains (e.g., approximately US$ 3.6 billion in 2030, compared to the baseline) of the non-tropical 'winners' in LAC represent 14% of the economic losses experienced in the tropical areas, with area expansion outside the tropical zone representing about 3% of area saved in the tropical zone. The ban also promotes agricultural expansion and change *outside* of the LAC region as farmers in other producing areas compensate for reductions in supply from LAC; such 'leakages' will likely play fundamental roles in the design and implementation of policies for managing agricultural GHG emissions.

While the local effects on production and agricultural income are substantial, as one moves away from tropical areas in LAC to assess the broader impacts of the land clearing ban, the effects are quickly muted. Area expansion outside tropical LAC, increased productivity within and outside tropical LAC, and decreases in global demand for some agricultural products (all in response to small increases in product prices) are sufficient to 'cover the gap' in food production that saving the natural vegetation in tropical areas in LAC would create. Therefore, at global level, the overall effects on commodity prices (including prices of beef products) of the simulated ban on area expansion on LAC are not large and (hence) the effects on childhood malnutrition are small.

2. Introduction

The world demand for food will increase by between 50% and 85% from 2009 to 2030 (Msangi and Rosegrant 2009). The LAC contains some of the few remaining large areas available in the world that could be converted to agriculture; there will be great pressure on the region to do so to help meet global food needs (Nepstad et al. 2008). Increased demand for animal products in general, and for beef products in particular, will intensify the pressure to expand pasture area in LAC due (in part) to the extensive nature of cattle production systems and relatively low stocking rates in the region (Torre et al. 2010). A substantial part of the growth in demand for food will be met by intensifying production activities on existing agricultural lands; this combination of agricultural extensification and intensification will have environmental consequences – our focus here is on greenhouse gas (GHG) emissions.

But this pressure to expand and to intensify agriculture will not be spatially uniform within the region; site-specific and product-specific production and transportation costs, on the one hand, and product-specific demand, on the other, will jointly determine where pressure for increased agricultural land and productivity growth will be most intense, and when this will occur (Braun 2007, Fearnside 2001). Agricultural and other policies can affect costs and hence the location of area expansion and other investments in agriculture.

Regardless of how and where these pressures play out, expanding cultivated area in LAC will lead to deforestation which is, by far, the largest per-hectare agricultural generator of GHG emissions (Nepstad et al. 2006a). However, the amount of emissions associated with land clearing varies greatly within LAC, and also within some countries in LAC (Klink et al. 2005). Therefore, 'steering' forest/savannah-clearing activities towards these relatively low-emitting areas may be one strategy for reducing the GHG implications of an expanding agricultural sector in LAC.

However, regardless of where forest/savannah clearing has occurred, the vast majority of agricultural activities cannot 'replace' even a small fraction of the natural stocks of above-ground carbon (Fearnside et al. 2009). Notable exceptions are agroforestry systems, some of which can replace up to about half of the carbon stocks of native vegetation (Vosti et al. 2001). With a few exceptions (e.g., coffee and citrus), limited demand for the products produced by these systems limits the cultivated area they will occupy; public policy efforts to artificially boost demand for such products have by-and-large failed.

Switching from one agricultural product to another can have implications for GHG emissions, and the same can be said for changes in production technologies for many crops. But per-hectare reductions in GHG emissions associated with changes in product mix or production technology will be small, certainly vis-à-vis the GHG emissions associated with expanding cultivated area (Bernoux et al. 2006). That said, because cultivated area in LAC is so large (and likely to grow), these small changes could add up to very substantial reductions in GHG emissions.

Due to the size of potential expansion of cultivated area in LAC, the remaining substantial scope for agricultural intensification in some areas, and the possibility of rapid changes in product mix in large parts of the region, the feedback effects of policies designed to reduce GHG emissions in agriculture could have significant impacts on commodity prices.

Finally, any rapid expansion of agriculture production in the region could easily undo, locally and regionally, any progress made on REDD+ (Reduced Emissions from Deforestation and Forest Degradation) and other policies aimed at retaining native vegetation to safeguard biodiversity and to reduce the contribution of agriculture to global climate change. REDD programs, in particular, are designed to share with land user groups some of the benefits associated with retaining forested areas, and hence hold the promise of influencing their land and forest use decisions (Kossoy and Ambrosi 2010). However, local 'successes' may be undermined by higher commodity prices making REDD programs more costly. Or, local 'successes' may deflect the demand for new agricultural land to other areas where REDD policies are not being pursued or are less effective. Therefore, unless REDD programs are carefully orchestrated within LAC, their overall effects on GHG emissions from forest/savannah conversion may be small (Angelsen 2010). Orchestrating REDD programs with *other* policies that affect site-specific demand for agricultural land may also be pivotal to local or regional success.

Thus, an important challenge for LAC is to increase agriculture production to meet this growing global demand for food, fiber and energy without proportionally increasing greenhouse gas emissions. Helping countries in the region to re-emphasize rural development along pathways that retain forests and other non-agricultural landscapes is a difficult task, but an important ingredient to achieving agricultural and environmental objectives.

While progress has been made in measuring the site-specific and activity-specific GHG emissions associated with an array of land clearing and agricultural activities that are practiced or could be practiced in LAC (IPCC 2006), there are important gaps in knowledge that need to be filled before informed policy action can proceed. For example, what is the current contribution of agriculture to GHG emissions in LAC and which sub-sectoral activities generate the most emissions? If current trends in the world food supply-demand nexus continue, what will be the contribution to GHG emissions of LAC agriculture in 2030? If aggregate levels of GHG emissions from agriculture in LAC are deemed to be excessive, what would be the *local* implications for food production, gross value of agricultural output and rural employment of managing agriculture to reduce agricultural GHG emissions? At *national level*, what would be the implications for reducing agricultural GHG emissions for food trade patterns and possibly for national food security strategies? At *national level* for large and ecologically diverse countries, and for the region as a whole, there may be 'winners' and 'losers' associated with efforts to curb GHG emissions in agriculture (Chomitz 2007) – who are these 'winners' and 'losers,' and what are the sizes of their respective gains and losses? Finally, what might be the global implications for food prices and malnutrition of LAC actions to substantially reduce agricultural GHG emissions?

To begin to address these issues, a global model of agriculture (the IFPRI IMPACT model) was enhanced to examine agriculture-GHG emissions links and the effects of policy and other changes on these links. Once enhanced, the model was used to address the following specific issues.

First, we assess the recent and future contributions under a "business as usual" baseline scenario of agriculture in LAC to GHG emissions, both directly in terms of agricultural production activities, and indirectly via the clearing of forested areas for these activities. This assessment is made at multiple spatial scales, beginning with the Food Production Unit (FPU) as identified in the IFPRI IMPACT model, then moving to the more aggregate country, regional and global levels.

Second, we examine the contributions of increases in food demand from India, China and Brazil to this "business as usual" baseline scenario to assess the relative contribution of these fast-growing countries to agricultural change in LAC, and the GHG emissions consequences of those changes.

Third, to begin to understand the effects of managing agriculture to reduce GHG emissions in LAC, we examine the effects of a somewhat extreme (though not arbitrary) policy regarding the expansion of the agricultural frontier in the region -- a total and effective ban on all agriculture-led land clearing in the tropical areas of LAC.

The remainder of the report is structured as follows. The next section identifies and defends the choice of the modeling tool used, and reports the enhancements introduced to the model to improve its ability to address the research issues set out above. We then report the results of the baseline and policy scenarios associated with the IMPACT model. The final section presents conclusions and their policy implications.

3. Choice of Predictive Models to Address Agriculture GHG Issues

3.1 Model Choice

An array of models is available to assess the effects of agricultural change on GHG emissions. For example, beginning at the most disaggregated level, plot-level models can provide very detailed characterizations of production technologies, but generally do not capture the optimizing nature of farmer decisions (Bennett 2009). Farm-level models are better equipped to deal with farm-level decision making (Vosti et al. 2001), but are generally very site-specific and almost always autarchic in the sense that farmers' actions do not influence input or output prices, which is a critical feed-back loop for the research questions being examined here. Regional and national (programming) models of agriculture can effectively capture both the details associated with agricultural production activities and the input/output markets associated with them, but these models take international prices as 'given' and tend to be less useful for long-term assessments of the effects of policy changes (Janssen 1998). Econometric models at national and regional scales can also be quite useful in predicting the effects of some policy changes (e.g., price policies), but the market effects of farmer adjustments to such policy changes are generally not captured. To address the research issues set out above, the following model was selected for its relative strengths.

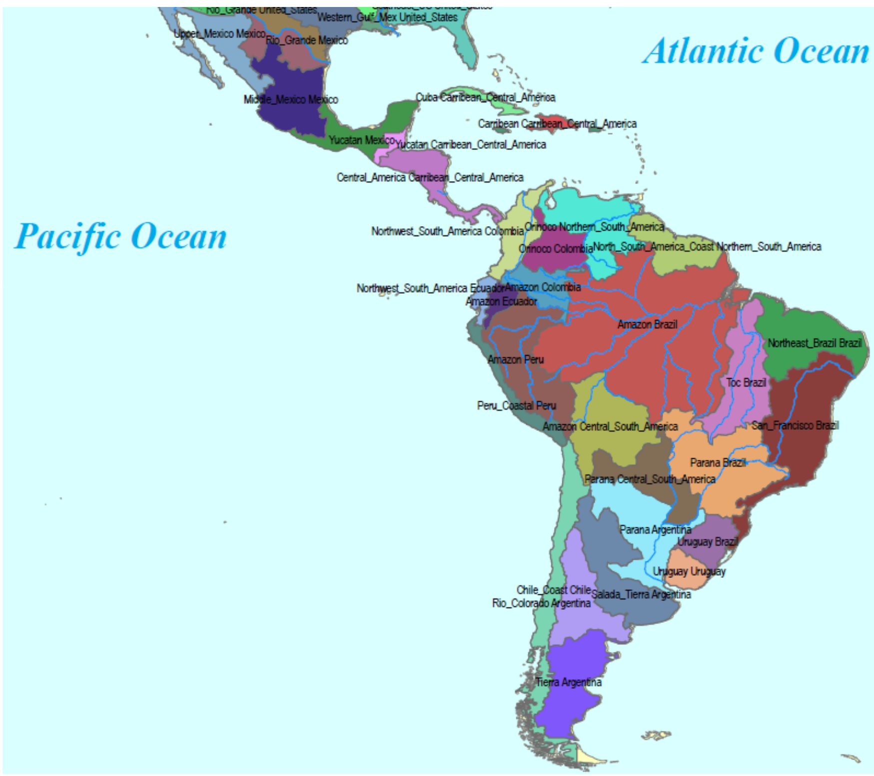
The IMPACT model was chosen to provide broad regional and global coverage for several reasons. First, the model is global in scope and contains sufficient detail regarding world-wide agricultural demand/supply interrelationships to assess the potential effects of policy changes in LAC on world food prices. Second, the model sufficiently disaggregates the LAC region to allow for the identification of spatial differences in the costs/benefits associated with policy changes. Third, the model is able to produce stable, long-term results, which is important since the policy effects examined in this project take time to play out. Fourth, the model has an established, credible long-term baseline against which to compare the results of policy simulations. Fifth, the model uses site-specific constraints on water availability in determining crop mix and production technology, a key strength given the pivotal role that irrigation will play in meeting future food/fiber/fuel needs. Finally, the model has an algorithm for converting changes in world food prices into estimates of malnutrition; this dovetails with our concerns for the effects of policy and other changes on malnutrition.

3.2 The IFPRI IMPACT Model

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) developed at the International Food Policy Research Institute (IFPRI) is used to generate some of the simulation results presented below. In a nutshell, the partial-equilibrium, multi-market model encompasses most of the countries and regions in the world and the main agricultural commodities produced in them. The model is comprised of systems of supply and demand equations that represent market equilibrium interactions that produce a baseline and alternative scenarios for global food demand, supply, trade, income and population. Within each country or region the levels of supply, demand, and net trade of agricultural commodities are determined in relation to prices transmitted from the world market, such that international trade flows are balanced, and provide the linkage between all countries and regions.

Supply and demand functions incorporate supply and demand elasticities to approximate the underlying production and consumption behavior. World agricultural commodity prices are determined annually at levels that clear international markets. Domestic crop production is determined by area and yield response functions which are specific to food production units (FPU), some of which fall within countries while others span international borders. The FPUs that comprise the LAC region are identified in Figure 1. Harvested area is specified as a response to the crop's own price, the prices of other competing crops, the projected rate of exogenous (non-price) growth trends in harvested area, and the availability and use of water. The projected exogenous trend in harvested area captures changes in area resulting from factors other than direct crop price effects, such as expansion through population pressure and contraction from soil degradation or conversion of land to nonagricultural uses. Yield is a function of the commodity price, the prices of labor and capital, water, and a projected non-price exogenous trend factor that reflects productivity growth driven by changes in intrinsic crop traits and technology improvements. Livestock production is modeled similarly to crop production except that livestock yield reflects only the effects of expected developments in technology. Total number of livestock slaughtered is a function of the livestock's own price and the price of competing commodities, the prices of intermediate inputs, and a trend variable reflecting growth in the livestock slaughtered.

Figure 1: The IMPACT Model's Food Production Units within the LAC Region



Agricultural supply is also determined by the availability and use of water. Hydrologic processes, such as precipitation, evapotranspiration, and runoff are taken into account to assess total renewable water in a set of the world's most important food-producing river basins. Water demand for domestic, industrial, livestock, and irrigation uses are determined, and the available water resources area allocated across sectors on the basis of priority in order to meet these competing demands.

Commodity-specific domestic demand is the sum of its demand for food, feed, and other uses. Food demand is a function of the price of the commodity and the prices of other competing commodities, per capita income, and total population. Per capita income and population increase annually according to country-specific population and income growth rates. Feed demand is a derived demand determined by the changes in livestock production, feed ratios, and own- and cross-price effects of feed crops. Demand for feedstock for biofuels production is imposed exogenously on the model on the basis of implied policy-driven growth in ethanol and biodiesel production volumes.

Prices are endogenous in the system of equations for food. Domestic prices are a function of world prices, adjusted by the effect of price policies and expressed in terms of the producer subsidy equivalent (PSE), the consumer subsidy equivalent (CSE), and the marketing margin (MI).

Country and regional sub-models are linked through trade. Commodity trade by country is the difference between domestic production and demand.

4. Establishing Agriculture-GHG Links for the IMPACT model

Agriculture contributes to GHG emissions (positively and negatively) in several ways. First, where agriculture replaces natural vegetation GHG emissions occur, with the types and amounts of GHG emissions depending on the type of vegetation being cleared and the methods used to do so (Zanocco and Vosti 2010a, IPCC 2006, Fearnside et al. 2009). Second, ongoing cropping activities being practiced on cleared land can either emit or fix GHG, depending on the products produced, the location of production, and production technologies used (Hutchinson et al. 2006, Bernoux et al. 2010, Cerri et al. 2010). Finally, livestock can also contribute significantly to GHG emission; these contributions, too, vary depending on the type of livestock and the technologies used to feed and manage herds.

Existing data agriculture-GHG links and spreadsheet-based models used to manage such data were tapped to generate estimates of the various type of agricultural GHG emission for each of the LAC FPUs in the IMPACT model. The following three sections summarize the methodologies we adopted.

4.1 Estimating GHG Emissions Associated with Area Expansion in Agriculture in LAC

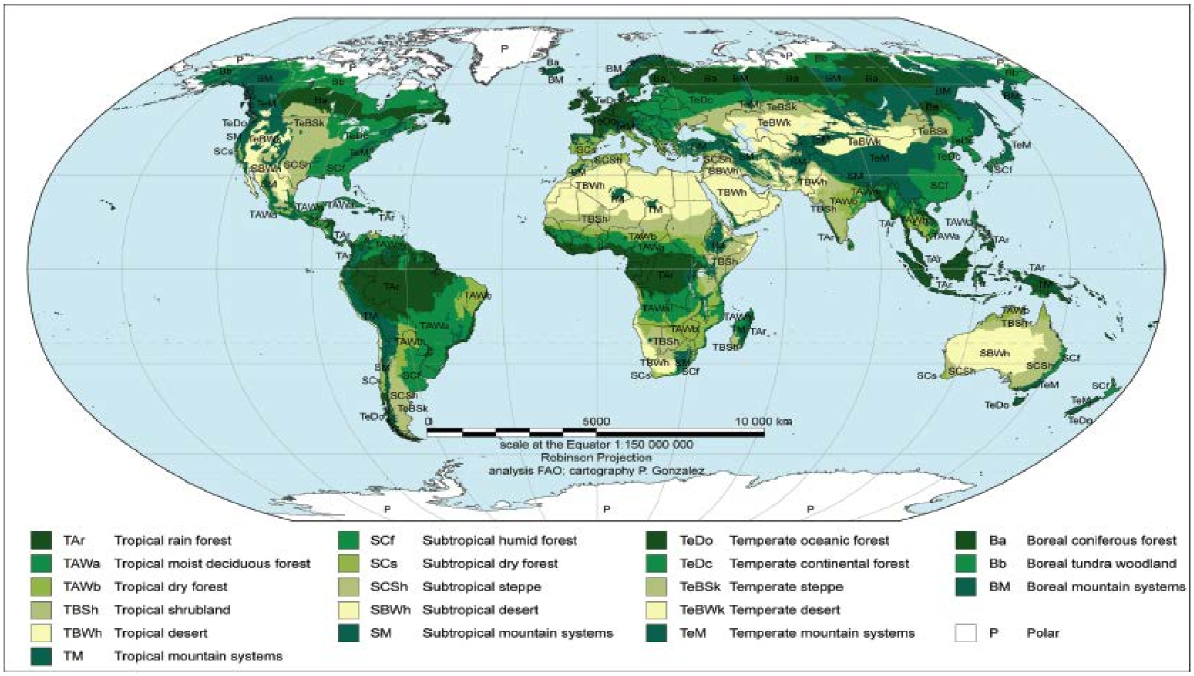
We adopt a three-part strategy for estimating the amount of carbon that would be released from the agriculture-led conversion of natural vegetation for each of the IMPACT model's FPUs in the LAC Region. We first map ecological zones[2] into the FPUs using GIS. The next step involves generating estimates of carbon stocks in native vegetation for each ecological zone. The final (trivial) step involves summing up per-hectare carbon losses across the (pre-determined) ecological zones that comprise each FPU.

Mapping Ecological Zones into the IMPACT Model's FPUs

To account for the heterogeneity of ecological zones and forest types within each FPU, we compare the mapping of ecological zones estimated by IPCC (2006) with the map of the FPUs in LAC (IFPRI 2008). A map of the ecological zones developed by the IPCC is used (Figure 2). Utilizing spatial mapping software, estimates of the proportion of ecological zones lying within each of the FPUs in LAC are made.

[2] Spatial data for ecological zones was obtained from FAO: GeoNetwork, http://www.fao.org/geonetwork/, shapefile last updated 2002-05-31.

Figure 2: Ecological Zones of the World



Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Inspection of Figure 2 reveals the following ecological zones that are relevant for LAC: subtropical mountain systems (SM), tropical moist deciduous forest (TAWa), tropical dry forest (TAWb), tropical rain forest (TAr), tropical mountain systems (TM), subtropical humid forest (SCf), subtropical dry forest (SCs), subtropical steppe (SCSh), temperate steppe (TeBSK), temperate continental forest (TeDo), tropical shrubland (TBSh), subtropical desert (SBWh), and temperate mountain system (TeM).

Figure 2 depicts the 32 FPUs within the IMPACT model that are relevant for LAC. Figure 3 presents the overlay of the FPUs onto the map of ecological zones. Using spatial mapping software, assessments of the proportions of each of the ecological zones that comprise each of the FPUs were made. These proportions form the grey-shaded core of Table 1.

Figure 3: Overlay of IMPACT Model FPUs and IPCC Ecological Zones

Table 1: Above-Ground Carbon Stocks in Native Vegetation for FPUs in LAC

		Estimated Average Above-Ground Carbon Stocks in Native Vegetation, by Ecological Zone in LAC (t C/ha)													**Average Carbon Stocks, by FPU (t C/ha)**
	TM	*TBSh*	*Tar*	*TAWa*	*TAWb*	*SCf*	*SCs*	*SM*	*SBWh*	*TeDo*	*TeBSK*	*TBWh*	*TeM*	*SCSh*	
Average A-G Carbon, by Biome	94	53	198	133	55	133	130	69	3.1	72	31.5	4.1	69	31.5	
FPUs in the IMPACT Model		Proportion of Land in Each FPU Belonging to Each Ecological Zone													
Amazon Brazil	0.002	0	0.918	0.08	0	0	0	0	0	0	0	0	0	0	**192.59**
Central Amazon	0.325	0	0.407	0.155	0.113	0	0	0	0	0	0	0	0	0	**138.00**
Amazon Colombia	0.058	0	0.941	0.002	0	0	0	0	0	0	0	0	0	0	**191.91**
Amazon Peru	0.406	1E-05	0.593	0	0	0	0	0	0	0	0	0	0	0	**155.72**
Amazon Ecuador	0.502	0	0.498	0	0	0	0	0	0	0	0	0	0	0	**145.82**
Caribbean	0.186	0	0.602	0.212	0	0	0	0	0	0	0	0	0	0	**164.89**
Central America	0.064	3E-04	0.471	0.343	0.119	0	0	0	0	0	0	0	0	0	**151.43**
Coastal Chile	0.19	0.004	0	0	0	0	0.145	0.071	0	0.272	0.065	0.107	0.078	0.055	**70.83**
Cuba	0.051	0	0.199	0.733	0.017	0	0	0	0	0	0	0	0	0	**142.66**
Central Mexico	0.18	0	0.014	0.141	0.083	0	0	0.074	0.272	0	0	0	0	0.235	**56.34**
Northern South America	0.032	0	0.672	0.295	0	0	0	0	0	0	0	0	0	0	**175.448**
Northeast Brazil	0	0	0.127	0.468	0.405	0	0	0	0	0	0	0	0	0	**109.66**
Northwest Colombia	0.339	0.002	0.372	0.227	0.044	0	0	0	0	0	0	0	0	0	**138.28**
Northwest Ecuador	0.348	4E-04	0.477	0.087	0.073	0	0	0	0	0	0	0	0	0	**142.60**
Orinoco Colombia	0.127	0	0.477	0.39	0.006	0	0	0	0	0	0	0	0	0	**158.59**
Orinoco, Northern SA	0.156	0.001	0.33	0.444	0.063	0	0	0	0	0	0	0	0	0	**142.58**
Parana Argentina	0.113	0	0.032	0.424	0.208	0.224	0	0	0	0	0	0	0	0	**114.41**
Parana Brazil	0.042	0	0.020	0.825	0.003	0.110	0	0	0	0	0	0	0	0	**132.43**
Parana South America	0.151	0	0.040	0.291	0.517	0	0	0	0	0	0	0	0	0	**89.34**
Coastal Peru	0.558	0.017	2E-04	0	0.011	0	0	0	0	0	0	0.191	0	0	**54.60**
Rio Colorado Argentina	0	0	0	0	0.012	0.017	9E-05	0.25	0	0.006	0.089	0	0.006	0.62	**43.34**
Rio Grande Mexico	0.017	0	0	0	0	0	0	0.039	0.606	0	0	0	0	0.337	**16.85**
Salada Tierra Argentina	0.087	0	0	9E-06	0.216	0.485	0	0.052	0	0	0	0	0	0.16	**93.19**
San Francisco Brazil	0.072	0	0.166	0.394	0.34	0.028	0	0	0	0	0	0	0	0	**114.41**
Tierra Argentina	0	0	0	0	0	0	0	0	0	0.055	0	0	0.19	0.755	**40.85**
Tocantins Brazil	0.018	0	0.26	0.722	0	0	0	0	0	0	0	0	0	0	**149.20**
Northern Mexico	0	0	0	0.02	0.148	0	2E-04	0.263	0.499	0	0	0	0	0.068	**32.75**
Uruguay-Brazil	3E-04	0	0.002	4E-06	0	0.997	0	0	0	0	0	0	0	0	**133.15**
Uruguay	0	0	0	0	0	1	0	0	0	0	0	0	0	0	**133**
Yucatan Caribbean	0.143	0	0.384	0.461	0.01	0	0	0	0	0	0	0	0	0	**151.35**
Yucatan Mexico	0.177	0	0.169	0.575	0.075	0	0	0	0	0	0	0	0	0.004	**130.81**

Estimates of Above-Ground Carbon Stocks in Native Vegetation for Ecological Zones

The next step involves estimating carbon stocks stored in native vegetation for each of the ecological zones that comprise the FPUs. An array of scientific sources was used for this purpose, the most important being the Commission Decision (2010)[3]. All values are in tones of carbon per hectare (t C/ha). In Table 1, these values[4] appear in the grey shaded third row.

Based on carbon estimates for each of the ecological zones and on the proportion of each of these zones in each of the FPUs, we generate estimates of the average carbon losses associated with agriculture-led conversion of native vegetation for each FPU. These (bolded) estimates appear in the final column of Table 1.

Many important caveats apply; we mention three here. First, one key assumption underlying all carbon stock estimates for land use change is that the carbon within the biomass will eventually be volatilized[5], either by burning[6] or by decay[7]. Second, our estimates do not account for the loss of the yearly carbon sink that some types of land cover generate over time for land cover types that have not reached their climax (most ecological systems in the LAC region have reached this state). Third, the method of land conversion can also matter; processes involving large machines (compared with essentially manual conversion practices) can add substantially to the GHG emissions associated with the conversion of native vegetation.

[3] Source: Guidelines for the calculation of land carbon stocks, Official Journal of the European Union (2010). Adapted from Table 17 (L 151/37): Vegetation values for forested land with more than 30% canopy cover.

[4] For more information on how these estimates were obtained, reference the research brief "Estimating GHG Emissions Associated with Area Expansion in Agriculture in LAC." (Zanocco and Vosti 2010a)

[5] To obtain emission estimates for preliminary modeling purposes, we assume that all above-ground carbon biomass is volatilized into carbon dioxide. This assumption implies that above-ground biomass is cleared without burning practices. Using a value of 12 g/mol for carbon and 44 g/mol for carbon dioxide, the conversion ratio for carbon to carbon dioxide is 44/12 or *44/12*C => CO_2* (UNFCCC 2009). This conversion factor provides a way to estimate GHG emissions associated with land-use change without knowing specific clearing methods or practices. Additionally, it is the default conversion factor used by FAO's EX-ACT model for non-burning aboveground biomass clearing (based on IPCC guidelines).

[6] While burning practices vary substantially, as an example, we consider the carbon emissions associated with flaming combustion. For every 1 ton of carbon volatilized by flaming combustion, approximately 7% of total emissions (in tons) is emitted as CO and less the 0.1% is emitted as CH_4. The remaining carbon is volatized as CO_2. With typical biomass burn efficiencies below 50% in the tropics, we expect the differences in net emissions from land clearing practices (logging, burning, logging + burning, etc.) to have a small yet difficult to measure effect on our estimates. See Fearnside (2000) and UNFCC (2009) for a more in-depth discussion of this topic.

[7] Biomass carbon volatized from decay is nearly completely converted to CO_2, with less than 0.003% of carbon volatized as CH_4. See Fearnside (2000) for further explanation of greenhouse gas emissions associated with decomposition from land-use change.

4.2 Greenhouse Gas Emissions Associated with Annual and Perennial Crop Production Activities

Agricultural activities being practiced on cleared land can either emit or fix GHG, depending on the products produced, the location of production, and production technologies used (Hutchinson et al. 2006; Bernoux et al. 2010; Cerri et al. 2010). In this section, we provide estimates of the average annual flows of GHG (in terms of CO_2 equivalents)[8] generated by one-hectare units of cropland dedicated to an array of crops produced in five agroecological regions in Brazil (North, Northeast, Centre West, Southeast and South), using different production technologies. Most of our estimates are generated by a spreadsheet-based calculator (EX-ACT9) developed by FAO that employs an IPCC accounting methodology to calculate NO_2, CH_4, and CO_2 emissions. For agricultural production activities not currently supported by EX-ACT, we reference studies that provide emission estimates using IPCC guidelines.[10]

The EX-Ante Carbon-Balance Tool (EX-ACT)

The EX-ACT model was developed by the FAO to measure the impacts of policy-induced and other changes in forestry and agricultural activities on net carbon balance (Bernoux et al. 2010). This land-use-based accounting system measures changes in carbon soil stocks, and CH_4 ,N_20 and CO_2 emissions associated with agricultural and forestry activities, and expresses them in terms of net flows of t CO_2 eq./ha/year. The purpose of this tool is to estimate the impacts of proposed GHG mitigation interventions at the scale of the proposed intervention, but results can be scaled up to the regional and nation levels (Cerri et al. 2010). The EX-ACT tool is comprised of 18 linked Microsoft Excel sheets that contain IPCC-compatible information on soil type, climatic conditions, and land-use and management practices needed to generate estimates

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[8] Although many greenhouse gas emissions are associated with farm activities, CO_2, CH_4, and N_2O (carbon dioxide, methane, and nitrous oxide) are recognized as the most prominent contributors (Smith et al. 2008; Paustian 2004); we focus on these. CO_2 is the product of residue burning, machine use, and tillage practice; CH_4 emissions result from flooding soils for rice cultivation; and N_2O is the product of nitrogen-based fertilizer application. Conversion to CO_2 equivalents takes into consideration the different reflective capacities of each gas in the atmosphere (IPCC 2006).

[9] This accessible tool was developed to estimate the emission mitigation potential of rural development and other agricultural projects. It is based on international standards and methods developed by the IPCC and FAO.

[10] In earlier briefs "Estimating GHG Emissions Associated with Livestock Production in LAC" and "Estimating GHG Emissions Associated with Area Expansion in Agriculture in LAC," IPCC National Inventories Guidelines were used in all cases that were applicable.

of GHG emissions, and provides "business-as-usual"[11] and intervention mitigation scenarios as outputs.

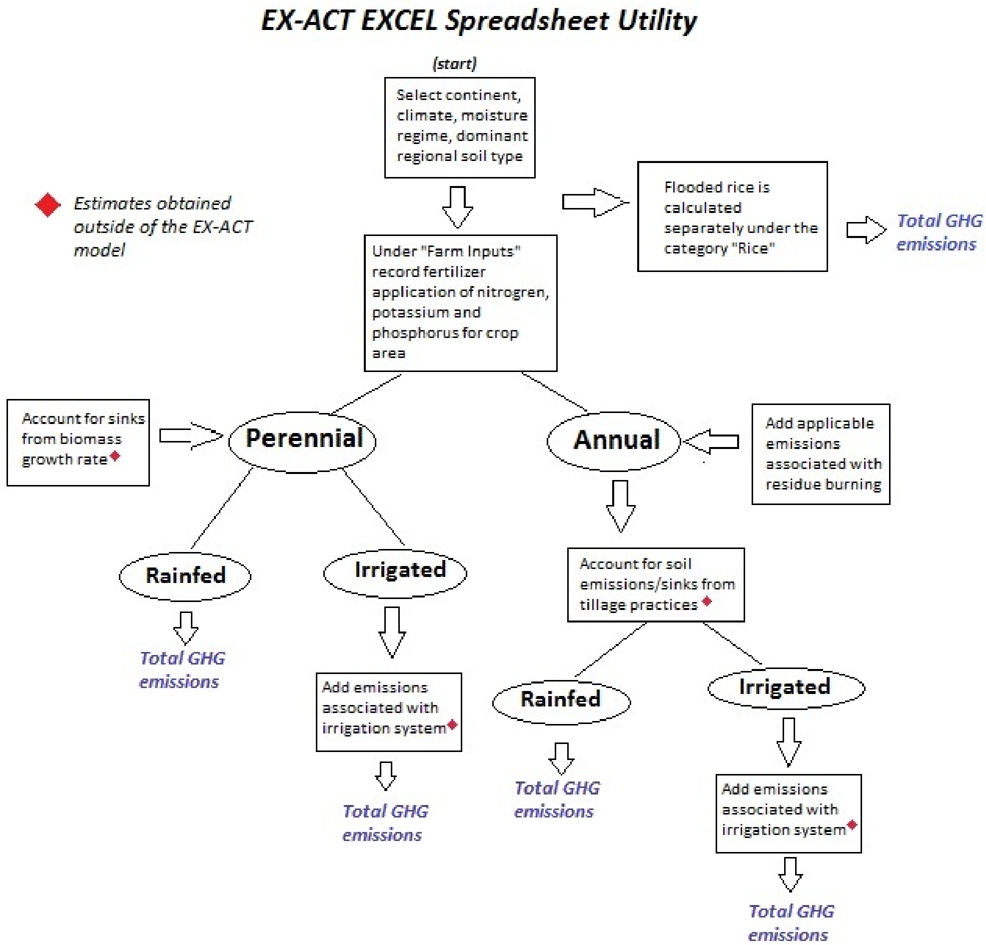
The sequence of steps used by the EX-ACT tool to asses GHG emissions is similar to the thought process a farmer would use in making his/her decisions: where to plant, what to plant, and what production technology to use. While this logical agricultural decision making framework allows us to estimate emissions from fertilizer application, fuel usage, etc., quite accurately, there are gaps in the model's internal accounting system that can be addressed using outside sources (e.g., the absence of irrigation as a contributing factor to crop- and technology-specific GHG emissions). The flow chart below (Figure 4) describes the steps[12] involved in using EX-ACT to generate estimates of CO_2 emissions for each crop, the step-specific information contained in the model to facilitate this process, and identifies the points at which data from outside the model are required.[13]

[11] "Business as usual" is defined as the land use strategy that is being supplanted by the proposed intervention. Examples include replacing forested land with annual crops, or, switching from annual crops to perennial tree crops. In both examples, the GHG emissions associated with the land use existing prior to the intervention would be the "business as usual" scenario.

[12] For a complete explanation of how these estimates were obtained, see the research brief "Greenhouse Gas Emissions Associated with Annual and Perennial Crop Production Activities" (Zanocco and Vosti 2010c).

[13] These are estimates that do not have direct default values in the EX-ACT model.

Figure 4: Crop-Specific GHG Emissions Estimation Pathways in EX-ACT



GHG emissions coefficients for five macro regions of Brazil (plus one national summary measure) for rice production and for establish coffee production appear in Table 2; a complete set of coefficients is presented in the Appendix in Table 11. The case of rice production is showcased for several reasons. First, note that GHG emissions vary by region of Brazil, due to differences in soil types, mainly. Second, emissions vary under different production technologies; irrigation dramatically increased GHG emissions, due primarily to fertilizer applications. Third, soil management practices have the ability to 'shift' GHG emissions from a source to a sink, though the potential for doing so varies by region, primarily (once gain) due to differences in soil type. Soil management practices are not relevant for (e.g.) established coffee production systems (second half of Table 2), which *emit* about one ton of CO_2 eq ha/year – as a comparison, newly established coffee production systems can *sequester* up to about 5 tons of CO_2 ha/year (see Table 11).

Table 2: GHG Emissions for Rice and Coffee Production in Brazil, by Production Technology and by Region

Crop	Regions in Brazil	Irrigated vs. Rainfed	Emissions flows associated with fertilizer application in CO_2 eq./ha/year	CO_2 equivalent per year associated with irrigation	Range of SOC sequestration or emissions, rotation crop systems, -0.627 to +0.687		Range of yearly net flow of CO_2 equivalent per hectare of cropland		
					sequest	emit	Low	High	Average
Rice	North	upland rainfed	0.08	0	-0.627	0.687	-0.55	0.77	**0.1**
		upland irrigated	0.08	0.15	-0.627	0.687	-0.55	0.77	**0.1**
		flooded	4.10	0.15	0	0	0	0	**4.3**
	Southeast	upland rainfed	0.30	0	-0.627	0.687	-0.33	0.99	**0.3**
		upland irrigated	0.30	0.15	-0.627	0.687	-0.33	0.99	**0.3**
		flooded	4.10	0.15	0	0	0	0	**4.3**
	Northeast	upland rainfed	0.15	0	-0.627	0.687	-0.48	0.84	**0.2**
		upland irrigated	0.15	0.15	-0.627	0.687	-0.33	0.99	**0.3**
		flooded	4.10	0.15	0	0	4.25		**4.3**
	South	upland rainfed	0.35	0	-0.627	0.687	-0.27	1.04	**0.4**
		upland irrigated	0.35	0.15	-0.627	0.687	-0.12	1.19	**0.5**
		flooded	4.10	0.15	0	0	4.25		**4.3**
	center west	upland rainfed	0.29	0	-0.627	0.687	-0.34	0.97	**0.3**
		upland	0.29	0.15	-0.627	0.687	-0.19	1.12	**0.5**
		flooded	4.10	0.15	0	0	4.25		**4.3**
	avg. input across Brazil	upland rainfed	0.25	0	-0.627	0.687	-0.38	0.94	**0.3**
		upland irrigated	0.25	0.15	-0.627	0.687	-0.23	1.09	**0.4**
		flooded	4.10	0.15	0	0	4.25		**4.3**
Coffee (established plantation)	North	rainfed	0.26	0	-0.627	0.687	-0.37	0.95	**0.3**
		irrigated	0.26	0.15	-0.627	0.687	-0.37	0.95	**0.3**
	Southeast	rainfed	1.04	0	-0.627	0.687	0.41	1.73	**1.1**
		irrigated	1.04	0.15	-0.627	0.687	0.41	1.73	**1.1**
	Northeast	rainfed	0.54	0	0	0	0.54		**0.5**
		irrigated	0.54	0.15	0	0	0.69		**0.7**
	South	rainfed	1.28	0	0	0	1.28		**1.3**
		irrigated	1.28	0.15	0	0	1.43		**1.4**
	center west	rainfed	0.99	0	0	0	0.99		**1.0**
		irrigated	0.99	0.15	0	0	1.14		**1.1**
	avg. input	rainfed	0.97	0	0	0	0.97		**1.0**
		irrigated	0.97	0.15	0	0	1.12		**1.1**

Note to Table: For details regarding content, see Table 11 in the Appendix.

Extrapolating Brazil-Based GHG Emissions to the Rest of LAC

Brazil was selected for this pilot exercise because of the country's broad array of ecological conditions. For the time being, the region-specific, crop/production technology-specific GHG emission coefficients contained in Table 3 were strategically allocated to similar ecoregions throughout LAC. This provides the IMPACT model with a comprehensive (albeit preliminary) set of GHG emissions estimates for all products produced in every FPU in LAC.[14]

4.3 Estimating GHG Emissions Associated with Livestock Production in LAC

This section sets out the strategy used to estimate GHG emissions from livestock production activities in LAC, and reports the results of its implementation. We adapt the greenhouse gas accounting methodology outlined by the IPCC (2006). The two major forms of emissions associated with livestock production are CH_4 from enteric fermentation and N_2O from animal waste. We focuses on these two emissions sources and do not account for potential CO_2 emissions associated with machinery used in herd management or the CO_2 sinks/sources from pasture establishment/management activities. At this juncture, emissions estimates associated with types of livestock are generalized for the entire LAC region.[15]

Livestock Emissions

The LAC cattle herd is comprised predominantly of two types of animals (dairy cattle and beef cattle), each of which is managed in accordance with a fairly homogeneous production system (IPCC 2006). The commercialized dairy sector is based on grazing on managed pastures with some stall feeding. Each dairy cow is assumed to weigh approximately 400 kg and to produce an average of 800 kg of milk per year. Beef cattle are included in the IPCC category of other cattle, which includes steers, bulls and very young cattle; these animals are managed on pastures and rangelands. The average weight of all other cattle is assumed to be 305 kg per head.

The methane emissions estimates for these two types of cattle are 72 kg CH_4/head/yr for dairy cattle and 56 kg CH_4/head/yr for other cattle. Under current pasture- and range-based manure management systems in Latin America, average methane emissions from manure is 1 kg

[14] Future work will focus on generating more refined estimates of crop-/production-technology-specific GHG emissions for LAC FPUs located outside of Brazil.

[15] Future research will focus on refining GHG emissions estimates for livestock activities at the more disaggregate FPU level.

CH_4/head/yr for both dairy cattle and other cattle. The sums of these two methane estimates for dairy cattle and for other cattle are reported in column D of Table 4 as total kg CH_4/head/yr.

The second major animal-based contributor to GHG emissions is animal waste. Columns E-H account for this source. Estimates of kilograms of nitrogen excreted are a function of animal body weight (IPCC 2006); on average, dairy cows produce 0.19 kg of nitrogen per day per kg of live weight, while beef cattle produce about 0.11 kg of nitrogen per day per kg of live weight. Adjusting from day-length measures to annual measures and multiplying by live body weight (column A) yields an estimate of total nitrogen excreted per head per year (column F). Approximately 2% of excreted nitrogen is volatized as N_20 (column G). Finally, multiplying the volatized amount of nitrogen by the total amount excreted provides an estimate of total N_20 emitted from animal waste, per animal per year.

To arrive at CO_2 equivalent measures, annual N_2O and CH_4 emissions per head are normalized to tons of CO2 per head using the global warming potential (GWP) conversion factors of 21 units of CO_2 per unit of CH_4 and 310 units of CO_2 per unit of N_2O (IPCC 1995). Estimates of the total global warming potential associated with dairy cattle (1.97 t CO_2/head/year) and beef cattle (1.45 t CO_2/head/year) can be found in the first two rows of Table 4, under the final column (K).

This GHG emissions calculation procedure was repeated for sheep, goats, alpacas, buffalo and swine. Our estimates for all of these animals are consistent with those provided by Embrapa (2002).[16] IPCC data were insufficient for estimating the greenhouse gas emissions associated with poultry and llama production systems, so a separate method[17] was utilized.

[16] To check these estimated values, the Brazilian Agricultural Research Background Reports "Methane from Livestock" and "Nitrous Oxide Emissions from Agricultural Soils" were consulted. Using 1995 data, total estimated emissions of livestock animals was divided by the total head counts, and per-ton CO_2/head/yr estimates were obtained (bold, next sentence). The animal-type-specific estimates are consistent with our method (CH_4+N_2O); dairy *cattle* **1.59**, *beef cattle* **1.43**, and *sheep* **0.18**. Our estimates for dairy cattle are somewhat higher than those of Embrapa. Embrapa estimates based only on CH_4 emissions are *goats* **0.1**, *buffalo* **1.19**, *swine* **0.4**, and *poultry* **0.002**.

[17] Verge et al. (2009) estimates annual poultry emissions as being in the range of 1.06 – 2.16 kg CO_2 per 1 kg of live weight. For the purposes of this study, we will use a mean value of 1.61 CO_2 kg/yr per 1 kg of live weight. Live bird weight estimates range between 1.5 -2 kg (FAO 2007). For our purposes, we assume mean live bird weight to be 1.75 kg. Based on these assumptions, we estimate GHG emissions from poultry to be 0.003 ton CO_2/beak/yr.

Table 3: Estimates of CO_2 Emissions for LAC, by Livestock Category

		Methane Calculations			Nitrous Oxide Calculations				Converting N_2O to CO_2	Converting CH_4 to CO_2	Final Calculation of CO_2
Livestock Category	Average weight in kg per head from IPCC 2006[18]	Entric Fermen-tation kg CH_4/head/yr, from IPCC 2006[19]	Manure production in kg CH_4 per head per yr, from IPCC 2006[20]	Total kg CH_4/head/yr	Conversion factor of live weight to Kg N excreted per 1000 kg animal per day[21] (IPCC 2006)	Kg N excreted per head per year	Kg N excreted conver-sion factor to Kg N_2O[22]	Total kg N_20/head/yr	GWP of N_20 factor (*310) to kg CO_2	GWP of CH_4 factor (*21) to kg CO_2	tons CO_2/head/year
	A	B	C	D	E	F	G	H	I	J	K
Dairy cattle	400	72	1	73	0.48	70.08	0.02	1.40	434.50	1533	1.97
other cattle	305	56	1	57	0.36	40.08	0.02	0.80	248.48	1197	1.45
Sheep	45	8	0.28	8.28	1.13	18.56	0.02	0.37	115.07	173.88	0.29
Goats	40	5	0.2	5.2	1.37	20.0	0.02	0.40	124.01	109.2	0.23
Alpacas	65	8	0.28	8.28	1.13	26.81	0.02	0.54	166.22	173.88	0.34
Buffalo	300	55	1	56	0.32	35.04	0.02	0.70	217.24	1176	1.39
Swine	100	1.5	1	2.5	1.64	59.90	0.02	1.20	371.13	52.5	0.42
Poultry	n/a	n/a	n/a	n/a	0.82	n/a	n/a	n/a	n/a	n/a	0.003[23]
Formulas				A + C = D		(A x E) *(365/1000) = F		F x G = H	H x 310 = I	D x 21 = J	(I + J)/1000 = K

The values of GHG emissions for each type of livestock that comprise the LAC region are reported in final column of Table 4. We apply these emissions estimates uniformly across all FPUs. This homogeneity, which may indeed represent true GHG emissions values for livestock

[18] From Table 10.10, 2006 IPCC: Emissions from Livestock and Manure Management

[19] From Table 10.10, value for Developing Countries was assumed, 2006 IPCC: Emissions from Livestock and Manure Management

[20] Manure methane emissions estimates are from Table 10.14 and 10.15, assuming warm/Latin America, 2006 IPCC: Emissions from Livestock and Manure Management

[21] The units of the default IPCC values for nitrogen excretion rate in Latin America are in Kg N/ (1000 kg animal mass) a day. Equation 10.30 was used from 2006 IPCC: Emissions from Livestock and Manure Management.

[22] Conversion factor of kg N excreted to kg N_20 is based on the IPCC calculations that Cederberg et al. (2009) use for generalized pasture excretion. In these calculations, 2% of the kg Nitrogen excreted by the animal in the form of manure was volatilized into kg N_2O, or 0.02*kgN = kg N_2O. The value is the same as assuming a dry lot area for the default emissions factors for direct N_2O in Table 10.21 of 2006 IPCC: Emissions from Livestock and Manure Management.

[23] This estimated emission is from Verge et al. (2009).

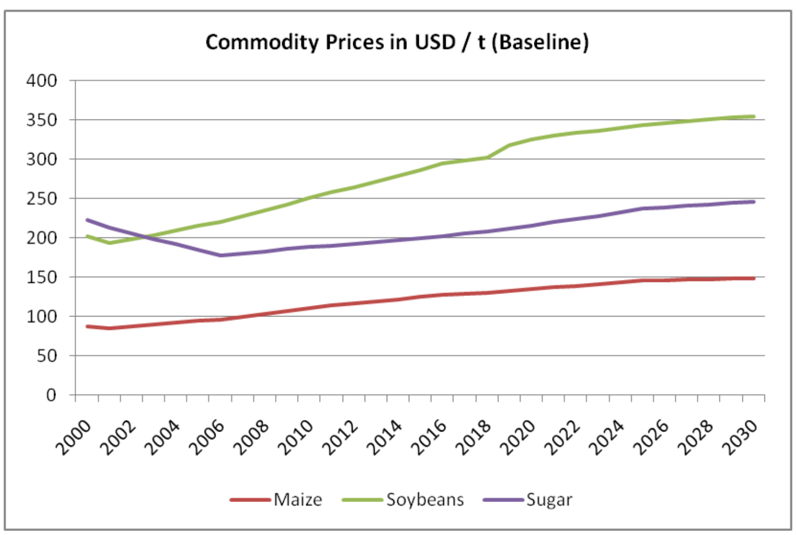
in LAC, will serve as placeholders at this juncture – future work will aim to generate more precise, FPU-specific estimates.

5. Results of Model Simulations

5.1 IMPACT Model's Baseline Simulation

The baseline simulation is that currently reported by IFPRI (Rosegrant and Msangi 2009), which includes the recent, significant effects of current and future expected demand for biofuels. This baseline predicts an array of supply/demand adjustments that lead to increases in real prices for most staple commodities over the next 20 years or so, and more gradual increases in the prices of animal products (especially beef). Figure 5 and Figure 6 report these trends for selected commodities; increases in real food prices will have negative consequences for the poor in developing countries and policy actions anywhere in the world that put further upward pressure on food prices will only exacerbate this problem. Recall that price signals in the IMPACT model are global in nature (i.e., all countries face identical border prices), but that FPUs *within* specific countries face prices that may be distorted by national agricultural or other policies.[24]

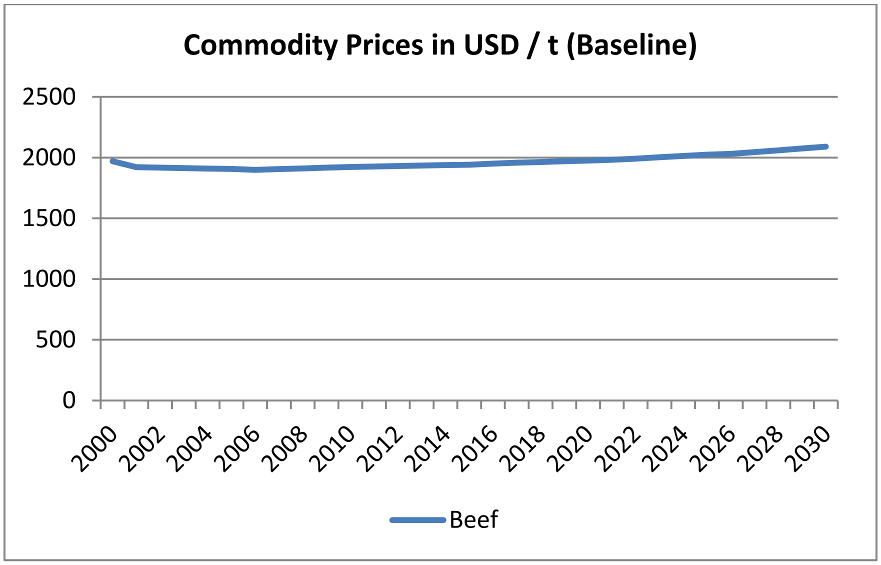
Figure 5: Projected World Prices for Key Commodities--Baseline Scenario (US$/mt)



Source: IMPACT model simulations.

[24] The reader should also note that no bilateral or multi-lateral restrictions or preferences are imposed in international trade in the IMPACT model. The model also does not address temporary or long-term trade restrictions associated with foot-and-mouth disease in cattle, or any other product quality issues.

Figure 6: Projected World Prices for Beef – Baseline Scenario (US$/mt)



Source: IMPACT model simulations.

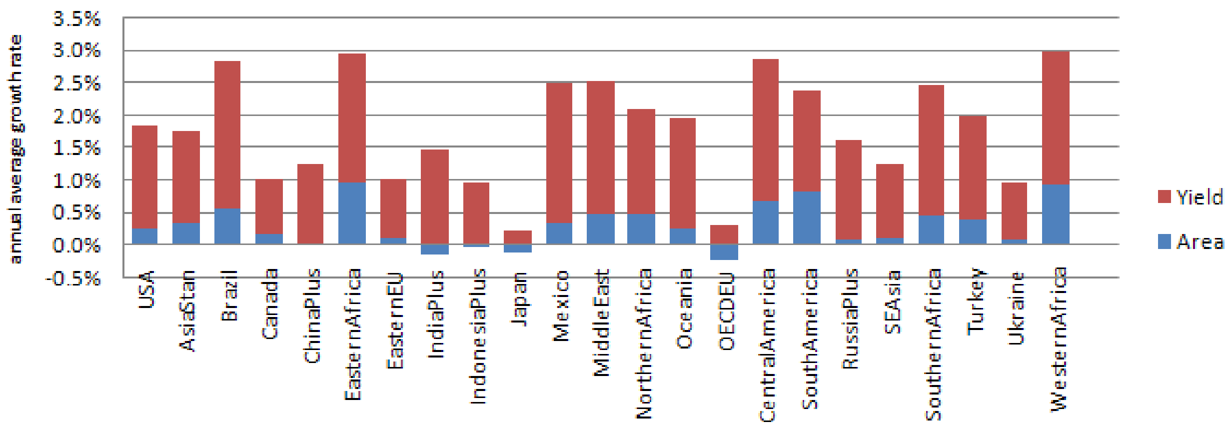
The baseline simulation also produces estimates of *all* of the products produced in *each* of the FPUs throughout the world, including all of the FPUs that comprise the LAC region, and the land and water resources required to produce them. We report here on a subset of the area and production results that are relevant for the issues we set out to address. More specifically, we have selected 2030 as our 'snapshot' year for reporting on land clearing and as our 'ending year' for reporting GHG emissions that accumulate from 2010 (our 'baseline year') to 2030.

Sources of growth in the baseline

Before assessing the marginal effects of any policy affecting agricultural GHG emissions in LAC, it is important to know and to understand likely trends in global agriculture and the driving forces behind these trends. Although LAC's contribution to global food production is quite significant, farmers outside of LAC will always provide the majority of the world's food supply, so global trends can mute or make more costly any policy effort to manage agricultural GHG emissions in LAC.

When we look at the baseline trajectory of production to 2030, from the IMPACT model, we can identify the sources of growth (from extensification or intensification) for each region, and use it as an indicator of where more pressure will be put on land cover to meet future demands for food and feed, and which regions have underexploited the land-saving gains that could be achieved through increasing yield further. As noted by FAO (2002), about 70% of crop production growth to 2030 is be expected to come from yield growth; this is especially true in developing countries, where much of the yield potential has yet to be fully exploited. This pattern largely holds at the global level (Figure 7).

Figure 7: Decomposition of Annual Average Rates of Cereal Production Growth to 2030 (Global)

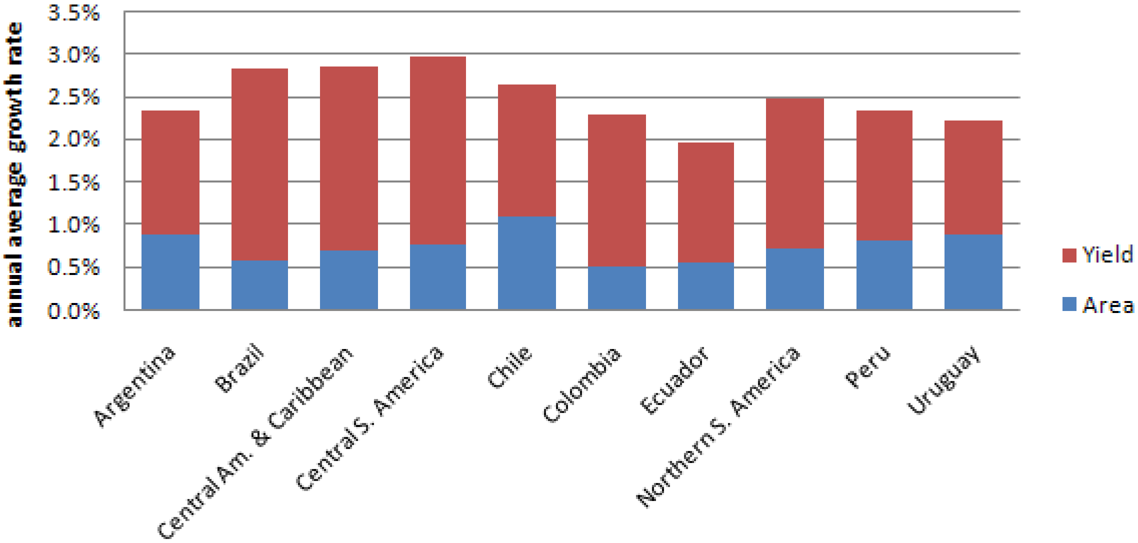


Source: IMPACT model simulations.

Africa is expected to have the highest rates of area expansion (reaching almost 1% p.a. growth), and Latin America ranks the next highest as a region. This is in contrast with the EU countries and with both East and South Asia, where very high population densities amidst well-established systems of irrigated agriculture have already exploited most of the area available for agriculture. Sub-Saharan Africa, by contrast, has exploited only about 2% of its irrigation potential and has much unexploited land that is suitable for agricultural – poor market linkages and infrastructure conditions continue to constrain the expansion of cultivated area and the modernization of agriculture in this region.

Within LAC, the sources of future agricultural growth are somewhat more uniform (Figure 8). That said, Chile and Argentina will likely have the highest rates of area expansion to 2030, compared to countries like Colombia, where much area expansion is a more costly way to increase total than yield growth.

Figure 8: Decomposition of Annual Average Rates of Cereal Production Growth to 2030 (Latin America)



Source: IMPACT model simulations.

Perhaps surprisingly, Brazil is likely to benefit disproportionally (vis-à-vis other countries in LAC) from yield growth; this is in part attributable to the very substantial investments made in agricultural research over the past several decades which is now fueling productivity increases, cost savings to farmers, and (for some crops and in some regions of Brazil) reductions in GHG emissions (Cerri 2009). Other countries, such as Central America and the Caribbean, are starting from much lower yield levels for cereal crops and will likely rely relatively heavily on area expansion to increase output over the next two decades.

Global demand growth and its impact on GHG emissions in Latin America

Taking the baseline case of the IMPACT model, we can now examine the growth of agricultural GHG emissions in Latin America from 2010 to 2030, and try and attribute this growth to the demand-side drivers of change that are most dynamic within the world food economy over this period. Recall that agricultural GHG emissions can arise from three sources: area expansion, crop production (on established and newly cleared lands), and livestock – all three of these sources are explicitly included in our calculations. [25] The final (shaded) row of

[25] For data and methodologies used to calculate agricultural GHG emissions, see previous sections titled *Estimating GHG Emissions Associated with Livestock Production in LAC*, *Greenhouse Gas Emissions Associated with*

Table 5 reports the summary measures of GHG emissions: currently (2010), agriculture in LAC emits approximately 980 million tons of CO_2 equivalent per year, this expected to decrease to 946 million tons by 2020, and to approximately 871 million tons by 2030.

Increasing demand for food, globally, exerts a ‘pull’ on agriculture in Latin America through the market forces that elicit ever-increasing levels of grain and livestock exports from the region, and which are fastest-changing in the emerging ‘giants’ of the global economic landscape – namely, China, India and Brazil. To illustrate the impact of these countries’ food demand growth on GHG emissions from agriculture in LAC, a simple simulation was run in which we hold the socio-economic growth of a subset of these countries constant over the 2000-2030 period, and examine the effects of how this modeler-imposed ‘slow-down’ in food and feed demand translates into lower agricultural expansion and production in LAC and fewer agricultural GHG emissions. By doing this sequentially – such that food demand is ‘frozen’ for one, then two and finally all of the ‘BrIC[26]’ countries – we are able to derive the decomposition shown in the middle section of Table 5, below.

Table 4: Decomposing Demand Drivers of Agricultural GHG Emissions in LAC (2010 to 2030)

	Agricultural GHG Emissions in LAC (millions of tons CO_2 eq./yr)			**Agricultural GHG Emissions (% of total LAC Agricultural Emissions)**		
	2010	**2020**	**2030**	**2010**	**2020**	**2030**
China	47.4	43.5	39.8	5%	5%	5%
India	16.7	14.4	14.5	2%	2%	2%
Brazil	10.0	13.8	12.6	1%	1%	1%
Rest of the World	906.4	874.3	804.1	92%	92%	92%
Total LAC	980.4	946.0	871.0			

Source: IMPACT simulations

Annual and Perennial Crop Production Activities and *Estimating GHG Emissions Associated with Area Expansion in Agriculture in LAC.*

[26] In this case, we deviate from the usual definition of ‘BRIC’ by leaving out Russia, in order to simplify the comparison.

Note that China has the largest share of the BrIC countries' contribution to demand-driven GHG emission growth in the LAC region, and (by 2030) is more than twice that of India and Brazil. In aggregate, though, the BrIC countries account for only up to 8% of the LAC emissions growth over the simulation period; it is difficult to 'blame' the BrIC countries for fueling agricultural change and the resulting GHG emissions from agriculture in LAC. However, the fact that only approximately 1% of that is attributed to the fastest-growing LAC country (Brazil) illustrates how important China and India are in shaping the market dynamics of the world food market, especially over the medium term. While the best policy response to this is not necessarily to put restrictions on trade of LAC products – there is obviously a need for a coordinated and global policy mechanism to account for the carbon contribution of agricultural products, so that appropriate labeling, pricing or other consumer-oriented policies can be instituted (globally) to persuade commodity brokers, food processors and (ultimately) consumers to consider the environmental externalities of their food consumption patterns when making choices.

Behind the summary GHG emissions numbers reported for the LAC region in Table 5 lay patterns and trends regarding the contributions of agricultural sub-sectors – land expansion, cropping activities and livestock production. Table 6 reports the percentage contributions of these three sub-sectors to total agricultural GHG emissions for countries or groups of countries that comprise the LAC region, for 2010 and for 2030. Note the very substantial contribution of livestock production activities to aggregate GHG emissions for virtually all LAC countries. The calculations are straightforward – on average, beef cattle emit approximately 1.47 t CO_2 eq head/year.[27] For a Brazilian beef cattle herd of approximately 200 million, this translates into approximately 294 million tons of CO_2 equivalent, each year. Second, cropping activities make up a relatively small and temporally stable share of aggregate GHG emissions. While area dedicated to cropping is larger than that dedicated to livestock production in most LAC countries, the per-hectare emissions tend to be low and can be negative for perennial tree crops during the establishment phase.[28] Third, while the per-hectare contribution of land expansion is by far the highest-emitting sub-subsector (with emissions volumes reaching over 700 tons of

[27] See previous section *Estimating GHG Emissions Associated with Livestock Production in LAC* for details.
[28] See previous section *Greenhouse Gas Emissions Associated with Annual and Perennial Crop Production Activities* for details.

CO_2 eq./hectare in densely forested areas)[29], the absolute number of hectares converted to agriculture is small in 2010 and declining thereafter, relative to the total acreage under plow or dedicated to pastures to sustain livestock herds.

Table 5: Agricultural GHG Emissions, by Sub-Sector, 2010 and 2030

	Contribution of Sectors to Total GHG Emissions under Baseline (%)					
	2010			2030		
	Land Expansion	Cropping Activity	Livestock	Land Expansion	Cropping Activity	Livestock
Argentina	61%	6%	33%	44%	9%	47%
Brazil	40%	6%	54%	26%	7%	67%
Central America & Caribbean	59%	5%	36%	41%	7%	52%
Central South America	51%	6%	44%	27%	7%	65%
Chile	40%	7%	52%	18%	9%	73%
Colombia	26%	4%	70%	10%	4%	85%
Ecuador	50%	5%	45%	26%	6%	68%
Mexico	34%	11%	55%	16%	12%	72%
Northern South America	39%	7%	54%	18%	7%	75%
Peru	56%	8%	36%	29%	11%	60%
Uruguay	28%	6%	66%	8%	7%	85%

5.2 Using the IMPACT Model to Assess the Effects of a Major Policy Change

At this point, we put the IMPACT model to work on identifying the consequences of managing agriculture in LAC in ways that reduce GHG emissions. There are many potential points of departure for such an exercise, some of which have already begun to gain traction in policy arenas. For example, regional and national plans have been established or are being established to set aside forested and other areas (in part to retain the carbon fixed in native vegetation these areas contain), and to develop alternative land use and farming practices that can reduce the agricultural GHG emissions; e.g., Brazilian National Law for Climate Change (Lei n. 12,187) or the Action Plan for Preventing and Controlling Land Clearing and Vegetation Burning in the Savannahs (Serviço Público Federal 2010). Moreover, policy instruments to help secure the

[29] *See previous section Estimating GHG Emissions Associated with Area Expansion in Agriculture in LAC* for details.

success of these action plans and law are being developed and tested, e.g., REDD+ (Nepstad 2009). All of these plans and laws will be costly to implement and will likely succeed to differing degrees in meeting their stated objectives.

But what if they are successful? What would be the consequences, intended and otherwise – locally, nationally and globally – of such successes, taken together? For the most part, we do not know. Local environmental successes are sometimes touted (e.g., reductions in deforestation rates in some parts of the Brazilian Amazon), but few are keeping track of even in local consequences, let alone broader consequences. Informed policy action requires knowledge of all benefits and costs.

To begin to explore the environmental and economic consequences of successfully managing agricultural GHG emissions, we focus on a one aspect of agricultural change that (on a per-hectare basis) is *the* most important contributor to GHG emissions – land clearing for agriculture. Moreover, to fully assess the consequences of success, we model *complete* success – i.e., we use the IMPACT model to establish 'upper bound,' site-specific estimates of the total agricultural GHG emissions reductions that *could be achieved* by a complete halt to the expansion of agriculture into forested and other areas containing natural vegetation. In the process, we will also discover what the agricultural and other consequences of such a successful land use policy would be. While there is no reason to believe (or to hope) that such a policy would be successful throughout LAC in the near term, policy action is being taken in most countries in LAC to reduce or to manage the location of the expansion of the agricultural frontier. Therefore, while the policy experiment might seem draconian, it takes as its point of departure as an ongoing effort throughout the region to manage agriculture-led land clearing.

To be more specific, we use the IMPACT model to simulate the effects of a *complete and effective ban* on the expansion of area dedicated to agriculture in each of the FPUs within the IMPACT model that lie within the tropical forest swath running from the Yucatan Peninsula to the bottom of the Amazon Forest.[30] Within each of the FPUs lying in this tropical zone, the land dedicated to agriculture in the base year of the simulation (2010) may remain in use, and product mixes and production technologies are free to respond to economic incentives and to water availability. All of the remaining spatial units of agricultural production in the model (within

[30] Beef cattle and milk cow herds are also 'frozen' at 2010 levels in each of the FPUs that are in tropical areas of LAC.

and outside of LAC) are allowed to adjust cultivated area, product mix and production technology choices in response to changes in relative prices brought about by the simulated ban on area expansion in the selected tropical zone within LAC.

The policy simulation effectively halted the expansion of the agricultural frontier in the tropical areas of the LAC region. Total gross 'savings' of natural vegetation in 2030 amounted to approximately 3,339,000 hectares (Table 5). Approximately one third of these gross savings occurred in the FPUs that comprise the Amazon forest; the remaining two thirds of these savings are distributed throughout tropical LAC, but are heavily concentrated in the northern 'rim' of South America surrounding the Amazon and in the Yucatan Peninsula and Central America. The reader will note that the ban on land clearing in tropical areas promotes increased land clearing (vis-à-vis the baseline simulation) in *non*-tropical areas in LAC of approximately 88,000 hectares (from Table 7, below).[31] Hence, the net 'savings' to LAC in terms of cleared land is approximately 3,251,000 hectares.

Table 6: Agricultural area and GHG emissions in 2030, baseline and no expansion policy

	Change in Agricultural Area (thousands of hectares)			Change in Ag GHG Emissions (millions of tons CO_2 eq./yr)		
	2030 Baseline	2030 No-Expansion	Change	2030 Baseline	2030 No-Expansion	Change
Argentina	34,876	34,888	12	164	165	1
Brazil	57,360	57,011	(349)	407	395	(12)
Central America & Caribbean	9,786	8,473	(1,313)	74	34	(40)
Central South America	6,965	6,707	(258)	41	33	(7)
Chile	2,294	2,296	2	20	20	0
Colombia	3,804	3,537	(268)	47	36	(11)
Ecuador	2,790	2,519	(271)	20	12	(8)
Mexico	19,399	19,106	(292)	28	20	(8)
Northern South America	2,417	2,145	(273)	29	18	(11)
Peru	3,593	3,351	(242)	21	14	(7)
Uruguay	1,006	1,007	0	20	20	0
Total LAC	144,291	141,040	(3,251)	871	766	(105)

[31] As the reader will see below, land-clearing activities *outside* LAC are also influenced by the ban on area expansion in LAC. Future work will focus on locating and measuring these important extra-LAC effects.

Source: IMPACT simulations

In addition to this, we see (from Table 7) that the net savings in terms of GHG emissions from agriculture is over 100 million tons of CO_2 equivalent, just in the year 2030. But since the emissions from agricultural (and other) activities have a cumulative effect over time – we want to look at the total savings in GHG emission from agriculture over the simulation time horizon. Table 8 reports the results of these calculations (first three columns) and examines the relative contributions of land clearing, cropping activity and livestock production to these GHG emissions 'savings' (final set of columns).

Table 7: Cumulative Agriculture GHG Emissions (2010-2030), Baseline and No Expansion Policy Scenario

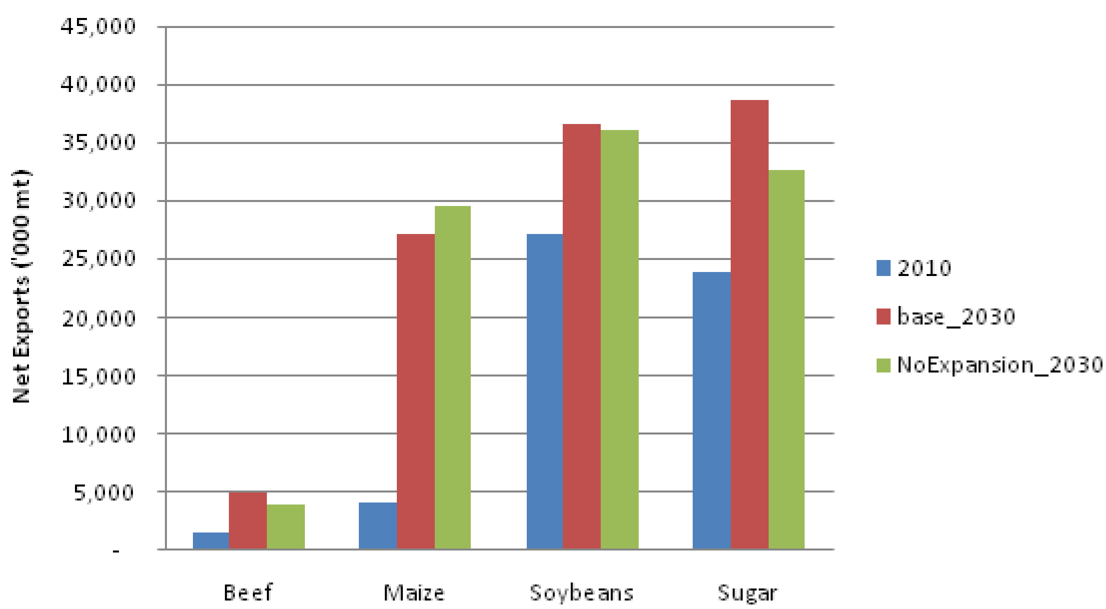
	Cumulative Ag GHG Emissions (millions of tons CO_2 equivalent)			Contribution to Emissions Reduction (thousands of tons CO_2 equivalent)		
	2010-2030 Baseline	**2010-2030 No-Expansion**	**Change**	**Land Clearing**	**Crop Activity**	**Livestock**
Argentina	3,892	3,903	11	3,737	113	6,777
Brazil	8,909	8,601	(308)	(270,204)	(1,589)	(36,092)
Central America & Caribbean	1,599	761	(839)	(735,833)	(7,490)	(95,473)
Central South America	889	734	(156)	(131,308)	(1,372)	(22,947)
Chile	418	420	1	294	11	764
Colombia	979	763	(216)	(143,489)	(1,056)	(70,959)
Ecuador	434	257	(177)	(143,030)	(753)	(33,121)
Mexico	620	437	(183)	(142,521)	(2,636)	(38,324)
Northern South America	606	398	(208)	(145,811)	(2,312)	(60,117)
Peru	462	300	(162)	(138,899)	(958)	(22,332)
Uruguay	399	400	1	50	7	1,188
Total LAC	19,209	16,973	(2,236)	(1,847,015)	(18,036)	(370,637)

Source: IMPACT simulations

In terms of the total savings in agricultural GHG emissions over the simulation period, we see that the *no-expansion* policy realizes a total savings of approximately 2.2 billion tons of CO_2 equivalent over the 2010-2030 period. This is a very considerable volume of GHG. Also noteworthy is the very different contributions across LAC countries of area expansion, cropping and livestock activities to these reduced emission flows. As expected, in Brazil area expansion (mainly clearing in the Amazon forest) is the largest single contributing factor. However, in Colombia, reductions in emissions from cattle ranching contribute the largest share of GHG emissions reductions.

The amounts and types of agricultural products that are exported by LAC countries are also affected by the ban on area expansion in tropical FPUs in the region, but marginal effects for the region as a whole are small compared with the dramatic shift in trade patterns that are expected to take place over the next two decades even *without* taking the extreme policy action to protect forests included in our experiment. Figure 9 depicts the net export levels for all of Latin America for soybeans, maize, beef and sugar under the baseline case, as well as under the simulated ban on deforestation.

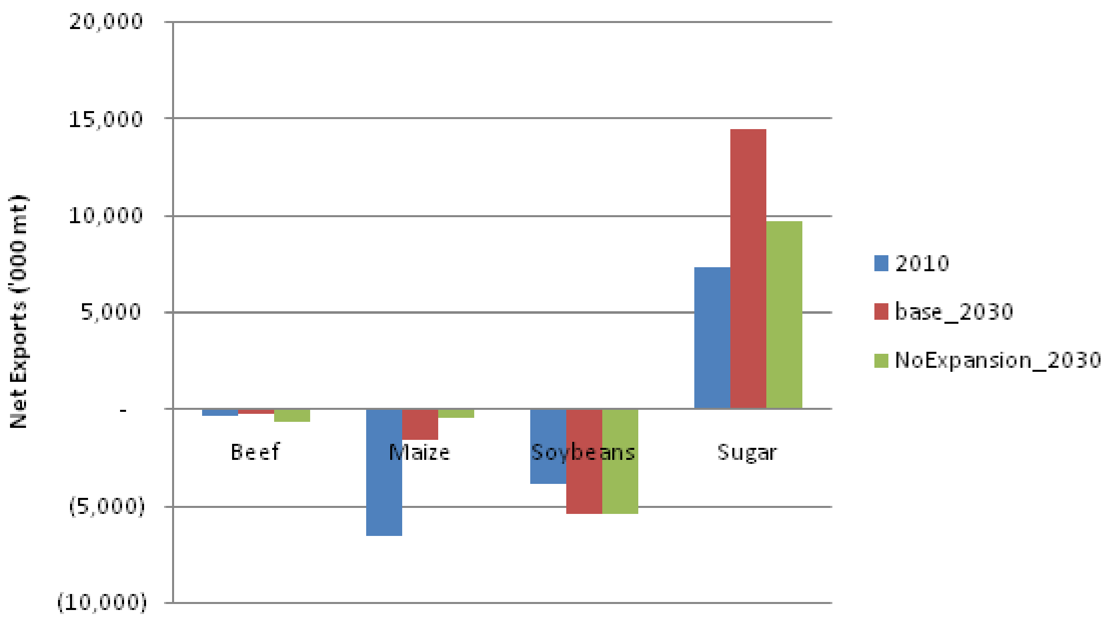
Figure 9: Net Trade in Selected Commodities, LAC Region



Source: Authors' calculations.

Note that only the maize exports increase once the area expansion ban is in place (after 2010), reflecting the fact that as prices rise, producers allocate more land and other resources to this now more profitable crop. The decrease in export levels in other crops reflects the decline in the area dedicated to soybeans and (especially) sugar and beef. By-and-large, however, the LAC region remains a major exporter of all these commodities, even with the ban on area expansion in place.

Figure 10: Net Trade in Selected Commodities, Central America and the Caribbean



Source: Authors' calculations.

The same is not true, however, for Central America and the Caribbean (Figure 10). We note, immediately, that this region is a net importer for most commodities, except sugar – which sees a decline in net exports, as was seen elsewhere in LAC. We also see, though, that the net imports for maize decrease, which is along the same trend as that seen for the other maize-exporting regions of LAC, and reflects the fact that maize production is increasing in the no-expansion scenario, as well.

While the effects of the ban on area expansion led to fairly homogeneous effects on trade patterns within LAC (Central America and the Caribbean being the notable exception), the economic effects of the ban varied quite significantly across the region. The simulated ban on area expansion in tropical FPUs reduced most, but not all, agricultural activities in these FPUs *from what they would have been* (as predicted by the baseline simulation). The implications of the area expansion ban for total agricultural GDP in the tropical FPUs are clearly negative and large. For example, the gross value of agricultural production in 2030 in the Amazon region is approximately \$3.4 billion lower than in the (unconstrained) baseline; for the tropical FPUs taken as a whole, the figure is approximately \$12.7 billion (see final two sets of columns of Table 9). This decline is partially offset by increases in the gross value of agricultural production in *non*-tropical FPUs in LAC of approximately \$3.4 billion; some of this increase is attributable to area expansion, but most of it is attributable to changes in product mix in these FPUs. Therefore, the overall net effect (in terms of the decline in the gross value of agricultural production) for LAC is approximately \$9.3 billion.

Table 8: Cultivated Area & Gross Value of Agriculture in 2030, Baseline & Policy Simulation

	Total Agricultural Area (Thousands of Hectares)			Total Gross Value of Agriculture (Billions of 2000 USD)		
FPUs	**Baseline 2030**	**Simulation 2030**	**Change**	**Baseline 2030**	**Simulation 2030**	**Change**
Amazon Brazil	4,720	4,303	(417)	13.44	12.29	(1.15)
Central Amazon	2,276	2,016	(260)	4.53	3.93	(0.60)
Amazon Colombia	196	180	(16)	1.26	1.12	(0.14)
Amazon Peru	2,479	2,236	(242)	8.87	7.80	(1.08)
Amazon Ecuador	516	449	(67)	2.74	2.37	(0.38)
Total Amazon	10,187	9,185	(1,002)	30.85	27.50	(3.35)
Caribbean	1,988	1,740	(248)	7.21	6.33	(0.88)
Central America	5,529	4,792	(737)	17.58	15.49	(2.09)
Cuba	1,519	1,290	(229)	4.67	4.02	(0.65)
Northern South America	286	263	(23)	0.96	0.78	(0.17)
Northwest Colombia	2,726	2,530	(196)	13.38	12.35	(1.03)
Northwest Ecuador	2,274	2,070	(205)	10.44	9.33	(1.11)
Orinoco Colombia	882	827	(56)	5.47	5.11	(0.36)
Northern Orinoco	2,131	1,882	(249)	9.69	8.27	(1.42)
Yucatan Caribbean	750	652	(99)	2.35	2.08	(0.27)
Yucatan Mexico	5,517	5,221	(295)	20.39	19.01	(1.38)
Total Tropical LAC	33,790	30,451	(3,339)	122.99	110.27	(12.71)
Coastal Chile	2,294	2,296	2	17.82	17.97	0.14
Central Mexico	10,771	10,772	1	34.47	34.80	0.33
Northeast Brazil	6,451	6,461	10	16.69	16.95	0.27
Parana, Argentina	16,899	16,905	6	25.27	25.49	0.22
Parana, Brazil	24,185	24,223	38	58.38	59.27	0.89
Central Parana	4,689	4,691	2	7.45	7.51	0.06
Coastal Peru	1,114	1,115	1	4.12	4.16	0.04
Rio Colorado, Argentina	630	630	1	3.38	3.42	0.04
Rio Grande, Mexico	968	969	1	4.93	5.00	0.08
Salada Tierra, Argentina	17,306	17,312	6	25.35	25.57	0.22
San Francisco, Brazil	12,001	12,016	15	48.87	49.45	0.59
Tierra, Argentina	40	40	0	1.04	1.06	0.02
Tocantins, Brazil	3,833	3,836	2	8.88	9.01	0.13
Northern Mexico	2,143	2,144	1	8.71	8.82	0.11
Uruguay-Brazil	6,170	6,172	2	14.22	14.41	0.19
Uruguay	1,006	1,007	0	3.52	3.57	0.04
Total *Non*-Tropical LAC	110,501	110,589	88	283	286	3.369

At country level, the economic effects of the ban on area expansion in the tropics is more muted, in part because most countries in the region have ongoing and expanding agricultural activities in non-tropical FPUs and these areas generally profited from the no-expansion policy. That said, at country level the effects of the ban were not uniform. Table 10 presents for 2030 a comparison of total gross value of agriculture for the baseline and for the policy simulation, the change in gross agricultural production value attributable to the no-expansion policy, and the percentage of total agricultural GDP that change represented in 2030. While most countries with tropical FPUs suffered some declines in the gross value of agricultural output, not all did; Brazil, which suffered the largest decline in cleared area in the Amazon (416,000 hectares by 2030) actually benefited from the ban because other FPUs within Brazil (e.g., the Parana and San Francisco FPUs) expanded agricultural area and altered product mix in ways that overcame the 'losses' in the Amazon FPU. Other countries or groups of countries were not so fortunate. In absolute terms, Central America & Caribbean suffered the most significant decline in absolute agricultural gross value. Colombia, Ecuador, Mexico, Northern South America and Peru each lost between 1 and 1.6 billion US$ as a consequence of the ban on area expansion. The largest proportional loss was felt by Ecuador, which suffered a 1.7% decline in total agricultural gross value, which represents almost a quarter of the agricultural value added within the economy. For other regions, however, the relative size of the shock is much smaller.

Table 9: Gross Value of Agriculture, Baseline and Effects of No Expansion Policy

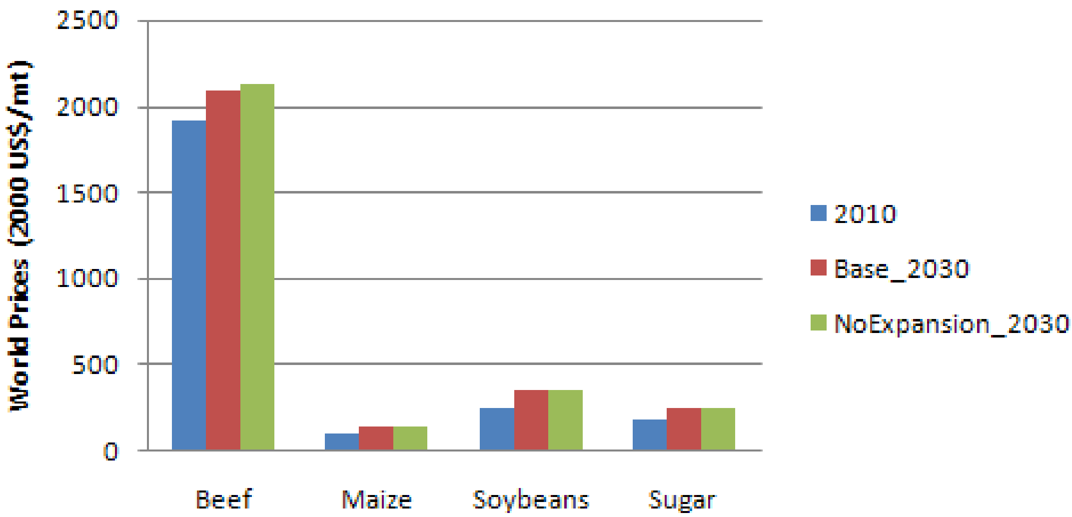
	Total Gross Value of Agriculture (Billions of USD)			% of Total Agricultural GDP 2030	Agricultural value-added (as % of total GDP)*
	Baseline 2030	Simulation 2030	Change		
Argentina	55	56	0.50	0.06%	10%
Brazil	160	161	0.91	0.04%	6%
Central America & Caribbean	32	28	(3.89)	-1.24%	
Central South America	12	11	(0.54)	-0.80%	
Chile	18	18	0.14	0.04%	4%
Colombia	20	19	(1.53)	-0.37%	9%
Ecuador	13	12	(1.49)	-1.71%	7%
Mexico	20	19	(1.38)	-0.13%	4%
Northern South America	11	9	(1.59)	-0.52%	
Peru	13	12	(1.04)	-0.41%	7%
Uruguay	4	4	0.04	0.07%	11%

* Note: these data are from WDI, however values for aggregated IMPACT regions are not available

As indicated at the outset of this DP, at global level there is concern about the effects on world food prices of managing agriculture to reduce GHG emissions, and there is skepticism regarding the potential for policy action to reduce emissions in LAC without increasing emissions elsewhere on the planet to meet food needs. We address these issues in turn.

We can use the IMPACT model to assess the effects of the no-expansion policy in tropical LAC on global-level market prices, which drive the trade and production response of the model, in regions outside of Latin America.

Figure 11: World Commodity Price Changes Associated with No-Expansion Scenario



Source: IMPACT simulations.

Figure 11 shows the effects of the ban on the expansion of agricultural area in tropical LAC on world prices for beef, soybeans, sugar and maize. Soybean and maize price changes associated with the simulated ban on area expansion are less than one-half of one percent higher than baseline prices in 2030, and the price changes for sugar are also small (about 1.5% higher than baseline 2030 levels). Beef prices, however, increase significantly more (about 4% above baseline prices in 2030), and stand out in this comparison given the much higher value of beef, compared to the other crop commodities. Overall, the price effects associated with the area expansion ban are relatively small.

The simulation results for one key product (beef) explain why world price changes associated with the considerable decline in cultivated area in tropical LAC (over 3.3 million hectares) are small. As one would expect, all of the countries containing the targeted tropical FPUs report significant declines in beef exports – e.g., net beef exports in 2030 from Colombia decline by 622 percent vis-à-vis what would have been exported in 2030 under the baseline scenario.[32] However, in response to increases in beef prices, other countries either increase the supply of beef (e.g., Argentina increased beef exports by 15 percent) or decreased net imports (e.g., China reduced beef imports by 26 percent). Similar supply/demand adjustments occur

[32] See *The Effects of Banning Agricultural Area Expansion in LAC's Tropical Zones: An IMPACT Model Simulation* (Msangi et al 2010) for details.

globally for other commodities, as well, and tend to dampen the price effects of the area expansion ban imposed on the tropical region of LAC.

This is one example of 'leakage' that results from market-mediated price transmission, which causes agents in regions outside the policy target area to respond in ways that offset the effect of the policy. In this set of simulations, we have not calculated the global agricultural GHG emission changes that would be implied by these changes, due to lack of (time and) data on the appropriate GHG coefficients to apply to all the 281 FPUs in IMPACT model. This would have illustrated what the carbon leakage would have been, from only imposing a carbon-focused policy in one region of the world – and is analogous with other policies that try and address climate mitigation on a regional scale. To illustrate – one of the topics being debated currently on biofuels policy in the US, is how to account for the carbon leakage transmitted through global fuel and feedstock markets that might induce 'indirect land use changes' (iLUC) that offset the carbon-savings of switching to a non-fossil-based fuel. Searchinger *et al.* (2008) brought this issue into clear focus, and has stimulated a debate over the measurement of iLUC and how to account for indirect effects when designing low-carbon fuel policies, such as the one currently in force in the state of California (Farrell and Sperling, 2007). As was illustrated by a recent study commissioned by the European Commission (Edwards *et al.*, 2010) – it is a complex issue to address and reach agreement upon, given the wide variety of modeling methods that can be used to measure market impacts and land use changes.

In this study, we have employed one global model, IMPACT, in order to illustrate the possible 'rebound' or 'leakage' that can occur when restrictions on production (or the technologies of production) are imposed in a particular region that is well-connected to other regions through global trade. The importance of Latin America in the global food economy will only grow as we move towards 2030, and the influences of other regions and their increasing demand for the agricultural exports coming from the LAC region will serve as a stronger pull for agricultural production and land, which has implications for the design, implementation and cost of national and regional environmental policies.

Finally, improving child health is an agreed-upon international objective and hence merits attention in this brief. In the IMPACT model, childhood malnutrition is determined (essentially) by the cost of obtaining calories to consumers. By this metric, the global effect of the simulated ban on area expansion in LAC on child malnutrition is small, but not insignificant

– the number of malnourished children is expected to increase by about 50,000 in developing countries, mostly in Asia. However, the ban on area expansion will likely have negative income and employment effects *within* topical FPUs in LAC that are not addressed in the IMPACT model; and these effects may lead to local increases in childhood malnutrition, especially within poorer households.

6. Conclusions and their Policy Implications

Several important conclusions emerge from the IMPACT model baseline simulation, and from the comparison of the baseline results with those of the policy simulation that banned area clearing for agriculture in tropical LAC, and some of these may have important policy implications.

First, agriculture in LAC contributes very substantially to GHG emissions. Emissions in 2010 were approximately 980 million metric tons of CO_2 eq. and are expected to fall to approximately 871 million tons per year by 2030. In most countries, the majority of GHG emissions are from livestock and that share will likely increase throughout LAC over the next 20 years.

Second, the net GHG emissions that could be avoided *in LAC* by a complete and effective ban on agriculture-led land clearing in tropical areas of the region are quite substantial. For the region as a whole, GHG emissions could be reduced by approximately 2.2 billion tons of CO_2 eq. over the 2010-2030 period. Most reductions would come in the form of reduced land clearing, but reductions in (especially) livestock production and cropping activities would also contribute to emissions reductions.

Third, these avoided GHG emissions may be quite valuable, so it may be possible to tap REDD+ and other market-based mechanisms to cover some of the costs of restricting agricultural expansion to reduce GHG emissions. However, the wide range of market prices for CO_2 over the past five years or so make the task of valuing GHG emissions challenging and the results uncertain. [33]   That said, at the average price of CO_2 equivalent OTC transactions in LAC

[33] For example, the Chicago Climate Change was trading at 4.40 t/CO_2 equivalents in 2008 and is currently no longer in operation. European markets have fared better, with carbon equivalents trading at $15.20 in 2009. We adopt a conservative approach using a combination of regulated and voluntary carbon emission mechanisms for our estimation purposes. See Vosti et al. (2010) for more explanation on this topic.

in 2009 (roughly US$ 4.30/t CO_2 eq.), our estimates suggest such compensation schemes could cover well over 1/2 of the value of the losses in agricultural output in 2030 in the tropics associated with the ban.

Fourth, any attempt to manage agricultural GHG emissions in LAC may cause agricultural GHG emissions to increase in other regions of the world. While we have not yet measured these 'leakage' effects outside of LAC, our results suggest that it will be challenging to convince donors and others financing policy actions to reduce GHG emissions in LAC that such 'leakage' will not occur.

Fifth, the key position of Latin America as a supplier of agricultural products to the rest of the world (and particularly the fast-growing economies of Asia) make the 'rebound' effects of instituting a region-focused policy more pronounced than it would otherwise be if LAC were mainly an importer that was driving the demand of other regions.

Sixth, the local costs of a ban on agricultural expansion would be substantial. Vis-à-vis the baseline, the gross value of forgone agricultural production for all of the tropical FPUs would be approximately US$ 12.7 billion in 2030. But these costs would not be born uniformly across the Latin American countries. For example, in 2030, Central America & Caribbean would face losses of about US$ 3.9 billion and Ecuador would lose 1.7 percent of agricultural GDP, while Argentina would gain US$ 0.5 billion and Brazil (which would lose over 400,000 hectares of agricultural area by 2030, primarily in the Amazon) would actually gain about US$ 0.9 billion from the area expansion ban. This non-uniform distribution across FPUs (and across countries) may call for spatially non-uniform policies for administering the land clearing ban or for compensating 'local' stakeholders, or both.

Seventh, substantial shifts in trading patterns for maize and soybeans are predicted to occur in the region *in the absence* of the ban on area expansion; the marginal effects of the ban on these patterns for the countries that comprise the tropics of LAC, and for the region as a whole, would not be great. That said, the ban on the expansion of agricultural lands would 'speed up' expected shifts in trade patterns in most cases. However, the ban could cause net exports of beef and sugar from the region to fall, but these effects would differ by sub-region and country; e.g., net sugar exports would decline markedly from the Central America and the Caribbean, but increase from Brazil.

Finally, the overall *global* effects of banning agriculture-led land clearing in tropical LAC on food production and food prices would be relatively small, and the effects on childhood malnutrition would also be small but not insignificant. Our analysis highlights the ability of the global food production system to adjust to the reduction in area available for agriculture by changing product mix, increasing productivity in areas currently under plow, and by expanding cultivated area in other regions of the world. While we have not made it explicit in our analysis, we also know that these adjustments are governed by site-specific characteristics such as production costs and water availability. While some might expect to see more dramatic effects resulting from a ban on area expansion in environmentally sensitive tropical regions, this analysis shows that global food demand and food trade trends adjust to policy-induced changes in relative prices, further muting the effects of the ban on area expansion in LAC.

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Technical Appendix: Greenhouse Gas Emissions from Agricultural Activities in Brazil, by Commodity and by Production Technology

Table 10: Regional Crop-Specific Greenhouse Emissions for Brazil

Crop	Regions in Brazil[34]	Irrigated vs. Rainfed	Emissions flows associated with fertilizer application in CO_2 eq./ha/year,[35]	CO_2 equivalent per year associated with irrigation[36]	Range of SOC sequestration or emissions, rotation crop systems, -0.627 to +0.687[37]		Range of yearly net flow of CO_2 equivalent per hectare of cropland[38]		
					sequest	emit	Low[39]	High[40]	Average[41]
Cotton	North	rainfed	0.00	0	0	0	0	0	**n/a**
		irrigated	0.00	0	0	0	0	0	**n/a**
	Southeast	rainfed	0.93	0	-0.627	0.687	0.30	1.62	**1.0**
		irrigated	0.93	0.15	-0.627	0.687	0.30	1.62	**1.0**
	Northeast	rainfed	0.49	0	-0.627	0.687	-0.14	1.17	**0.5**
		irrigated	0.49	0.15	-0.627	0.687	0.01	1.32	**0.7**
	South	rainfed	1.09	0	-0.627	0.687	0.46	1.78	**1.1**
		irrigated	1.09	0.15	-0.627	0.687	0.61	1.93	**1.3**
	center west	rainfed	0.89	0	-0.627	0.687	0.26	1.58	**0.9**
		irrigated	0.89	0.15	-0.627	0.687	0.41	1.73	**1.1**
	avg. input	rainfed	0.82	0	-0.627	0.687	0.19	1.50	**0.8**
		irrigated	0.82	0.15	-0.627	0.687	0.34	1.65	**1.0**
Rice	North	upland rainfed	0.08	0	-0.627	0.687	-0.55	0.77	**0.1**
		upland irrigated	0.08	0.15	-0.627	0.687	-0.55	0.77	**0.1**
		flooded	4.10	0.15	0	0	0	0	**4.3**
	Southeast	upland rainfed	0.30	0	-0.627	0.687	-0.33	0.99	**0.3**
		upland irrigated	0.30	0.15	-0.627	0.687	-0.33	0.99	**0.3**

[34] There are 5 listed regions in Brazil: North, Northwest, Centre West, Southeast, and South.
[35] Estimates of the amounts of fertilizer application were obtained from Table 14, *Fertilizer use by crop in Brazil* (FAO 2004)
[36] Obtained from *Soil Management Concepts and Carbon Sequestration in Cropland* (Follet 2001)
[37] Range obtained from *Microbiological parameters as indicators of soil quality under various soil management and crop rotation systems in southern Brazil* (Franchini et al. 2007), conventional tillage with crop rotation.
[38] This is the summation of fertilizer application, irrigation and sequest/emit. The midpoint of the **low** (sequestered) and **high** (emission) estimation is listed as **average**. This amounts to soil emissions of 0.03 t CO_2 eq./ha/yr. This component of the estimation process will need to be revisited in the next phase of work.
[39] **Low =** fertilizer emissions + irrigation emissions + SOC sequestration
[40] **High** = fertilizer emissions + irrigation emissions + SOC emissions
[41] **Average** = (**Low** + **High**)/2

		flooded	4.10	0.15	0	0	0	0	**4.3**
	Northeast	upland rainfed	0.15	0	-0.627	0.687	-0.48	0.84	**0.2**
		upland irrigated	0.15	0.15	-0.627	0.687	-0.33	0.99	**0.3**
		flooded	4.10	0.15	0	0	4.25		**4.3**
	South	upland rainfed	0.35	0	-0.627	0.687	-0.27	1.04	**0.4**
		upland irrigated	0.35	0.15	-0.627	0.687	-0.12	1.19	**0.5**
		flooded	4.10	0.15	0	0	4.25		**4.3**
	center west	upland rainfed	0.29	0	-0.627	0.687	-0.34	0.97	**0.3**
		upland	0.29	0.15	-0.627	0.687	-0.19	1.12	**0.5**
		flooded	4.10	0.15	0	0	4.25		**4.3**
	avg. input across Brazil	upland rainfed	0.25	0	-0.627	0.687	-0.38	0.94	**0.3**
		upland irrigated	0.25	0.15	-0.627	0.687	-0.23	1.09	**0.4**
		flooded	4.10	0.15	0	0	4.25		**4.3**
Potato	North	rainfed	0.00	0	0	0	0	0	**n/a**
		irrigated	0.00	0	0	0	0	0	**n/a**
	Southeast	rainfed	1.27	0	-0.627	0.687	0.64	1.95	**1.3**
		irrigated	1.27	0.15	-0.627	0.687	0.64	1.95	**1.3**
	Northeast	rainfed	0.66	0	-0.627	0.687	0.04	1.35	**0.7**
		irrigated	0.66	0.15	-0.627	0.687	0.19	1.50	**0.8**
	South	rainfed	1.41	0	-0.627	0.687	0.78	2.10	**1.4**
		irrigated	1.41	0.15	-0.627	0.687	0.93	2.25	**1.6**
	center west	rainfed	1.23	0	-0.627	0.687	0.60	1.92	**1.3**
		irrigated	1.23	0.15	-0.627	0.687	0.75	2.07	**1.4**
	avg. input	rainfed	1.32	0	-0.627	0.687	0.70	2.01	**1.4**
		irrigated	1.32	0.15	-0.627	0.687	0.85	2.16	**1.5**
Coffee (established plantation)	North	rainfed	0.26	0	-0.627	0.687	-0.37	0.95	**0.3**
		irrigated	0.26	0.15	-0.627	0.687	-0.37	0.95	**0.3**
	Southeast	rainfed	1.04	0	-0.627	0.687	0.41	1.73	**1.1**
		irrigated	1.04	0.15	-0.627	0.687	0.41	1.73	**1.1**
	Northeast	rainfed	0.54	0	0	0	0.54		**0.5**
		irrigated	0.54	0.15	0	0	0.69		**0.7**
	South	rainfed	1.28	0	0	0	1.28		**1.3**
		irrigated	1.28	0.15	0	0	1.43		**1.4**
	center west	rainfed	0.99	0	0	0	0.99		**1.0**
		irrigated	0.99	0.15	0	0	1.14		**1.1**
	avg. input	rainfed	0.97	0	0	0	0.97		**1.0**
		irrigated	0.97	0.15	0	0	1.12		**1.1**
Coffee (newly established	North	rainfed	1.54	0	-5.6		-4.06		**-4.0**
		irrigated	0.26	0.15	-5.6		-5.19		**-5.2**
	Southeast	rainfed	1.04	0	-5.6		-4.56		**-4.6**
		irrigated	1.04	0.15	-5.6		-4.4		**-4.4**

plantation)[42]	Northeast	rainfed	0.54	0	-5.6		-5.06		**-5.1**
		irrigated	0.54	0.15	-5.6		-4.91		**-4.9**
	South	rainfed	1.28	0	-5.6		-4.32		**-4.3**
		irrigated	1.28	0.15	-5.6		-4.17		**-4.2**
	center west	rainfed	0.99	0	-5.6		-4.61		**-4.6**
		irrigated	0.99	0.15	-5.6		-4.46		**-4.5**
	avg. input	rainfed	0.97	0	-5.6		-4.63		**-4.6**
		irrigated	0.97	0.15	-5.6		-4.48		**-4.5**
Sugar cane *with* residue burning[43]	North	rainfed	0.17	0	-0.627	0.687	-0.46	0.85	**0.2**
		irrigated	0.17	0.15	-0.627	0.687	-0.46	0.85	**0.2**
	Southeast	rainfed	0.59	0	-0.627	0.687	-0.04	1.27	**0.6**
		irrigated	0.59	0.15	-0.627	0.687	-0.04	1.27	**0.6**
	Northeast	rainfed	1.82	0	-0.627	0.687	1.20	2.51	**1.9**
		irrigated	1.82	0.15	-0.627	0.687	1.35	2.66	**2.0**
	South	rainfed	2.21	0	-0.627	0.687	1.58	2.90	**2.2**
		irrigated	2.21	0.15	-0.627	0.687	1.73	3.05	**2.4**
	center west	rainfed	2.08	0	-0.627	0.687	1.45	2.77	**2.1**
		irrigated	2.08	0.15	-0.627	0.687	1.60	2.92	**2.3**
	avg. input	rainfed	2.05	0	-0.627	0.687	1.42	2.73	**2.1**
		irrigated	2.05	0.15	-0.627	0.687	1.57	2.88	**2.2**
Sugar cane without residue burning	North	rainfed	0.17	0	-0.627	0.687	-0.46	0.85	**0.2**
		irrigated	0.17	0.15	-0.627	0.687	-0.46	0.85	**0.2**
	Southeast	rainfed	0.59	0	-0.627	0.687	-0.04	1.27	**0.6**
		irrigated	0.59	0.15	-0.627	0.687	-0.04	1.27	**0.6**
	northeast	rainfed	0.31	0	-0.627	0.687	-0.32	1.00	**0.3**
		irrigated	0.31	0.15	-0.627	0.687	-0.17	1.15	**0.5**
	South	rainfed	0.69	0	-0.627	0.687	0.07	1.38	**0.7**
		irrigated	0.69	0.15	-0.627	0.687	0.22	1.53	**0.9**
	center west	rainfed	0.56	0	-0.627	0.687	-0.06	1.25	**0.6**
		irrigated	0.56	0.15	-0.627	0.687	0.09	1.40	**0.7**
	avg. input	rainfed	0.53	0	-0.627	0.687	-0.10	1.22	**0.6**
		irrigated	0.53	0.15	-0.627	0.687	0.05	1.37	**0.7**
Beans	North	rainfed	0.03	0	-0.627	0.687	-0.59	0.72	**0.06**
		irrigated	0.03	0.15	-0.627	0.687	-0.59	0.72	**0.06**
	Southeast	rainfed	0.11	0	-0.627	0.687	-0.52	0.79	**0.1**
		irrigated	0.11	0.15	-0.627	0.687	-0.52	0.79	**0.1**
	Northeast	rainfed	0.06	0	-0.627	0.687	-0.57	0.75	**0.1**
		irrigated	0.06	0.15	-0.627	0.687	-0.42	0.90	**0.2**
	South	rainfed	0.13	0	-0.627	0.687	-0.50	0.81	**0.2**
		irrigated	0.13	0.15	-0.627	0.687	-0.35	0.96	**0.3**
	center west	rainfed	0.11	0	-0.627	0.687	-0.52	0.79	**0.1**
		irrigated	0.11	0.15	-0.627	0.687	-0.37	0.94	**0.3**
	avg. input	rainfed	0.08	0	-0.627	0.687	-0.55	0.76	**0.1**
		irrigated	0.08	0.15	-0.627	0.687	-0.40	0.91	**0.3**

[42] Rate of 1.33 tonne biomass accumulation for Arabica coffee saplings (Moraes et al. 2010)

[43] Emissions include 1.515 t CO_2eq/ha/yr related to burning practices, from Wang et al. (2007)

Citrus (established plantation)[44]	North	rainfed	0.13	0	0	0	0.163		**0.2**
		irrigated	0.13	0.15	0	0	0.163		**0.2**
	Southeast	rainfed	0.51	0	0	0	0.539		**0.5**
		irrigated	0.51	0.15	0	0	0.539		**0.5**
	Northeast	rainfed	0.26	0	0	00	0.26		**0.3**
		irrigated	0.26	0.15	0	0	0.41		**0.4**
	South	rainfed	0.62	0	0	0	0.62		**0.6**
		irrigated	0.62	0.15	0	0	0.77		**0.8**
	center west	rainfed	0.48	0	0	0	0.48		**0.5**
		irrigated	0.48	0.15	0	0	0.63		**0.6**
	avg. input	rainfed	0.48	0	0	0	0.48		**0.5**
		irrigated	0.48	0.15	0	0	0.63		**0.6**
Citrus (newly established plantation)[45]	North	rainfed	0.13	0	-6.6		-6.47		**-6.5**
		irrigated	0.13	0.15	-6.6		-6.32		**-6.3**
	Southeast	rainfed	0.51	0	-6.6		-6.09		**-6.1**
		irrigated	0.51	0.15	-6.6		-5.94		**-5.9**
	Northeast	rainfed	0.26	0	-6.6		-6.34		**-6.3**
		irrigated	0.26	0.15	-6.6		-6.19		**-6.2**
	South	rainfed	0.62	0	-6.6		-5.98		**-6.0**
		irrigated	0.62	0.15	-6.6		-5.83		**-5.8**
	center west	rainfed	0.48	0	-6.6		-6.12		**-6.1**
		irrigated	0.48	0.15	-6.6		-5.97		**-6.0**
	avg. input	rainfed	0.48	0	-6.6		-6.12		**-6.1**
		irrigated	0.48	0.15	-6.6		-5.97		**-6.0**
Soybeans	North	rainfed	0.60	0	-0.627	0.687	-0.03	1.29	**0.6**
		irrigated	0.60	0.15	-0.627	0.687	-0.03	1.29	**0.6**
	Southeast	rainfed	0.14	0	-0.627	0.687	-0.48	0.83	**0.2**
		irrigated	0.14	0.15	-0.627	0.687	-0.48	0.83	**0.2**
	Northeast	rainfed	0.08	0	-0.627	0.687	-0.55	0.77	**0.1**
		irrigated	0.08	0.15	-0.627	0.687	-0.40	0.92	**0.3**
	South	rainfed	0.15	0	-0.627	0.687	-0.48	0.83	**0.2**
		irrigated	0.15	0.15	-0.627	0.687	-0.33	0.98	**0.3**
	center west	rainfed	0.15	0	-0.627	0.687	-0.48	0.84	**0.2**
		irrigated	0.15	0.15	-0.627	0.687	-0.33	0.99	**0.3**
	avg. input	rainfed	0.15	0	-0.627	0.687	-0.48	0.83	**0.2**
		irrigated	0.15	0.15	-0.627	0.687	-0.33	0.98	**0.3**
Wheat	North	rainfed	0.00	0	0	0	0	0	**n/a**
		irrigated	0.00	0	0	0	0	0	**n/a**
	Southeast	rainfed	0.14	0	-0.627	0.687	-0.48	0.83	**0.2**
		irrigated	0.14	0.15	-0.627	0.687	-0.48	0.83	**0.2**
	Northeast	rainfed	0.00	0	0	0	0	0	**n/a**
		irrigated	0.00	0	0	0	0	0	**n/a**
	South	rainfed	0.16	0	-0.627	0.687	-0.47	0.84	**0.2**

[44] Established plantations have no net yearly biomass accumulation.
[45] Use a value 1.6 tonnes biomass accumulation rate from USAID Forest Carbon Calculator: Data and Equations for the Agroforestry Tool.

		irrigated	0.16	0.15	-0.627	0.687	-0.32	0.99	**0.3**
	center west	rainfed	0.15	0	-0.627	0.687	-0.48	0.83	**0.2**
		irrigated	0.15	0.15	-0.627	0.687	-0.33	0.98	**0.3**
	avg. input	rainfed	0.16	0	-0.627	0.687	-0.47	0.85	**0.2**
		irrigated	0.16	0.15	-0.627	0.687	-0.32	1.00	**0.3**
Maize	North	rainfed	0.11	0	-0.627	0.687	-0.52	0.79	**0.1**
		irrigated	0.11	0	-0.627	0.687	-0.52	0.79	**0.1**
	Southeast	rainfed	0.39	0	-0.627	0.687	-0.24	1.08	**0.4**
		irrigated	0.39	0.15	-0.627	0.687	-0.24	1.08	**0.4**
	Northeast	rainfed	0.20	0	-0.627	0.687	-0.42	0.89	**0.2**
		irrigated	0.20	0	-0.627	0.687	-0.42	0.89	**0.2**
	South	rainfed	0.46	0	-0.627	0.687	-0.17	1.15	**0.5**
		irrigated	0.46	0.15	-0.627	0.687	-0.02	1.30	**0.6**
	center west	rainfed	0.37	0	-0.627	0.687	-0.26	1.06	**0.4**
		irrigated	0.37	0.15	-0.627	0.687	-0.11	1.21	**0.6**
	avg. input	rainfed	0.36	0	-0.627	0.687	-0.27	1.05	**0.4**
		irrigated	0.36	0.15	-0.627	0.687	-0.12	1.20	**0.5**
Other Crops[46]	North	rainfed	0.03	0	-0.627	0.687	-0.60	0.71	**0.06**
		irrigated	0.03	0.15	-0.627	0.687	-0.60	0.71	**0.06**
	Southeast	rainfed	1.27	0	-0.627	0.687	0.64	1.95	**1.3**
		irrigated	1.27	0.15	-0.627	0.687	0.64	1.95	**1.3**
	Northeast	rainfed	0.07	0	-0.627	0.687	-0.56	0.76	**0.1**
		irrigated	0.07	0.15	-0.627	0.687	-0.41	0.91	**0.3**
	South	rainfed	0.65	0	-0.627	0.687	0.03	1.34	**0.7**
		irrigated	0.65	0.15	-0.627	0.687	0.18	1.49	**0.8**
	center west	rainfed	0.69	0	-0.627	0.687	0.06	1.38	**0.7**
		irrigated	0.69	0.15	-0.627	0.687	0.21	1.53	**0.9**
	avg. input	rainfed	0.39	0	-0.627	0.687	-0.23	1.08	**0.4**
		irrigated	0.39	0.15	-0.627	0.687	-0.08	1.23	**0.6**

[46] Other crops include vegetables and fruits for export, no further information is given in "Fertilizer use by Crops" (FAO 2004)