RESEARCH PAPER

A compilation of agricultural models assessing sectoral dynamics, GHG emissions and abatement opportunities.

The cases of Brazil, Chile, Colombia and Peru under the MAPS Programme

ISSUE 47
A compilation of agricultural models assessing sectoral dynamics, GHG emissions and abatement opportunities.
The cases of Brazil, Chile, Colombia and Peru under the MAPS Programme.

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Country: South Africa

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1. INTRODUCTION

Agriculture is key to rural livelihoods and economic development in many developing countries. It is also a significant source of greenhouse gas (GHG) emissions in many of these countries. Globally, the agriculture, forestry and land use sector (also known as AFOLU) is responsible for 24% (~10 – 12 GtCO₂eq / yr) of anthropogenic GHG emissions, mainly from deforestation and livestock-, soil- and nutrient-management emissions (Smith et al., 2014). The agricultural sector alone is the largest contributor to global anthropogenic non-CO₂ GHGs, accounting for 56% of emissions in 2005 (U. S. EPA, 2011) and 10–12 % of emissions in 2010¹(5.2 – 5.8 GtCO₂eq / yr) (FAOSTAT, 2013; Tubiello et al., 2013).

Research has also found that the sector shows a relatively high potential for GHG mitigation (Smith et al. 2007). According to the IPCC, mitigation in the sector can be tackled with supply-side and demand-side options. The supply options address emissions reduction, emissions avoidance or displacement and enhancement of sinks. The demand options abate GHG by reducing losses and wastes of food, changes in diet and changes in wood consumption.

Several challenges emerge, however, when attempting to mitigate GHG emissions in the agriculture sector. A well-known barrier for assessing climate-related impacts of policy interventions in the sector is the lack of system-wide models that are sufficiently rich to capture local GHG changes or farm system models that are able to capture GHG changes of the whole sector (Rahlao, 2013). Moreover, few models can fully replicate empirical evidence about the agriculture sector, land allocation and land use dynamics or address the entire potential of mitigation actions within the sector. Equally challenging is the paucity of models in the sector that can address social and economic implications of these climate-driven interventions.

This paper aims to provide an extensive review of agriculture modelling frameworks that explain the dynamics of the sector, estimate anthropogenic agriculture GHG emissions, or assess emission changes through mitigation options. The dynamics of the sector can be described both at the sector-wide level (such as the supply and demand of agricultural products and land competition for crops, pasture and forest) and at the farm level (such as soil carbon and nutrient dynamics). The literature review carried out for this paper showed that only a few modelling frameworks can address both agriculture and land use dynamics and the mitigation potential of the sector as a whole. This review is used to compile a database of models that can inform and support modellers and policy makers to develop a country-specific modelling framework or to decide on a set of models that fit best the context of a given country.

Additionally, in order to provide some practical examples, the paper presents the modelling frameworks, data sets, assumptions and the drivers of emissions used to model the agriculture sector in Brazil, Chile, Colombia and Peru under their respective MAPS processes. The ways in which these exercises assess mitigation of non-CO₂ emissions are also described. Both the country case studies and the database can be useful resources for other countries when examining policy interventions to transition to a low-carbon society.

¹ Share decrease largely due to increases in emissions in the energy sector (Smith et al, 2014).
2. METHODOLOGY AND DATA SOURCES

This document is the product of an extensive review of the main characteristics of the models developed and used worldwide to assess the agriculture sector. The Agri-Lab\(^2\) results served as initial input for this paper. The Agri-Lab was a workshop held in Bogota in February 2012, where agriculture experts from Chile, Peru, Colombia and the U.S. discussed the main features of relevant and known models formulated for the sector. Additional desktop-based research was conducted to expand the number of agricultural models, to better understand them and to validate the information discussed during the Lab with the developers of the different agricultural models. Subsequently, the models were classified into three categories according to their scope: farm-level approaches, sector-wide approaches and economy-wide approaches. Additional characteristics, such as the timing of the model, the type of data it uses, and the universe it assesses, are also included in the classification. Table 1 shows the variables used to classify the models.

Table 1. Classification variables

<table>
<thead>
<tr>
<th>Scope</th>
<th>Main characteristics</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm-level models</td>
<td>Dynamic</td>
<td>Models designed to assess farm practices or systems behaviours.</td>
</tr>
<tr>
<td></td>
<td>Static</td>
<td>Models designed to assess the agriculture sector activity as a whole.</td>
</tr>
<tr>
<td>Sector-wide models</td>
<td>Empirical</td>
<td>Models designed to assess the impacts of sectoral variations (changes in land values, supply and demand, and commodity production) in the economy as a whole.</td>
</tr>
<tr>
<td>Economy-wide models</td>
<td>Mechanistic</td>
<td>Models that account for time-dependent changes.</td>
</tr>
<tr>
<td></td>
<td>Emissions. Carbon accounting/Mitigation actions models</td>
<td>Models that are system-analytical or based on the underlying physics and chemistry governing the behaviour of a process. They rely on fundamental knowledge of the interactions between process variables and experiments.</td>
</tr>
</tbody>
</table>

\(^2\) The analysis of mitigation actions in the agriculture sector workshop (Agri-Lab) took place on 15–17 February 2012 in Bogota, Colombia. The objective of the workshop was to understand options and challenges for analysing mitigation actions in the agricultural sector within the context of MAPS country processes, including data requirements and the suitability of tools.
The models overview was then complemented with the assessment of four recent agricultural modelling exercises undertaken by developing countries in Latin America. These four countries, Brazil, Chile, Colombia and Peru, are also part of the MAPS³ community and country-specific data for them was readily available in MAPS documentation, although some of the information was corroborated with the country teams through consultations.

All of the models described in this paper only address anthropogenic (non-energy related) agriculture emissions. Energy emissions from this sector, such as consumption of electricity or fuels from the farming, harvesting or breeding processes, are typically estimated with energy models (e.g., LEAP).

The structure of this paper is as follows. The next section (Database of Agriculture Models) presents the compilation of agriculture models based on a literature review. Tables 2 and 3 provide the characteristics of each model and describe how they are used to mitigate GHG emissions (when relevant). Section 4 describes the modelling frameworks used to assess the agriculture sector under the MAPS processes in the four countries studied. Section 5 reflects and compares on the highlights and shortcomings of the models used under MAPS, and Section 6 presents the conclusions of this analysis and provides recommendations based on the findings of this research.

3. DATABASE OF AGRICULTURE MODELS

The agricultural sector models and tools described in this section are listed in Table 2 and Table 3. They include sector-wide and farm-level models respectively, ranging from accounting to optimization models. The sector-wide models presented in Table 2 (e.g., IMPACT and FASOM GHG) assess market dynamics of agriculture products and land as a whole. They range from non-energy-related GHG accounting tools (IPCC or ASMGHG) to optimizing simulations of the land use and the agriculture activity of a given country (IMPACT). The farm-level models presented in Table 3 address matters from soil carbon and nutrient dynamics to impacts of various management and climate change scenarios on single crops (e.g., WOFOST, ICASA, ORYZA), multiple crops (e.g., APSIM), and entire ecosystems (e.g., CENTURY). Table 4 presents a model – IDSS-SESA Climate Change – that integrates several of the agriculture models described in Table 2 and Table 3. The third kind of model, economy-wide (e.g., CGE, DSGE and input-output accounting), assists the user in evaluating the socioeconomic impacts (e.g., employment of the sector, productivity or added GDP) of changing land values, supply and demand, or commodity production resulting from climate change (UNFCCC, 2008). These models will not be described in this paper because their main goal is not to explain the agriculture sector market dynamics, GHG emissions or emission changes but, rather, use these as inputs to estimate whole-economy reactions to changes in policy, technology or external factors.

³ The Mitigation Actions Plans and Scenarios (MAPS) programme aims to assess developing countries’ climate change mitigation potential that align economic development with poverty alleviation (www.mapsprogramme.org).
Table 2. Sector – economy-wide approaches to model the agriculture sector

<table>
<thead>
<tr>
<th>MODELLING FRAMEWORK</th>
<th>CHARACTERISTICS</th>
<th>HOW THE MODEL IS USED TO ASSESS GHG MITIGATION</th>
<th>SCOPE</th>
<th>MAIN FEATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. IPCC (TIER1)</td>
<td>An empirically based approach used to determine national greenhouse gas inventories that includes soil organic carbon (SOC) stock changes for all land use systems, including agriculture. The model uses a set of coefficients (stock change factors) based on soil type, climate, tillage, productivity and other management practices. The Tier 1 model uses default stock change factors and reference SOC stock provided in the IPCC (2006) Guidelines. (Hillel et al., 2011).</td>
<td>The IPCC methodology is a carbon-accounting approach that uses a generic framework, with increasing levels of data quality and complexity, namely TIER 1, TIER 2 and TIER 3 (Bird et al., 2010). The Tier 1 model uses default carbon stock change factors and reference soil organic carbon stock provided in the IPCC (2006) Guidelines (Hillel et al., 2011). It quantifies three types of carbon pools: (i) change in carbon stock from aboveground biomass; (ii) change in carbon stock from below ground biomass; and (iii) change in soil carbon stock (Timilsina et al., 2011). Tier 2 uses the same methodological approach as Tier 1 but applies country- or region-specific parameters and activity data that are more appropriate for the climatic conditions and land use and agricultural systems in the country (Bird et al., 2010). Carbon-accounting estimates existing carbon stock, which is then used to further assess the scope for additional carbon-stocking in specific regions. Carbon-stocking in tropical forest ecosystems may be an effective way to mitigate climate change by promoting afforestation/reforestation and slowing down deforestation (Lykke et al., 2009).</td>
<td>Sector-wide model (Default to country - Regional specific data)</td>
<td>Static, Empirical, Carbon accounting, Emissions accounting</td>
</tr>
<tr>
<td>2. IPCC (TIER2)</td>
<td>An empirically-based approach used to determine national GHG inventories that include SOC stock changes for all land use systems, including agriculture. The model uses a set of coefficients (stock change factors) based on soil type, climate, tillage, productivity and other management practices. The Tier 2 model uses the same equations but with user-defined change factors and reference SOC stocks. (Hillel et al., 2011).</td>
<td></td>
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<tr>
<td>3. ALU</td>
<td>The Agriculture and Land Use Greenhouse Gas Inventory (ALU) is mostly based on IPCC (2006) equations. It simulates emissions from various types of animals, manure storage and soil using a factorial approach – i.e., nutrient flows from one section (e.g. animals) do not necessarily follow to next phase in the farm (Agri-Lab, 2012).</td>
<td>The ALU simulates emissions from various types of animals, manure storage and soil (Agri-Lab, 2012). The software program is designed to support an evaluation of mitigation potentials using the inventory data as a baseline for projecting emission trends associated with management alternatives.</td>
<td>Sector-wide model (Default to country regional-specific data)</td>
<td>Static, Empirical, Emissions accounting</td>
</tr>
<tr>
<td>4. ASMGHG</td>
<td>The Agricultural Sector and Greenhouse Gas Mitigation Model is a market and spatial equilibrium mathematical programming model designed to assess GHG emission mitigation options through agriculture and forestry. ASMGHG is the US agricultural and mitigation of GHG model. GHG emissions and emission reductions are accounted for all major sources, sinks and offsets from agricultural activities for which data are available. For mitigation purposes, ASMGHG considers, amongst others (i) carbon savings from increases in soil organic matter (reduced tillage intensity and conversion of arable land to grassland) and from afforestation; (ii) carbon offsets from bioenergy production; (iii) methane savings from changes in manure management and grazing management (Schneider et al., 2005).</td>
<td>Sector-wide model</td>
<td>Dynamic</td>
<td></td>
</tr>
<tr>
<td>5. Ex-ACT tool</td>
<td>A-based accounting system, measuring C stocks, stock changes per unit of land, and CH₄ and N₂O emissions expressed in t CO₂e per hectare and year. The main output of the tool is an estimation of the C-balance that is associated with adoption of alternative land management options, as compared to a business as usual scenario. The Ex-Act model is a carbon accounting system, measuring C stocks, stock changes per unit of land, and CH₄ and N₂O emissions expressed in t CO₂e per hectare and year. Its main output is an estimation of the C balance with and without the project, indicating the net amount of C sequestered as a result of adopting alternative land management options (afforestation, reforestation, low tillage etc.), as compared to a business-as-usual scenario. It shows whether a project is able to supply environmental services in the form of C sequestration, thus contributing to climate change mitigation. This assists project designers to select the project activities, which have higher benefits both in economic and climate change mitigation terms (FAO, 2010).</td>
<td>Sector-wide model</td>
<td>Dynamic</td>
<td></td>
</tr>
<tr>
<td>6. Fasom GHG model</td>
<td>The model is used to evaluate the joint economic and biophysical effects of GHG mitigation scenarios in forestry and agriculture. Accounts for changes in CO₂, CH₄ and N₂O including carbon sequestration and emissions over time. The models run simulations for 100-year periods and reports results on a decadal basis. FASOMGHG tracks five forest product categories and over 2,000 production possibilities for field crops, livestock, and biofuels for private lands in the conterminous United States broken into 11 regions. The model simulates the allocation of land over time to competing activities in both the forest and agricultural sectors and the resultant consequences for the commodity markets supplied by these lands and, importantly for policy purposes underlying the development of this model, the net GHG emissions. The Fasom model is used to evaluate the joint economic and biophysical effects of GHG mitigation scenarios in forestry and agriculture. Accounts for changes in CO₂, CH₄ and N₂O including carbon sequestration and emissions over time (Adams, et al., 1996).</td>
<td>Sector-wide model</td>
<td>Dynamic</td>
<td></td>
</tr>
<tr>
<td>7. GAINS</td>
<td>The Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model compares GHG mitigation potentials and costs across Annex I Parties to the UNFCCC. Includes all six gases that are included in the Kyoto Protocol (i.e., CO$_2$, CH$_4$, N$_2$O, HFCs, PFCs, SF$_6$) and covers all anthropogenic sources that are included in the emission reporting of Annex I Parties to the UNFCCC. The model provides a consistent framework for the analysis of co-benefits reduction strategies from air pollution and GHG sources.</td>
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<td></td>
<td>The GAINS model provides low-carbon strategies, synergizing air pollution control and GHG mitigation strategies. The methodology considers (i) conservation, to prevent emissions from existing carbon pools; (ii) sequestration, to increase stocks in existing pools; and (iii) substitution, to substitute energy-intensive products or products on fossil fuel basis with products based on regrowing resources (Böttcher et al., 2008). It demonstrates that the additional costs of climate-friendly measures, such as energy-efficiency improvements, are more than compensated for by savings in air pollution control equipment. GAINS demonstrates that low carbon strategies result in lower emissions of SO$_2$, NO, and fine particulate matter at no additional costs. This is important information for judging the net benefits of greenhouse gas mitigation strategies (IIASA, 2014).</td>
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<tr>
<td></td>
<td>Sector-wide model</td>
<td>Dynamic Emissions accounting</td>
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</tbody>
</table>

| 8. GLOBIOM | The Global Biosphere Management Model (GLOBIOM) is a recursive dynamic partial equilibrium model integrating the agricultural, bioenergy and forestry sectors, aiming to provide policy analysis on global issues concerning land use competition between the major land-based production sectors. The GHG emissions from land use change are derived from the carbon content of above- and below-ground living biomass. |
|  | GLOBIOM integrates the agricultural, bioenergy and forestry sectors with the aim to provide policy analysis on global issues concerning land use competition between the major land-based production sectors. For mitigation purposes, the methodology considers land use change-related options such as afforestation and avoided deforestation to promote C-sequestration (Böttcher et al., 2008). Furthermore, it assesses the marginal costs and challenges associated with reducing deforestation in order to limit climate change (Havlik et al., 2010). |
|  | Sector-wide model | Dynamic Empirical Sector-wide economic model |

<p>| 9. IMAGE | The Integrated Model to Assess the Global Environment (IMAGE) is an integrated assessment-modelling framework describing global environmental change in terms of cause–response chains (Bouwman et al., 2006). Its objective is to explore the long-term dynamics of global change as the result of interacting demographic, technological, economic, social, cultural and political factors. |
|  | IMAGE is a dynamic integrated assessment-modelling framework for global change. IMAGE aims at contributing to scientific understanding and supporting decision-making by quantifying the relative importance of major processes and interactions in the society-biosphere-climate system. IMAGE provides dynamic and long-term perspectives on the systemic consequences of global change; insights into the impacts of global change; a quantitative basis for analysing the relative effectiveness of various policy options addressing global change (Bouwman et al., 2006). |
|  | Sector-wide model | Dynamic Empirical Sector-wide economic model |</p>
<table>
<thead>
<tr>
<th>10. IFPRI IMPACT</th>
<th>Sector-wide model</th>
<th>Dynamic</th>
<th>Empirical</th>
<th>Sector-wide economic model</th>
</tr>
</thead>
</table>

The International Food Policy Research Institute’s International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model is a partial-equilibrium, multi-market model that 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 can be used to estimate emissions today and in 2050, in carbon dioxide equivalent (CO₂e) units (Nelson et al., 2009).

The IFPRI IMPACT model approximates growth in world crop production, disaggregated into 115 countries and includes 32 commodities. Once location-specific land uses have been identified, the next step is to identify the contributions of each of the land uses to the various GHG effects. In a particular case study for Indian agriculture, the methodology explored mitigation options for three agricultural sources of GHGs—CH₄ emissions from irrigated rice production, N₂O emissions from the use of nitrogenous fertilizers, and the release of CO₂ from energy sources used to pump groundwater for irrigation. The next step is estimating the opportunity costs of various mitigation options such as: changing irrigation management techniques for irrigated rice, changing the fertilizer type, raising the price of energy sources used in pumping groundwater, and paying farmers to adopt carbon sequestering management techniques (Nelson et al., 2009).
Table 3. Farm level approaches to model the agriculture sector

<table>
<thead>
<tr>
<th>MODELLING FRAMEWORK</th>
<th>CHARACTERISTICS</th>
<th>HOW THE MODEL IS USED TO ASSESS GHG MITIGATION</th>
<th>SCOPE</th>
<th>MAIN FEATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>11. IFSM</td>
<td>The Integrated Farm System Model (IFSM) is a mechanistic based model that simulates whole-farm emissions of GHG emissions of carbon dioxide, methane, and nitrous oxide. Estimations are done for all sources and sinks including crop production, fuel combustion, the animals, the barn floor, and manure storage (Rotz et al., 2011). Furthermore, it evaluates the overall impact of management strategies used to reduce CH₄ emissions. It uses Mills et al. (2003) equation to predict CH₄ emissions from enteric fermentation.</td>
<td>The IFSM simulates whole-farm emissions of GHG emissions of CO₂, CH₄ and NOₓ. For climate change mitigation purposes, it evaluates the overall impact of management strategies used to reduce CH₄ emissions.</td>
<td>Farm level</td>
<td>Dynamic Mechanistic Whole farm model and Emission accounting</td>
</tr>
<tr>
<td>12. Cowpoll</td>
<td>Polluting cow (Cowpoll) is based on Dijkstra et al. (1992) which is a dynamic and mechanistic model used to calculate methane production in cattle. It simulates the digestion, absorption and outflow of nutrients in the rumen (Kebreab, 2012). This model separates the microbial community into three groups: amylolytic, cellulolytic bacteria, and protozoa. Example of mitigation action: Cowpoll model was used for estimating enteric methane emissions from United States dairy and feedlot cattle (Kebreab, et al., 2008).</td>
<td>Two mechanistic models, Cowpoll and Molly, are used to estimate and calculate methane production in cattle. IPCC values can result in an overestimate of about 12.5% for dairy cattle and an underestimate of 9.8% for feedlot cattle. Cowpoll yields particularly accurate results for dairy cattle and Molly for that of feedlot cattle. Mechanistic models such as these provide improved estimates of emissions based on diets, that can be used to assess mitigation options such as changing source of carbohydrate or addition of fat to decrease methane (Kebreab et al., 2008).</td>
<td>Farm level (Possible to replicate at regional level)</td>
<td>Dynamic Mechanistic Emission accounting (of cattle)</td>
</tr>
<tr>
<td>13. Molly</td>
<td>A dynamic, mechanistic model used to calculate methane production in cattle. This model uses only one group of microbes. Example of mitigation action: The Molly model was used for estimating enteric methane emissions from United States dairy and feedlot cattle (Kebreab, et al., 2008).</td>
<td></td>
<td>Farm level (Possible to replicate at regional level)</td>
<td>Dynamic Mechanistic Emission accounting</td>
</tr>
<tr>
<td>14. Holos</td>
<td>Holos is a whole-farm modelling software program that estimates CO₂, CH₄ and N₂O from enteric fermentation and manure management, cropping systems and energy use. Carbon storage and loss from lineal tree plantings and changes in land use and management are also estimated resulting in a whole-farm GHG estimate. The main purpose of Holos is to mitigate GHG emissions from farms. It is Canadian-based and makes use of scenarios, where users select ones that best describe their farm and then add detail to the extent desired. Holos allows users to contemplate possible options that might reduce emissions, and to estimate how those options affect whole-farm emissions (Holos: GHG software for farms, 2009).</td>
<td>Holos is a whole-farm modelling software program that estimates CO₂, N₂O and CH₄ from enteric fermentation and manure management, cropping systems and energy use. Carbon storage and loss from lineal tree plantings and changes in land use and management are also estimated, resulting in a whole-farm GHG estimate. To mitigate GHG emissions from farms, users select a scenario that best describes their operation, and then contemplate possible options that might reduce emissions, such as planting trees for CO₂ sequestration, to see what effect each change has on GHG emissions (Holos: GHG software for farms, 2009).</td>
<td>Farm level</td>
<td>Dynamic Mechanistic Emission accounting</td>
</tr>
<tr>
<td>Model</td>
<td>Description</td>
<td>Level</td>
<td>Type</td>
<td>Model Characteristics</td>
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<tr>
<td><strong>15. Dairy Gas Emissions Model</strong></td>
<td>A dynamic and mechanistic based model that estimates GHG emissions, H\textsubscript{2}S and ammonia of dairy production systems as influenced by climate and farm management. It does this through daily simulations of feed use and manure handling, which is then summed to obtain annual values. The model is able to predict: CH\textsubscript{4} (enteric, barn floor, manure storage, faeces in pasture), N\textsubscript{2}O (crop and pasture), CO\textsubscript{2} (feed production, respiration), H\textsubscript{2}S, NH\textsubscript{3} (Rotz et al., 2011b).</td>
<td>Farm level</td>
<td>Dynamic Mechanistic</td>
<td>Whole farm model and emission accounting</td>
</tr>
<tr>
<td><strong>16. DSSAT</strong></td>
<td>The Decision Support System for Agrotechnology Transfer (DSSAT) is a decision support cropping system model that can be used at a farm level to determine the impact of climate change on crop production and potential adaptation practices that should be developed for farmers. On a regional level it can be used to determine the impact of climate change at different spatial scales, the main consideration being availability of accurate input data. The software has been used extensively in many different projects funded by US AID and other organizations to determine the impact of climate change on agricultural production and food security (Hoogenboom et al., 2004).</td>
<td>Farm level (Possible to replicate at regional level)</td>
<td>Dynamic Mechanistic</td>
<td>Emission accounting</td>
</tr>
<tr>
<td><strong>17. APSIM</strong></td>
<td>Agricultural Production Systems Simulator (APSIM) is used for analysing whole-farm systems, including crop and pasture sequences and rotations, for estimating GHG emissions and for tactical planning. It was developed to simulate biophysical process in farming systems, in particular where there is interest in the economic and ecological outcomes of management practice in the face of climatic risk. It allows users to improve their understanding of the impact of climate on crop and pasture production. APSIM is a powerful tool for exploring agronomic adaptations such as changes in planting dates, cultivar types, fertilizer/irrigation management, etc. (Thorburn et al., 2010).</td>
<td>Farm level (Possible to replicate at regional level)</td>
<td>Dynamic Mechanistic</td>
<td>Emission accounting</td>
</tr>
<tr>
<td><strong>18. Cool Farm</strong></td>
<td>The Cool Farm tool assesses the mitigation potential of GHG emission for specific farming systems. The software integrates several established empirical models for GHG emissions to give an overall emissions estimate as a function of current farming practice. Users are able to explore the most appropriate GHG mitigation options available to them with the management levers they have (Cool Farm Tool, 2010).</td>
<td>Farm level</td>
<td>Static Empirical</td>
<td>Whole farm model</td>
</tr>
<tr>
<td>Model</td>
<td>Description</td>
<td>Methodology</td>
<td>Spatial Scale</td>
<td>Type</td>
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<tr>
<td>Century</td>
<td>The Century model is a general model of plant-soil nutrient cycling, which simulates carbon (i.e., biomass), nitrogen and other nutrient dynamics. It simulates cropland, grassland, forest and savanna ecosystems and land use changes between these different systems.</td>
<td>The Century model evaluates among others, the impact of changing land management practices for the purpose of GHG mitigation. The methodology considers (i) no-tillage and reducing summer fallow; (ii) introduction of forages into crop rotations and conversion of croplands to grasslands; (iii) nutrient addition via fertilization as a means to increase C sequestration in agricultural soils. In a case study, Century and DNDC models were used to do simulations for five locations across Canada, for a 30-year time period, examining the potential trade-off between C sequestration and increased N₂O emissions. These simulations showed that converting croplands to grasslands resulted in the largest reduction in net GHG emissions, while nutrient additions via fertilizers resulted in a small increase of GHG emissions (Desjardins et al., 2005).</td>
<td>Farm level</td>
<td>Dynamic</td>
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<tr>
<td>DNDC</td>
<td>DNDC (i.e., DeNitrification-DeComposition) is a simulation model of carbon and nitrogen biogeochemistry in agro-ecosystems. The model can be used for predicting crop growth, soil temperature and moisture regimes, soil carbon dynamics, nitrogen leaching, and emissions of trace gases including N₂O, NO, N₂, NH₃, CH₄, and CO₂.</td>
<td>Scenario analysis involves using the model to explore the potential impacts of changes to production systems. In some ways this is similar to sensitivity analysis, except that combinations of changes are usually compared rather than just the effects of individual parameters. Different mitigation strategies can then be compared to assess which could potentially produce the greatest benefit. Scenario analyses can also be used to explore the impacts of climate change on agricultural production and emissions (Giltrap et al., 2010).</td>
<td>Farm level</td>
<td>Dynamic</td>
</tr>
<tr>
<td>WOFOST</td>
<td>WOFOST simulates the daily growth of a specific crop, given the selected weather and soil data. It is a mechanistic model that explains crop growth on the basis of the underlying processes, such as photosynthesis, respiration and how these processes are influenced by environmental conditions. WOFOST has been used by many researchers around the world and has been applied for many crops over a large range of climatic and management conditions (Hijmans et al., 1994).</td>
<td>WOFOST can be used to estimate crop production, indicate yield variability, evaluate effects of climate changes or soil fertility changes, and determine limiting biophysical factors. WOFOST has been used to study the impact of climate change on crop yield potentials and water use (Hijmans et al., 1994).</td>
<td>Farm level (possible to replicate at regional level)</td>
<td>Static</td>
</tr>
<tr>
<td>ORYZA 2000</td>
<td>ORYZA 2000 is a crop-modelling tool used to simulate the growth, development, and water balance of lowland rice under conditions of potential production, and water- and/or nitrogen-limitations. The model combines several modules: aboveground crop growth, evapotranspiration, nitrogen dynamics, soil-water balance, and others (Bouman et al., 2001).</td>
<td>ORYZA 2000 estimates the impact of climate change in rice yields. The model can explore changes in management’s options such as fertilizers, irrigation strategy, sowing date, cultivar type, etc. The key output of the model is rice yields for different climate change scenarios (Bouman et al., 2001).</td>
<td>Farm level (possible to replicate at regional level)</td>
<td>Static</td>
</tr>
<tr>
<td>MODELLING FRAMEWORK</td>
<td>CHARACTERISTICS</td>
<td>HOW THE MODEL IS USED TO ASSESS GHG MITIGATION</td>
<td>SCOPE</td>
<td>MAIN FEATURES</td>
</tr>
<tr>
<td>----------------------</td>
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<tr>
<td>24. IDSS-SESA Climate Change</td>
<td>The Information and Decision Support System for Climate Change Studies in South East South America (IDSS-SESA Climate Change) model is based on the linking and integration of maps and associated databases of soils, weather, land use, and political divisions; national and regional statistics (production, socioeconomic, demographic); prices of inputs and products; remotely sensed information (crops, pastures, natural resources, climate); simulation models of crop, pasture and forest growth, development and production (DSSAT, APSIM); climate change scenarios (GCMs, RCMs, and statistical methods); a statistical package for analysing climate data and generating synthetic weather (LARS and MARKSIM); methods for land use evaluation and for defining land use feasibility classes; a simulation model of soil carbon and nutrient dynamics (Century); tools for agricultural applications of global positioning systems and geographic information systems to process and analyse maps and databases and to generate information that can be easily understandable and applied by agricultural stakeholders (Baethgen, et al., 2001).</td>
<td>The model is used to study the impacts of possible climate change scenarios on different agricultural production systems (livestock, crops, mixed) and on the natural resource base, and explore adaptive technological options (crop/pasture management, input use, mixes of crop and pasture types). The model estimates changes in agricultural productivity and economic results, variation in agricultural and environmental risks, etc., for different climate change scenarios. Produces outputs (e.g., maps, tables, etc.) in formats easily understood by non-specialist users such as policy makers and farmers. Used in INIA-Uruguay, INTA-Argentina, IAPAR-Brazil, EMBRAPA-Trigo, Brazil, and the AIAACC project LA 27 (Baethgen, et al., 2001).</td>
<td>Agro-ecological zone level (national, regional)</td>
<td>Dynamic, Empirical</td>
</tr>
</tbody>
</table>
The selection of a modelling framework to assess agricultural dynamics, GHG emissions and emission changes is driven by the match between specific outputs that the framework is designed to estimate and the key outputs that the assessment is expected to deliver. Considerations about the geographical scope (e.g., national vs regional vs farm), the timing (annually vs daily), the coverage along the value chain (production, trade, retail, etc.) and the sub-sector specificity of the results (i.e. amount of crops included in the analysis) will be taken into account in the process of selecting the modelling framework. Having said that, data requirements are always found to be a determinant barrier to choose the most appropriate model to obtain the desired results.

Most of the sector-wide tools have a common methodological background to estimate GHG emission based on the AFOLU Guidelines for National Greenhouse Gas Inventories from the IPCC (IPCC, 2006; Colomb et al., 2013). The main difference between them is how data activity projections are incorporated into each model. Some tools use exogenous inputs such as governments or producers’ projections of cattle, crop production and land use allocation (e.g., IPCC, ALU, Ex-ACT Tool); others estimate these projections endogenously in the model (e.g., ASMGHG, FASOM GHG, IFRI IMPACT). Another difference is the variables used to inform projections of data activity: drivers of these projections range from macroeconomic to sectoral variables. In the case of livestock projections, for example, macroeconomic variables that could be included in the specification of the projection are national GDP, GDP share of the agricultural sector and population. Sectoral variables that could inform the projection are per capita consumption of meat or milk from the demand side or birth rate, mortality rate or productivity of cattle from the supply side. The depth of the analysis mainly depends on the availability of the data of the drivers of activity.

The farm-level models assess farm- and crop-specific sources and sinks of emissions. Most of these models are system-analytical or based on the underlying physics and chemistry governing the behaviour of the emission processes, which results in more accurate estimates of emissions. For this reason, farm-level models usually require data measured on site. Moreover, many of these models were also designed to evaluate overall impacts of management and adaptation strategies and different climate scenarios (e.g., Cowpoll, Molly, and Dairy Gem).

All the models described above have certain competitive advantages and each is often the best and only tool available in relation to its own field of specialization. A combination of different models is frequently used to achieve more wide-ranging results. This is the case of the IDSS-SESA climate change model, which combines the DSSAT or APSIM with statistical methods and, amongst others, the Century model. The models developed by MAPS countries, which will be described in the next section, generally combined statistical or partial equilibrium models with the IPCC methodological approach.

It is important to highlight that Tables 2, 3 and 4 should be considered as a comprehensive list of tools to assess the agriculture sector dynamics and its GHG emissions. However, the list is not exhaustive. Models that exclusively address climate change adaptation or crop responses to climate, soil, water availability or management practices were excluded. However, given that the line that separates mitigation and adaptation strategies in this sector is not clear, some models may address both issues (e.g., ASPIM). For a comprehensive review of adaptation models see UNFCCC (2005).

Finally, it should be mentioned that the Food and Agriculture Organization of the United Nations (FAO) has developed a multi-criteria GHG tool selector, which considers 18 GHG emission calculators (Colomb et al., 2012) and allows users to specify the main preferences for their analysis using criteria such as region and aim of the analysis, speed and ease of use and scope of the assessment. If the main objective of a modeller is to analyse the current situation of agricultural practices, estimate GHG emissions or assess agriculture strategies and policies, at the farm or country level, this tool may ease the model selection process.
4. AGRICULTURE MODELLING FRAMEWORKS USED IN MAPS
LATIN AMERICAN COUNTRIES

The following section explains the modelling frameworks used to model all non-energy emissions of the agriculture sector in Brazil, Chile, Colombia and Peru under their respective MAPS processes to date. An overview of the models and tools is described as well as the data sets, assumptions and the drivers of emissions used for the estimations. The ways in which these processes assessed mitigation of GHG emissions within the sector are also presented.

4.1 Brazil

In Brazil, the agriculture sector was first modelled outside the MAPS process, as part of a research study to simulate the AFOLU expansion in Brazil in the future (Nassar et al., 2011). This modelling exercise, developed in Excel spreadsheets, included estimations of the future supply and demand of agricultural products produced in Brazil and its impacts on the demand for land and on food, energy and the environment. These estimations were updated and refined by the Agroicone research team and then validated by stakeholders to assess the AFOLU sector’s GHG emissions in the medium term under the Brazilian MAPS process, known as IES Brasil.

The approach to model the sector was a one-country, multi-regional, multi-market, dynamic partial equilibrium economic model that calibrates parameters based on historical land use changes identified by satellite images and secondary data (Nassar et al., 2011). The BLUM tool modelled six different regions and included modules for supply and demand and land use of the agriculture and forestry sectors in Brazil. In the model, the domestic consumption, net exports and final stock at the end of each year defined the total demand. These responded to prices and to exogenous variables such as GDP, population, exchange rates, etc. The initial stock and the production of each year defined the supply. These responded to the profitability of each commodity, which depended on costs, prices and productivity. The market equilibrium was calculated annually at the country level through iterations that found a vector of prices that cleared all markets simultaneously. The model included the following products: soybean, corn and beans (first and second seasons), cotton, rice, cane sugar, wheat, barley, cattle dairy and beef, beef, pork and chicken and eggs. Commercial forests were incorporated as exogenous projections into the model. Combined, these activities were responsible for 95% of the total area used for agricultural production in 2008 (Nassar et al., 2011). BLUM took into account interactions among the sectors it analyses and between one product and its sub-products. For example, the soy complex, bran and soybean oil were part of the domestic demand for soybeans and were determined by the demand for crushing. Similarly, sugar and ethanol were components of the sugarcane demand.

The land use module defined the dynamics of the expansion and competition between crops and pasture, which were modelled as scale and competition effects. The competition effect consisted of a system of equations that allocate the share of agricultural area of each crop and pasture in each region as a function of their profitability (own and competitors). This ensures that, for a given amount of agriculture land, the increase in the relative profitability of an activity will result in an increase in the area dedicated to this activity and reduce the area of its competitors. For any set of these coefficients, BLUM calculated the impacts of and the competition between activities, thus estimating land allocations and land use

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4 AGROICONE in partnership with the Food and Agricultural Policy Research Institute - Center for Agriculture and Rural Development (FAPRI - CARD, Iowa State University).
6 Homogeneity, symmetry, and additiveness conditions are met so the matrix of elasticity (and their associated ratios) are theoretically consistent.
changes. To ensure consistency of these estimations, the pasture area was regional and endogenously determined, but it was considered as the difference between the total area allocated for agriculture activities and the area for crops.

Despite the fact that the competition effect described the dynamics of regions where agriculture was stable and close to the arable potential, in the Brazilian case, it was also necessary to analyse the dynamics of the agricultural frontier regions. The scale effect referred to the equations that define how the profitability of each activity determines the total area allocated for agricultural production. More precisely, the total area allocated to the agriculture sector was a share of the total arable land available in each region, and responded to changes in the average profitability of the agriculture sector.

In BLUM, the scale and competition effects were not independent. They were the two components of the profitability-elasticities of each activity. Ceteris paribus, an increase in the profitability of an activity $X$ would have three effects: an increase in the total area allocated to agriculture activities (from the average profitability), an increase in the area allocated to activity $X$ (share increase on total), and a reduction in the share of the area of other activities. At the same time, the land use regional elasticity (total area-profitability-elasticity) related to the average profitability, was the sum of the scale elasticities of each activity. Thus, the competition elasticities were calculated directly from the total area-elasticity, because each activity elasticity (area-elasticity related to the profitability of the activity) was obtained from econometric analysis and literature review.

For each year, BLUM estimated figures for regional land uses, national and regional production, prices, consumption and net exports for Brazil. For the IES Brazil project, BLUM was extended to calculate emissions from the AFOLU sector. Following the 2014 Third GHG National Inventory (MCTI, 2010), the methodology to model agriculture and land use emissions included enteric fermentation, manure management, agricultural soils, rice, agricultural waste burning and prescribed burning of savanna estimations. Following the Renewable Fuel Standard Program of the US Environmental Protection Agency methodology (US EPA, 2010), the land use, land use change and forests (LULUCF) emissions and removal included existing biomass carbon stocks change (above and below ground), soil carbon stock variation, loss of carbon sequestration in forests, fire use in deforestation and rice cultivation estimations. When available, the modelling exercise also included carbon stock data from the LULUCF carbon dioxide emissions reference report from the Second Inventory because they provide specific data of the Brazilian context. The emission factors were calculated following the IPCC Guidelines (2006) recommendations and weighted with GIS techniques.

The IES research team simulated three agriculture and land use emissions scenarios until 2030, with base year 2005: the Government Plan scenario (CPG), the Additional 1 Mitigation scenario (CMA1) and the Additional 2 Mitigation scenario (CMA2). For the three emission scenarios, the four main assumptions were:

- Deforestation resulting from the agricultural demand for land. Speculation on public land (grabbing), investment in infrastructure, and small-scale production (settlements) was not explicitly captured by the exercise;
- Despite limited literature available, absorption of carbon by SOC accumulation processes (soil organic carbon) for management changes was accounted, especially for degraded and agroforestry recovered areas;
- Climate change impacts on agricultural production were excluded from the analysis and;
- Agriculture activities related to energy used in agriculture were computed in the energy sector (IES Brasil, 2015).

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7 In the case of land use and changes in land use, BLUM already included equations to estimate emissions.

8 As the BLUM outputs were used as input for the general equilibrium model developed for IES Brazil - the IMA CLIM-BR, and both models must use the same base year, the research team decided to use the year 2005.
The Governmental Plan scenario consisted of AFOLU emissions resulting from mitigation policies and actions being adopted by the Brazilian government. IES Brasil considered eight mitigation actions for the CPG scenario, most of them related to the Brazilian Mitigation and Adaptation to Climate Change Sectoral Plan (ABC Plan). The ABC Plan aimed at organizing and planning actions to enable the adoption of sustainable development technologies in the agriculture sector in order to respond to GHG emission reduction commitments made by the country (Brasil MAPA, 2012). The IES research team modelled some of these mitigation actions as the government proposed them in the Plan and others were adjusted to replicate the adoption progress achieved to date. The team also included targets set in the energy plan for biofuels and restrictions to the expansion of the agricultural area to comply with forest conservation targets in the modelling. Additionally, given that the ABC Plan modelled emissions reductions until 2020, as that is the country’s agreement fulfillment year, the IES research team had to expand the ABC actions emission potential until 2030, according to the Scenarios Building Committee evaluation. Costs were updated considering an 8% a.a. discount rate. In general terms, for the 2020–2030 period the CPG assumed minor activity level changes from the 2010–2020 period.

In particular, the CPG scenario’s main assumptions were: maintenance of efforts to combat deforestation up to and beyond 2020; implementation of the ABC plan, with some flexibility in the implementation deadlines (no extension); complementarity between deforestation targets and forestry code: low impact of new forest code on agricultural dynamics and land availability; realignment of prices of ethanol and gasoline (an issue also addressed by the energy and transport stakeholders); no significant ethanol technology changes; low participation of biodiesel in diesel (5% between 2010 and 2013, 5.5% in 2014 and 7% from 2015 to 2030); low rates of productivity gains in agriculture due to a current high standard (the livestock sector will have the largest gains within the sector) and; Brazil continues to have a prominent role in the international market for food and fibre, as FAO projections suggest (IES Brasil, 2015).

The Additional 1 (CMA1) and Additional 2 (CMA2) mitigation scenarios were built on the CPG emissions scenario. They represented the maintenance, expansion and improvement of the actions included in the CPG. The IES research team modelled some actions, such as animal manure management, pasture recovery and agroforestry systems, identically in both CMA1 and CM2. The difference between the two scenarios lies in the context where the actions were adopted and the scope they had.

As for the costs of the mitigation actions, the research team identified that, in the CPG scenario, these tended to be very small or negative because they only included the capital expenditure and operational costs of the actions, and excluded hidden costs such as level of training and management capacity, degree of knowledge of the different technologies available, logistical difficulties and technology uncertainties. The CMAs scenarios assumed some kind of intervention or incentive for the actions.

The sector’s stakeholders involved in the IES Brasil process, also known as the Scenario Development Committee, discussed and agreed the parameters and assumptions taken and estimated for the sector. These represented public and private sector in Brazil, as well as Academia.

Table 5 summarizes the main features of the modelling framework of IES Brasil.
### Table 5. Summary of modelling framework and assessment of mitigation of IES Brasil

<table>
<thead>
<tr>
<th>MODELLING FRAMEWORK</th>
<th>MAIN FEATURES OF MODELLING FRAMEWORK</th>
<th>METHODOLOGY TO ASSESS MITIGATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>1. Dynamic partial equilibrium economic model.</td>
<td>1. Estimates cost and GHG reduction potential by action.</td>
</tr>
<tr>
<td></td>
<td>2. Top-down approach.</td>
<td>2. Bottom up approach.</td>
</tr>
<tr>
<td></td>
<td>3. One-country, multi-regional, multi-market.</td>
<td>3. National scope of implementation.</td>
</tr>
<tr>
<td></td>
<td>4. Integrated assessment of agriculture, forestry and land use.</td>
<td>4. Interactions between actions.</td>
</tr>
<tr>
<td></td>
<td>5. Modelled in Excel spreadsheets.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Drivers of emission are modelled in modules for the supply, the demand and the land use of the agriculture and forestry sectors using satellite images data and secondary information.</td>
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<tr>
<td></td>
<td>7. BLUM considers land expansion and land competition of AFOLU activities.</td>
<td></td>
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<tr>
<td></td>
<td>8. Specific methodology for different emissions sources of the agriculture sector.</td>
<td></td>
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<tr>
<td></td>
<td>9. Emissions are estimated by source and then the results are aggregated at national level.</td>
<td></td>
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<tr>
<td></td>
<td>10. Local emission factors for all emission sources.</td>
<td></td>
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<tr>
<td></td>
<td>11. The model takes into account interactions among the analysed sectors, and between one product and its sub-products.</td>
<td></td>
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<tr>
<td></td>
<td>12. GDP, population, prices, etc. projection are an exogenous input for estimation of the emission drivers.</td>
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</table>

### 4.2 Colombia

As part of the MAPS process known locally as the Colombian Low Carbon Development Strategy (CLCDS), the AFOLU sector in Colombia was modelled in order to build climate change mitigation scenarios for the country until 2040 and 2050. The baseline and mitigation scenarios developed until 2040 were part of the Phase I process, and the extensions until 2050, built upon the learning from Phase I, were part of the Phase II. The base year for all the baselines was 2010. For the agriculture sector, two reference cases were modelled: the “Inertial scenario” or Business as Usual (BAU) and the “Reference scenario”. The first used historical rates of the drivers of emission for the period 2000 – 2010 to project them into 2040 and 2050, respectively. The second included recent policy formulation and private efforts that could not be seen in the 2000 – 2010 periods but that had certainty of occurrence. The latter was scenario selected to compare the potential emissions reductions of the mitigation scenarios. Mitigation actions for the sector were identified and assessed, including costs and CO₂ abatement potential, and then were packed into mitigation scenarios.

During phase 1, all the parameters, assumptions and models estimated for the sector were discussed and validated with the main stakeholders of each sub-sectors, which included the ministries, the producers’ organization and academia that attended the Scenario Building Team meetings (SBTs). During phase 2, some of the assumptions and drivers of emissions were kept and some others were validated again with the main stockholders of the sector in bilateral meetings. Phase I was...
considered a critical step to build necessary capacity and generate a basis of information to move into Phase II. This paper focuses on the modelling framework of Phase II.

The modelling framework to build the country’s baselines of agriculture emissions was based on the 2006 IPCC methodology with Tier 1 and Tier 2 emission factors. This model is a carbon accounting approach that uses a generic framework, with increasing levels of data quality and complexity, namely TIER 1, TIER 2 and TIER 3 (Bird et al., 2010). The Tier 1 model uses default emission factors and reference soil organic carbon stock provided in the IPCC Guidelines and Good Practices Reports (1996, 2003 and 2006) (Hillel et al., 2011). For Colombia, the Tier 2 emissions factors used were for cattle emissions and forest biomass content. This approach was chosen to link previous efforts of data collection to estimate GHG emissions for the country and to make the results comparable with those of the GHG National Inventories. In addition, the IPCC model fitted the data constraints of the sector and provided with Excel worksheets and reporting tables that facilitated estimations of GHG emissions and removals.

For the agriculture sector, the IPCC classifies the sources of emission as Livestock, which is divided into enteric fermentation and manure management; N₂O Emissions from managed soils (that includes Direct and Indirect N₂O Emissions, Indirect emission from manure management); CO₂ emissions from lime and urea application; and CH₄ emissions from rice cultivation. As suggested by the IPCC, the main drivers of these emissions - the number of livestock, the cultivated area and the production from different rice systems - were projected in time until 2050 and then used to build each emission’s source projection, also referred as sub-sectoral baseline. The agriculture Reference scenario results from adding up their associated sub-sectoral baselines (i.e. the Reference scenario is composed by the sub-sectoral baselines modelled with a specific set of assumptions).

For the projection of the number of livestock, the Reference scenario assumes the government target of number of cattle up to 2050, which takes into account parameters that determine the country’s beefs demand, mainly the population growth rate. An additional increase of 10% in the livestock projection was included to account for expected future market demand. Colombia could become a large exporter of meat when it overcomes the sanitary barriers posed by international markets.

Projections for the pasture expansion over natural forest for the year 2050 were estimated, as well as the loading capacity of the livestock by determining the pasture area and the number of cattle, expressed in number of animals per hectare. The livestock projection was made over 7 different age and purpose classes, divided into high production milk cows, low production milk cows, cows for replacement, cows for meat purposes, bulls for breeding purposes, milking calves and fattening bulls. The data from the seven different ages and purposes is collected twice a year in the AFTOSA fever vaccination cycle survey, which also provides the information for calculating Tier 2 emission factors for enteric fermentation in cattle. The enteric fermentation emissions from other livestock species were developed with Tier 1 emission factors.

For the agricultural soils category, the driver of emission projected was the amount of nitrogen fertilizer sold in the country, which was linked to the number of hectares planted. This projection included the area planted with nitrogen fixing crops and the livestock in grasslands. In the projection of the amount of nitrogen fertilizer sold in the country, the reference scenario includes agricultural development of Eastern plains and a possible post conflict scenario, factors that result in a high growth rate of agricultural plantations for the country and also an increase fertilizer use.

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9 From now on, the sources of emission prioritized by the IPCC are also referred as sub-sectors or categories of the agriculture sector.
For the rice subsector, the main driver of emissions was the area planted with irrigated or rain-fed rice. Initially, three scenarios were projected in this sub-sector. The first assumed the average historical growth rate of total rice area for the years 2000 and 2010. The other two scenarios projected considered the negative effect of a recently signed free trade agreement, with the adoption or not of a Massive Technology (AMTEC) program proposed by the rice producers’ organization that aimed to increase the sector’s productivity. Finally, the reference scenario chosen was the one with the free trade agreement and the no implementation of the AMTEC program.

In terms of mitigating GHG emissions, the Colombian AFOLU team assessed the annual capital and operational costs and abatement potential until 2050 of twelve mitigation actions. Nine of these actions are from the agriculture sector. Three of them are agroforestry mitigation actions, two are from fertilizer efficiency in potato and rice cultivation and the other four are from higher efficiency and carbon pools enhancement of livestock production. To assess the reduction potential and cost of each action, sets of specific parameters with and without the introduction of the action were estimated and projected, such as on-field emission factors and costs from specific cattle and crop productive systems. Most of these estimations came from academic and on-field studies. Afterwards, these local and on-field parameters were extrapolated to similar agro-ecological regions where it could be feasible to implement the actions. Although the mitigation potential of all the actions can be added, because some interrelationships amongst them were taken into account when assessing the emissions potential of each action, only a dynamic equilibrium model for the sector would avoid duplications and omissions of the impacts generated by the actions. Table 6 summarizes the main features of the modelling framework and the way to assess mitigation actions of MAPS Colombia.

Table 6. Summary of the modelling framework and assessment of mitigation of MAPS Colombia

<table>
<thead>
<tr>
<th>MODELLING FRAMEWORK</th>
<th>MAIN FEATURES OF MODELLING FRAMEWORK</th>
<th>METHODOLOGY TO ASSESS MITIGATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colombia</td>
<td>1. Accounting-approach, built from scratch using Excel sheets based on the IPCC methodology.</td>
<td>1. Estimates cost and GHG reduction potential by action.</td>
</tr>
<tr>
<td></td>
<td>2. Top-down approach: sectoral and sub-sectoral BAUs at national level.</td>
<td>2. Bottom up approach: on-field/regional emission factors and costs.</td>
</tr>
<tr>
<td></td>
<td>3. Drivers of emission are projected with a linear model using historical data and expert advice.</td>
<td>3. Different scope by action at geographical, crop and producer level.</td>
</tr>
<tr>
<td></td>
<td>4. Specific methodology for different emissions sources of the agriculture sector.</td>
<td>4. Interactions between actions are introduced manually in the estimations.</td>
</tr>
<tr>
<td></td>
<td>5. Emissions are estimated by source and then the results are aggregated at national level.</td>
<td></td>
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<tr>
<td></td>
<td>6. Local emission factors for enteric fermentation and default emission factors for agricultural soils and rice.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Restrictions are included manually into the approach to meet certain assumptions and characteristics of the sub-sectors.</td>
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</tr>
<tr>
<td></td>
<td>8. Only interactions across emission sources included in the IPCC framework are contemplated.</td>
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<tr>
<td></td>
<td>9. Sectoral drivers’ projections have an indirect link with population and GDP projection.</td>
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</tbody>
</table>
4.3 Chile

Under the MAPS Chile process, the agriculture sector was modelled to generate robust and quality information about mitigation actions to develop scenarios that contain feasible options for the country until 2030. The process comprised two Phases. Phase 1 consisted of building baseline scenarios of GHG emissions (BAU’s) for different sectors between 2007 and 2030, as well as a Required by Science (RBS) scenario for the country. Phase 2 included the construction of an agriculture GHG emissions’ baseline between 2013 and 2050 and the assessment of mitigation scenarios, with their related costs and CO₂ abatement potential. Although during Phase 2 all models were run up to 2050, the results were only validated until 2030. Phase 2 was based on learnings from the Phase 1. The main differences between the BAU scenarios of Phase 1 and Phase 2 were the base year used in each scenario (2007 vs 2013) and the methodology used to project the drivers of emissions of the sector. Phase 1 was considered a critical step to build necessary capacity and generate a basis of information to move into Phase 2. Phase 2 modelling framework is the focus of the description below.

BAU emissions of the agriculture sector, in both Phases 1 and 2, were estimated based on the 2006 IPCC methodology for non-Annex 1 countries. Tier 1 emission factors were used, except for enteric fermentation and manure management from bovine cattle and pigs, for which Tier 2 was applied. In the Chilean case, the 2006 IPCC protocol was chosen because it coherently integrates the data from the agriculture sector with land uses and forestry activities (AFOLU). This avoids double counting and omissions, as well as improving transparency and completeness of the BAUs. The Chilean research team was able to use this approach because there was enough information available for both the agriculture and the land use and forestry sectors (Chile MMA, 2011). During phases 1 and 2, the data used to estimate the BAU of the agriculture sector combined official information of agriculture activity in Chile as well as international statistics of the country. This information included the Chilean National Inventories of GHG 1984/2006, the 2007 agriculture and forestry census and FAO-STAT data about fertilizer’s consumption, amongst others. The main drivers of emissions were the number of livestock and the total cultivated area. These two variables were projected into 2050 with base year 2007 during Phase 1 and with base year 2013 during Phase 2. Moreover, the 2006 IPCC guidelines also account for emissions of land use changes, thus projections of forestlands, forest plantations and grassland were also estimated.

The most important assumption employed to model the drivers of emissions of the sector, in both phases, was that the total area used for agriculture activities remained constant in time. This assumption was justified because Chile does not have much more additional available land to expand the agriculture frontier. However, the BAU scenarios of both phases used different methodologies to project the variations in land allocation of agriculture activities. During Phase 2, the land allocation and projection of land uses was the result of different models that assessed the supply of land expressed as cultivated area, the equivalent production and the demand of land from domestic crops. The market equilibrium was calculated annually at the country level through iterations that find a vector of prices that clears all markets simultaneously.

The supply of the cultivated area by crop or group of crops by period was estimated with an autoregressive vector (VAR) model. VAR models are econometric models used to capture the linear interdependencies among multiple time series. The Chilean VAR developed during Phase 2 was a simultaneous equation model that calculated interrelation coefficients of cultivated area by crop with one period lags of the cultivated area of the same crop and of the rest of crops and with the agricultural GDP as an exogenous variable. These coefficients were then used to project the area cultivated by crop or group of crops.

The agriculture GDP was projected each period outside the VAR model as a function of the agriculture GDP in the previous period and of an estimated rate of national gross domestic product (NGDP) in the same period. The MAPS Chile
A compilation of agricultural models assessing sectoral dynamics, GHG emissions and abatement opportunities

Domestic production of agriculture crops each period was calculated with a structural model that includes lags of the endogenous variables (prices) and a set of exogenous variables. The model strongly relied on the variable price of the crop of interest and on the price of those competing crops. The specification of the model also took into account the agriculture GDP and the population growth rate. Domestic demand of agriculture crops was expressed as tons of crop production each period. It was estimated as a function of the price of the crop of interest, of the price of those competing crops and of exogenous variables such as agriculture GDP and the population growth rate. As Chile has an open market economic policy, the domestic market was considered in the modelling framework as directly dependent on international prices of agricultural goods and transportation costs.

The supply model, expressed as cultivated area and the production model, expressed in terms of prices, in each period, generated the supply of agricultural products associated to a determined land distribution. Given that the supply and demand models estimated production and cultivated area separately, market equilibrium was calculated annually through iterations that found a vector of prices that cleared all markets simultaneously. The model assumed that the area that each crop will occupy in each period was determined by an equilibrium mechanism that is adjusted by international price of each crop and its influence on the domestic price. The optimization algorithm to determine the price vector was the generalized reduction gradient (GRG); which iterated and converged to an optimal solution. This optimization process was repeated annually to project the distribution of agricultural land amongst fifteen agriculture activities until 2050. (For more detailed information see MAPS Chile, 2013.) The results from the model were then used to calculate emissions from agriculture soils and land use changes using the same 2006 IPCC approach from Phase 1.

Emissions from the livestock subsector were similarly estimated. The annual number of cattle was estimated with a structural model that included lags of the variable of interest, price of the animal of interest and prices of the main inputs required to feed the animal of interest (maize and milk, when relevant). The animals that were modelled were cattle, pigs and chickens. The specification of the model also took into account Chilean GDP. The projections were estimated with ordinary least squares regressions. After forecasting the number of cattle by type and by year, historical distribution ratios were used to estimate the sheep and goats projection and to disaggregate the cattle and pigs projections by age and sex. Subsequently, enteric fermentation and manure management emissions were calculated using Tier 2 emission factor and the 2006 IPCC methodology.

For the GHG mitigation analysis, eight actions with their associated cost and CO2 abatement potential were assessed: three actions related to livestock activities, three related to agricultural soils and two that could be implemented in both subsectors. The assessment of the mitigation actions did not include interactions amongst them, beyond those suggested by the IPCC. Contrary to the Colombian and Peruvian cases, in Chile, the mitigation potential of each action was assessed against the BAU of each subsector (i.e. livestock and agriculture soils). Given that Chile has local emission factors for enteric fermentation and manure management of bovine cattle and pigs, the BAU of these sources of emission included specific local parameters that could be used as a reference scenario to assess the mitigation potential of the actions proposed for these subsectors. In this sense, differences between regions, productive systems and crops were accounted in the assessment.

Analysis of the potential of mitigation actions in the agricultural soils was also done against the subsectoral BAUs. However, these BAUs were estimated using IPCC Tier 1 emission factors, which means that the resulting GHG BAUs do not accurately reflect the local particularities of the country. Hence, the comparison between the emissions resulting when implementing these actions and their respective BAU produces an imprecise estimation of the emission abatement potential. Moreover,
differences in emission factors and emission reductions potentials across regions and crops are excluded from the analysis. These lead to over- or under-estimation of mitigation action abatement potentials.

The assessment of mitigation actions in Chile also included a qualitative review of financing options, different levels of implementation (feasibility assessment), as well as associated implementation barriers and co-benefits. After this analysis, the mitigation actions were prioritized and packaged into nine mitigation scenarios taking into account their feasibility of implementation.

The main stakeholders of the sub-sectors, including government and academia, validated all the parameters, assumptions and models estimated for the sector during Phase 2.

Table 7 summarizes the main features of its modelling framework and the methodology to assess mitigation actions.

Table 7. Summary of the modelling framework and assessment of mitigation of Phase 2 of MAPS Chile

<table>
<thead>
<tr>
<th>MODELLING FRAMEWORK</th>
<th>MAIN FEATURES OF MODELLING FRAMEWORK</th>
<th>METHODOLOGY TO ASSESS MITIGATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. Accounting-approach, built from scratch using Excel sheets based on the IPCC methodology.</td>
<td>1. Estimates cost and GHG reduction potential by action against sub-sectoral BAUs.</td>
</tr>
<tr>
<td></td>
<td>2. Top-down approach: sectoral and sub-sectoral BAUs at national level, using econometrics.</td>
<td>2. Top down approach: national emission factors and costs.</td>
</tr>
<tr>
<td></td>
<td>3. The land allocation and projection of land uses were estimated with different models that assessed the supply of land (VAR model), the agriculture production and the demand of land from domestic crops (structural models).</td>
<td>3. National scope of implementation.</td>
</tr>
<tr>
<td></td>
<td>4. The drivers of emission of the livestock subsector were projected with a structural model.</td>
<td>4. Interactions between actions are only those suggested by the IPCC.</td>
</tr>
<tr>
<td></td>
<td>5. Specific methodology for different emissions sources of the agriculture sector.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Emissions are estimated by source and then the results are aggregated at national level.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Local emission factors for enteric fermentation and manure management of bovine cattle and pigs and default emission factors for agricultural soils and rice.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8. Only interactions across emission sources included in the IPCC framework are contemplated.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9. GDP projection is an exogenous input for all the projections of the emission drivers.</td>
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</table>
4.4 Peru

Under the MAPS Peruvian process, also known as Planning for Climate Change project (PlanCC), the agriculture sector was analysed to develop climate change mitigation scenarios for the country in the 2021 and 2050 time horizons. PlanCC identified and assessed mitigation actions for the sector, including costs and GHG emissions abatement potential. IPCC 1996 methodology for non-Annex 1 countries as well as IPCC 2000 Good Practices for national inventories were used to build the national BAU of agriculture GHG emissions, developed on Excel spreadsheets. Apart from facilitating the analysis of GHG emissions and removals due to the provision of worksheets and reporting tables, in the Peruvian case, the IPCC approach was thought to be the most logical to estimate the emissions profile of the sector because of its simplicity and accuracy and because of the data constraints within the sector. Some regional specific emission factors exist in Peru for the livestock sub-sector but to ensure consistency, all the emissions of the sector were modelled using Tier 1 emission factors. The data used to estimate the agricultural BAU comes from official information about Peru’s historic agricultural activity.

Following the IPCC guidelines, the main drivers of the different sources of emission were the number of livestock, the cultivated area and the production from different rice systems projected into 2021 and 2050 with base year 2009. These were then used to build each emission sources projection, also referred to sub-sectoral projections. The agriculture BAU is a result of adding up these sub-sectoral projections.

Each of these drivers was projected separately using historical time series based on a linear model (from several model specifications, the linear model produced the best coefficient of determination (R2). The livestock subsector included information of the different types of livestock; the agriculture soils subsector included data of the different crops by region; and the rice subsector included information of the amount of production and land used from different rice systems in Peru.

The agriculture sector drivers’ projections did not have a direct link with GDP and population; only historical trends were used in the projections (e.g. number of livestock and demand of agriculture crops).

The key assumption in the projection of livestock is keeping a constant historical average share of beef cattle and dairy cattle in total cattle. The key assumption in the agriculture soils subsector projection is that the rate of applied kilograms of nitrogen to the soils over the total cultivated area each year remains constant in time. These assumptions are supported on the basis that in a BAU scenario, proportions are not expected to change - i.e., no change in changes in efficiency. The key assumption on the rice subsector projection is that it assumes the share of rice production systems to be constant.

PlanCC modelled 77 mitigation options in total, 8 being options for the agriculture sector. The analysis included CO2 abatement potential and cost-benefit analysis. Co-benefits of the most profitable mitigation actions were also discussed in economic, social and environmental terms. Eight mitigation actions were prioritized during the process; five aimed to reduce enteric fermentation emissions from livestock activities and the other three actions were related to crop emissions reductions.

As in Colombia, Peru lacks IPCC Tier 2 emission factors for all agriculture’s sources of emission. Therefore, the sub-sectoral projections were estimated with Tier 1 factors. For this reason, the Peruvian team also decided to assess each mitigation action, identifying and projecting on-field parameters with and without its introduction. These parameters included local and on-field emissions and costs from specific cattle and crop productive systems. Afterwards, they were extrapolated to similar agro-ecological regions where it could be feasible to implement the actions. All the parameters, assumptions and models estimated for the sector were discussed and agreed with the main stakeholders of the sub-sectors, which included the government and the Academia. Table 8 presents the main features of the modelling framework and the methodology to assess mitigation actions of PlanCC.
Table 8. Summary of the modelling framework and assessment of mitigation of PlanCC

<table>
<thead>
<tr>
<th>MODELLING FRAMEWORK</th>
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<th>METHODOLOGY TO ASSESS MITIGATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peru</td>
<td>1. Accounting-approach, built from scratch using Excel sheets based on the IPCC methodology.</td>
<td>1. Estimates cost and GHG emission abatement potential by action.</td>
</tr>
<tr>
<td></td>
<td>2. Top down approach: sectoral and sub-sectoral BAUs at national level.</td>
<td>2. Bottom up approach: on-field, regional emission factors and costs.</td>
</tr>
<tr>
<td></td>
<td>3. Drivers of emission are projected with a linear model using historical data.</td>
<td>3. Different scope by action at geographical, crop and producer level.</td>
</tr>
<tr>
<td></td>
<td>4. Specific methodology for different emissions sources of the agriculture sector, according to IPCC.</td>
<td>4. Interactions between actions are introduced manually in the estimations.</td>
</tr>
<tr>
<td></td>
<td>5. Emissions are estimated by source and then the results are aggregated at national level.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Restrictions are included manually into the approach to meet certain assumptions and characteristics of the sub-sectors.</td>
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<tr>
<td></td>
<td>7. Only interactions across emission sources included in the IPCC framework are contemplated.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8. Sectoral drivers’ projections do not have a direct link with population and GDP projection.</td>
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</table>

5. HIGHLIGHTS, SHORTCOMINGS AND COMPARISON OF MODELLING FRAMEWORKS

Highlights

Brazil

- BLUM can be used as an important tool to assess the dynamics of different land occupations and configurations at different geographical levels.
- It integrates agriculture, forestry and land use activities into one system.
- BLUM does not require advanced software to run it.
- Desegregated assessment of land use dynamics.
- BLUM takes into account interactions among the sectors it analyses, and between one product and its sub-products.
- BLUM can simulate demand shocks for a product and thus analyse how the other crops and pasture will react to the shock.
- The disaggregation of the expansion and competition amongst crops and pasture by region improves the accuracy of the GHG emissions calculations.

Chile

- 2006 IPCC guidelines integrate the data from the agriculture sector with land uses and forestry activities, which reduced double counting and omissions and improved transparency and completeness of the BAUs.
• Local emission factors for enteric fermentation and manure management of bovine cattle and pigs allow for precise estimation of GHG emissions abatement potential.
• A great amount of information is available for both the agriculture and the land use and forestry sectors.
• Great level of disaggregation in the analysis (e.g., by crop, by region, by year), which can improve the accuracy of the GHG emissions calculations.
• Inclusion of common assumptions, such as GDP, to project the drivers of emission of the sector.
• The model can generate different scenarios for land use and agricultural production.
• VAR models describe well the dynamic behaviour of a time series and are good for forecasting.

Colombia and Peru
• IPCC approach with Tier 1 emission factors adapts easily to the data constraints of the sector in both countries.
• BAU results are comparable with those of the GHG national inventories.
• Precise estimation of GHG emissions abatement potential and cost of each mitigation action. On-field parameters with and without the introduction of the action reduce uncertainties of using Tier 1 emission factors.

Shortcomings

Brazil
• Data requirements may be too large and impossible to meet for countries with data constraints.
• The BLUM is able to represent the Brazilian dynamics of the sector through price equilibrium because it is not required to include international prices as endogenous inside the model. Price-taker countries of international prices may need to define the external market in a different way.
• The BLUM models the competition for land across crops annually but there are countries that possess long-term land competition of crops such as fruits.

Chile
• The model developed during Phase 2 of the MAPS Chile process is very sophisticated and its complexity makes it hard for stakeholders to understand.
• The model does not seem replicable in any of the other Latin American countries because Chilean geographical and agro-ecological characteristics have little in common with those of the others.
• The comparison between the emissions resulting when implementing agricultural soil mitigation action and their respective BAU produce imprecise estimations of the emission abatement potential. This is a consequence of the lack of Tier 2 subsectoral emission factors and of regional and crop specific abatement potential.
• The model does not include interactions across mitigation actions beyond those suggested by the IPCC framework.

Colombia
• The model does not take into account possible changes in the structure of the land uses and the cultivated areas.
• The model does not include competition for land across crops, livestock and forestry activities.
• Use of Tier 1 emission factors means that (significant) regional differences within the country are not taken into account.
• The model does not include GHG emission and capture balance in the sectoral reference scenario due to local data limitations.
Different sources of information generate big uncertainties on the accuracy and robustness of the results (e.g., number of cattle).

Projections of the drivers of emissions are not estimated using common assumptions, such as GDP and population.

The model does not systematically link the interactions between mitigation actions.

Peru

- The model does not take into account possible changes in the structure of the land uses and the cultivated areas.
- The model does not include competition for land across crops, livestock and forestry activities.
- The agriculture BAU model does not include common assumptions – GDP and population – to project the sector’s drivers.
- Use of Tier 1 emission factors means that (significant) regional differences within the country are not taken into account.
- The model projects drivers for only two years. It would be more valuable to have an annual projection of the drivers of emissions.
- Projections of the drivers of emissions are not estimated using common assumptions, such as GDP and population.
- The model does not systematically link the interactions between mitigation actions.

Comparison of frameworks

The first step in determining projections of emissions from the AFOLU sector is to predict emission sources (enteric fermentation, agriculture soils, etc.). The drivers selected to impact the emission sources vary in each of the countries. The simplest approach, taken by Colombia and Peru, was to consider historical trends. The Chilean and Brazilian models included population and GDP predictions. BLUM went further and considered prices, the external market, costs, productivity, etc. In terms of modelling software, all of the four models were built in Microsoft Excel.

Once the projections of emission sources had been established, annual GHG emissions were determined. Brazil and Chile made use of the procedures presented in the 2006 IPCC guidelines and Colombia and Peru made use of the 1996 IPCC guidelines to calculate emissions from AFOLU activities. The 2006 guidelines are preferred to the 1996 guidelines as they incorporate land use and forestry interactions which reduces double counting and omissions and improved transparency and completeness of the emissions’ estimates. In applying the IPCC methodologies, the countries primarily made use of the default data offered in the guidelines, supplementing it with local data where available. More local data would clearly have produced results more relevant to the local context, as in Brazil, although in the absence of data the approach used was defensible.

The Brazilian Land Use Model is the only model that is able to integrate and assess the agriculture sector, the forestry sector and the land use dynamics together, improving the quality of its results. Separate emissions accounting of the three sectors decreases the robustness of the results.

In terms of mitigation, all of the countries developed a cost-benefit analysis to demonstrate the cost and emissions savings potential of each mitigation option. This includes consideration of year of commencement, the rate of implementation, scale of operation, location of implementation, and period of application.

The data availability differences across the four countries also led to the adoption of different approaches to assess mitigation options’ abatement potential. Lacking Tier 2 emission factors, Colombia and Peru assessed reduction potential of
each action with specific parameters with and without the introduction of the actions. Afterwards, local and on-field parameters were extrapolated to regions where it could be feasible to implement the actions. Brazil assessed the actions’ mitigation potentials against the reference scenario (governmental mitigation scenario) and Chile against BAU of each subsector (i.e. enteric fermentation or agricultural soils). All CPG’s subsectoral emissions lines, in Brazil, and enteric fermentation and manure management emissions of bovine cattle and pigs, in Chile, contained specific local parameters to be compared with the new parameters of the mitigation options. However, given that the Chilean agricultural soils BAU was estimated using IPCC Tier 1 emission factors, which does not accurately reflect the local particularities of the country, the comparison between the emissions resulting when implementing mitigation options and the BAU produced the most imprecise estimations of the emission abatement potential, from all the approaches mentioned above.

Aggregation of mitigation actions is an important consideration to explore as the extent of implementation of one mitigation option within a scenario in which mitigation actions are combined can impact on that of another. BLUM was the only model that systematically could assess the impacts of various mitigation actions in the AFOLU sector.

In conclusion, although the broad approaches off all four countries are similar (i.e. emission sources are the same), the details of modelling vary quite substantially. Some of the countries use more recent approaches (i.e. 2006 IPCC guidelines versus 1996 guidelines), some systematically link interactions between subsectors and mitigation actions (Brazil and Chile and Colombia to some extent), some linked GDP, population and others to activity level data of the sector and some have more country-specific information to populate the calculations. Furthermore, the number and type of mitigation actions differed between the countries.

6. CONCLUSIONS

This paper has described a number of modelling frameworks and tools to examine the agriculture sector, ranging from crop specific models, or region-specific models, to sector- and economy-wide models. The range of modelling approaches is based on a comprehensive literature review and on real experiences in modelling the sector with the aim of developing mitigation scenarios in four countries participating in the MAPS Programme. Few models can fully replicate empirical evidence about the agriculture sector, land allocation, land use dynamics as well as address the entire abatement potential of GHG emissions within the sector. The selection of a modelling approach becomes then, a matter of what specific outputs the framework can estimate and what the modeller wants to obtain. Considerations related to data needs, geographical scope, sub-sector specificity, amongst other factors, are also taken into account when a modeller choses a framework. The main consideration taken into account by the MAPS countries when selecting their modelling framework was the data needs.

Moreover, sectoral-wide models with an economic base are more complex and therefore require a greater quantity of information and algorithms for representing future situations for the AFOLU sector. Although this can be more onerous, both in terms of finances and time, making use of highly specialised professionals, they can be adjusted more easily to variations, both for national and international situations and therefore should deliver results that are more aligned with reality. In contrast, the models based on trends are simpler, given that they make use of fewer variables which may produce future projections that contain significant bias in relation to reality as they draw from historical conditions for the purpose of representing the future and therefore do not incorporate new technological options and cultural changes.
Most of the sector-wide tools use a common methodological background based on the Guidelines for National Greenhouse Gas Inventories from the IPCC (IPCC, 2006, Colomb et al. 2013) to estimate the sector’s emissions. However, as the IPCC methodology is only an accounting tool that transforms activity data into emissions, an additional model to estimate and project the activity data is needed. In this sense, the main difference amongst the sector-wide approaches is how the drivers and sources of emissions are estimated in each model. Some tools use exogenous inputs, while others estimate them endogenously in the model. Farm-level models, on the contrary, are system-analytical or based on the underlying physics and chemistry governing the behaviour of the emission processes, which results in more accurate estimates of emissions. Moreover, many of these models were also designed to evaluate overall impacts of management and adaptation strategies and different climate scenarios.

With regards to estimates of carbon emissions and captures, either for the BAU or mitigation scenarios, the use of the default emission (or removal) factors provided by the IPCC may lead to results that either over- or under-estimate the nature of each emission source modelled. The use of carbon emission or removal factors calculated for each country reflects more accurately local conditions. In this sense, for some of the MAPS countries, using the IPCC methodology together with another model to estimate the drivers of emission generated inconsistencies when assessing abatement potentials of the mitigation actions.

Three alternatives to assess mitigation options were taken. First, when base scenarios were modelled with local emission factors, the resulting BAUs of emission included specific local parameters that could be used directly to estimate the mitigation potential of the actions proposed in each country. Second, when base scenarios were modelled with IPCC Tier 1 emission factors because of the lack of national factors, a set of regional or crop specific parameters without the implementation of the action were estimated and projected, in order to have reference parameters to assess the abatement potential and costs of the mitigation actions. For some mitigation actions, farm-level models were used to estimate these parameters and the resulting crop or region specific sources and sink of emissions. Third, when base scenarios were modelled with IPCC Tier 1 emission factors and there were no farm-level or regional measurements, the mitigation actions abatement potential was calculated using its corresponding BAU. This exercise may produce the largest miscalculation of the real potential emissions reductions of any action, as the BAU of emissions does not accurately reflect the local particularities of the country and the differences across regions and crops are excluded from the analysis.

One could conclude, then, that future exercises that try to model emissions baselines and abatement potentials of mitigation options at the country level should first define the quantity and quality of the information available for the given country. If emission baselines are estimated with default data it is better to assess mitigation options against local parameters to more accurately estimate abatement potentials. If emissions baselines include local particularities, mitigation options can be assessed against them. It is recommended to avoid estimations of emissions reduction potential generated from default emissions baselines.

Another limitation preventing the accurate estimation of the mitigation potential of mitigation actions in the agriculture sector is that static models, such as the IPCC methodology, are not able to assess interrelations amongst them. The best tool to avoid duplications and omissions of the impacts generated by the actions are dynamic equilibrium models that capture and replicate the dynamics of the sector.

All the models described above have certain competitive advantages and are often the best and only tools available in their fields of specialization. A combination of different models is frequently used to achieve more precise and wide-ranging results.
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