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Simulation of REDD+ options using IIASA model framework

Mykola Gusti[a,b], Hannes Böttcher[a], Georg Kindermann[a], Petr Havlik[a], Michael Obersteiner[a]

a) International Institute for Applied Systems Analysis, Schlossplatz 1, A-2361 Laxenburg, Austria

b) Lviv National Polytechnic University, 12 Bandery Str., Lviv, Ukraine

gusti@iiasa.ac.at

Abstract: We present a modeling framework for simulating afforestation, deforestation and sustainable forest management that is composed of an interlinked economic model and a spatially explicit forestry model. The linkage of models allows addressing a number of important issues relevant to REDD+, in particular, estimation of cross-country comparable CO_2 mitigation potential for individual countries and selected activities, "carbon-leakage" problem, estimation of marginal abatement cost curves for the mitigation activities etc. We demonstrate the application of the model framework for development of marginal abatement cost curves and discuss the results.

Keywords: REDD+; model framework; economic model; forestry model; geographically explicit

1 INTRODUCTION

Reducing Emissions from Deforestation and Forest Degradation (REDD), sustainable management of forest and enhancement of forest carbon stocks (REDD+) is an international effort to give a value to the carbon stored in forest ecosystems and by that means control land use related emissions. REDD and later REDD+ are on the agenda of the international climate negotiations under the United Nations Framework Convention on Climate Change (UNFCCC) since 2005. To support the negotiations cross-country estimates of effectiveness of REDD+ options (direct forest carbon saving and co-benefits, e.g., reduction of species extinction [Busch et al. 2010, Venter et al. 2009, Strassburg et al. 2012]) and related costs are needed.

There is a number of models that simulate deforestation and mitigation measures on global scale with low geographical resolution (e.g., GTM, GCOMAP [Kindermann et al. 2008b], OSIRIS [Busch et al. 2010] and spatially explicit models on country or finer scale (e.g., Land Change Modeler [Clark Laboratories, 2008]). A national projection using models was presented by Sloan and Pelletier [2012] who concluded that small scale spatially explicit modelling has a very limited accuracy. There is a lack of models for detailed larger scale geographically explicit simulation of REDD+ options that results in comparable estimates across countries. Such projections might not substitute detailed national projections but can assist in developing plausible national baselines that take larger scale developments and competition between countries and sectors into account. The IIASA model framework, a combination of an economic land use model and a geographically explicit forestry model, estimates future emissions resulting from afforestation, deforestation, i.e. conversion of forest (managed or unmanaged) to another land use, and forest management (applying a cycle of harvesting, re-establishing and thinning of forest) and the impact of mitigation measures on carbon emissions. It compares the net present value (NPV) of different forestry and alternative land use activities and introduces a carbon price on emissions from these activities.

This paper presents the modelling framework including the models GLOBIOM and G4M. The framework containing the IIASA model framework in its core is presented in Section 2.1. Sections 2.2 and 2.3 are devoted to more detailed descriptions of the models composing the framework. In Section 3 we give an example of calculations performed with the framework and discuss the results. Section 4 lists challenges and follow-up issues for improving performance of the model framework.

2 IIASA MODEL FRAMEWORK

2.1. Modeling framework

To simulate CO_2 emissions from afforestation, deforestation and forest management and response of the emissions to CO_2 mitigation policies a framework of two models, an economic land use model (GLOBIOM) and a detailed forestry model (G4M) is applied. G4M alone does not take into account trade of forest products and agricultural commodities that can lead to overestimation of CO_2 mitigation potential [Gusti et al. 2009]. Coupling G4M with an economic model allows improving its performance for modeling REDD+ activities. The models exchange information on economical and biophysical parameters and are included in a broader framework for development of consistent projections of CO_2 emissions from forestry and land use change activities (Figure 1).

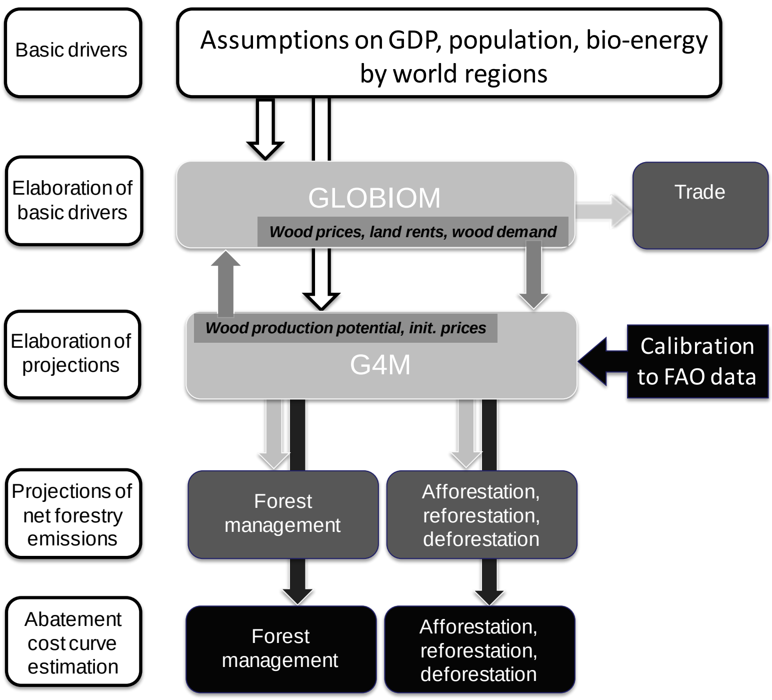

Figure 1. Modeling framework for simulation of REDD+ options using IIASA model framework.

GLOBIOM represents the forestry, agriculture, bioenergy and livestock sectors of 28 world regions. The model uses exogenous assumptions on future bioenergy demand and related assumptions on population growth, economic development (GDP), and technical progress rates as macroeconomic drivers (e.g., based on results of the POLES energy model).

For baseline and policy scenarios GLOBIOM projects domestic production and consumption, net exports and prices of wood and agricultural products. GLOBIOM is initialized with spatially explicit wood production potentials and levels of wood prices and agricultural land rents obtained from G4M. The sector specific information from the economic model and the exogenous assumptions on GDP and population development are used by the forest model to project GHG emissions and removals from forest management, afforestation/reforestation and deforestation activities. In the modelling framework G4M is setup to simulate sustainable forestry, i.e. harvest does not exceed forest growth. Based on a baseline projection it also provides abatement cost curves for the selected land use activities by introducing a carbon price. G4M is calibrated to match historic land use change dynamics on country scale provided by FAO and geographical patterns of deforestation in tropics provided by Hansen et al. [2010]. Main datasets used by the models are listed in Table 1.

2.2. GLOBIOM model

The Global Biosphere Management Model (GLOBIOM) is a global recursive dynamic partial equilibrium model integrating 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. GLOBIOM covers 28 world regions. The model accounts for about 20 globally important crops, a range of livestock production activities, forestry commodities as well as different energy transformation pathways [www.globiom.org; Havlik et al. 2011]. GLOBIOM disaggregates available land into several land cover/use classes that deliver raw materials for wood processing, bioenergy processing and livestock feeding. Besides forest land the model includes cropland, short rotation tree plantations, managed grassland, and ‘other natural vegetation’ (includes natural grassland).

GLOBIOM uses geospatial data made up of different layers: geospatial characteristics that do not change over time (due to climate change and/or management practices) such as altitude, slope, and soil are used to form geographical clusters or ‘Homogenous Response Units’ (HRU). On top of this layer containing time invariant characteristics come country boundaries and a 0.5° x 0.5° grid layer that contains more detailed information such as data on climate, land use/cover, etc. This information forms Simulation Units (SimU) that are the basic geographical unit for the analysis. For each SimU different management systems are distinguished: irrigated, high input – rainfed, low input – rainfed and subsistence management.

The global agricultural and forest market equilibrium is computed by choosing land use and processing activities to maximize the sum of producer and consumer surplus subject to resource, technological, and policy constraints. Prices and international trade flows are endogenously determined for the world regions. Imported and domestic goods are assumed to be identical, transportation costs and tariffs are not taken into account. Explicit policy constraints with respect to forests are that conversion is not allowed for protected areas. Explicit policy constraints are also, for example, the bioenergy mandates implemented by governments. Many other policies are in the baseline represented implicitly through the relative prices. For scenario analysis, additional policy constraints can be implemented, e.g., GHG reduction, biodiversity protection, food security, trade.

2.3. G4M model

The Global Forest Model (G4M) is used to estimate impacts of forestry activities (afforestation, deforestation and forest management) on biomass and carbon stocks. Decisions on afforestation or deforestation are made by comparing NPV of managed forest (difference of wood price and harvesting costs, income by storing carbon in forests) with NPV of an alternative land use on the same place. G4M is a spatially explicit (currently on a 0.5° x 0.5°resolution) model, therefore deforestation pressure at the forest frontier can also be displayed. The model uses external information (i.e. wood prices, agricultural land rents, wood demand and prescribed land use change) from GLOBIOM, which guarantee food security and land for urban development and other macro level assumptions. As outputs, G4M produces estimates of forest area change, carbon sequestration and emissions in forests, impacts of carbon incentives (avoided deforestation, stimulated afforestation and forest management aimed at carbon sequestration) and supply of biomass for bioenergy and timber [Gusti and Kindermann 2011]. On global scale G4M was validated by Kindermann et al. [2008b]. Gusti et al. [2009] tested the model performance in Ukraine, while Böttcher et al. [2012] described validation of the model for the European Union countries.

The model handles forest age classes with one year width. Forest age structure is initialised using country scale statistics (see Table 1), if available. The model performs final cuts in a manner, that all age classes have the same area after one rotation period. Increment is determined by a potential net primary productivity (NPP) map (Cramer et al. 1999) and translated into net annual increment (NAI). At present this increment map is static but can be changed to a dynamic growth model which reacts to, e.g. changes of temperature, precipitation or CO_2 concentration. Modelled initial forest biomass in each cell is adjusted by tuning stocking density using an iterative procedure bringing together observed stocking biomass, net annual increment per grid cell and country average age structure. The main forest management options considered by G4M are variation of thinning and choice of rotation length. The model gradually adjusts rotation length within maximum (usually maximises stocking biomass) and minimum (usually maximizes increment) rotation lengths to harvest the demanded amount of wood.

Table 1. Main data used by the models

Parameter	Resolution	Reference
PPP	Country	World Bank [2005]
Net annual increment, forest age structure	Country	MCPFE http://forestportal.efi.int/view.php?id=1895&c=E1
GDP, Population density	0.5x0.5 deg	Grubler et al. [2007] original or modified using Capros et al. [2010] or WEO or POLES
Land under infrastructure, secured cropland	0.5x0.5 deg	Tubiello and Fischer [2007]
Potential NPP	0.5x0.5 deg	Cramer et al. [1999]
Potential vegetation	0.5x0.5 deg	Ramankutty and Foley [1999]
Agriculture suitability	0.5x0.5 deg	Ramankutty et al. [2002] or Fischer et al. [2007] or Naidoo and Iwamura [2007]
Forest biomass, litter and coarse woody debris	0.5x0.5 deg	Kindermann et al. [2008a], Gallaun et al. [2010]
Protected forest	0.5x0.5 deg	WDPA Consortium [2004]
Landcover	0.5x0.5 deg	GLC2000 [JRC 2003], CORINE [CLC2000]

A baseline scenario projection is estimated without any carbon price incentives. Introducing a carbon price incentive to generate carbon abatement cost curves means that the forest owner is paid for the carbon stored in forest living biomass above a baseline or pays a tax, if the carbon in forest living biomass is below the baseline. The measures considered as mitigation measures in forestry in G4M are: reduction of deforestation area, increase of afforestation area, change of rotation length of existing managed forests in different locations, change of the ratio of thinning versus final fellings, and change of harvest intensity (amount of biomass extracted in thinning and final felling activity.

3 APPLICATION AND DISCUSSION

To illustrate application of the IIASA model framework we present forestry baseline emissions projections and associated Marginal Abatement Cost Curves (MACCs). In addition to the input data described above the following main scenario drivers are assumed:

- G4M is calibrated on country scale to forest area dynamics based on the FAO's Global Forest Resources Assessment 2010.
- We use regional specifications on how much biomass is burned or extracted through deforestation. This is relevant as it affects the timing of emissions through deforestation. The following shares are applied: Latin America 90% burned, 10% extracted; Africa 50% burned, 50% extracted. In all other regions 10% of the biomass is burned and 90% extracted.
- The extracted biomass (from deforestation but mainly forest management enters two pools of wood products: long and short living. For the long living pool we assume a decay rate of 0.03, for the short living pool the value is 0.5.
- To simulate the mitigation of emissions a carbon price is introduced. This price increases linearly from zero in 2010 to a specified value (10, 20, 30, 50, 70, 100, 200, 300, 500, 1000 USD/tC) in 2015 and then remains constant.

We present the results in relative terms to emphasise the dynamics in the numbers rather than absolute values, which very much depend on scenario assumptions and input data that cannot be presented in this short paper. The assumed baseline scenario results in G4M in a global afforestation rate (relative to forest area in 2010) that increases until 2020 from about 0.25% in 2010 and then drops by more than one third until 2050 compared to 2010. The gross deforestation rate drops globally from more than 0.30% to 0.19% between 2010 and 2030 and to 0.13% in 2050. Net forest area globally decreases until 2015 but increases thereafter when the deforestation rate falls under the afforestation rate (Figure 2). Despite a net increase of global forest area after 2015, net emissions from deforestation and afforestation are positive until 2045 as the newly afforested areas accumulate carbon rather slowly (Figure 3).

The potential for increasing negative emissions through afforestation is very limited mostly due to relatively low growth rates of newly established forests and high baseline afforestation, also avoided deforestation limits the land available for alternative land uses and therefore also limits the afforestation potential. The potential for avoiding emissions from deforestation is comparably high – from about 3% at 10 USD/tC, 65% at 30 USD/tC to more than 80% at 1000 USD/tC (Figure 4 and 5). The potential for forest management improvement is very similar (Figure 6), however the effect becomes positive after 2030 because G4M maximizes NPV by 2050 and adaptation of forest age structure to new forest management needs some time. At the price above 200 USD the potential is clearly constrained for both options. However, as the carbon price increases linearly until the year 2015, a part of the theoretical potential is not realised because the carbon price is not fully effective in the first year of future simulation. The potential increases with time while the potential for avoided deforestation decreases over time as the baseline deforestation rate decreases.

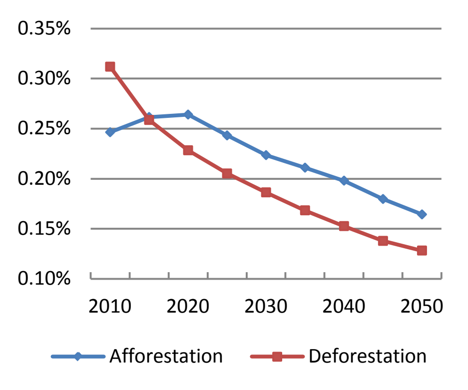

Figure 2. Development of afforestation area and deforestation area in baseline relative to forest area in 2010 (each point is a 5-year average).

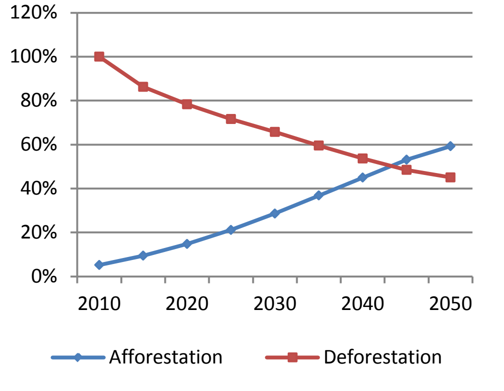

Figure 3. Development of afforestation removals and deforestation emissions in baseline relative to deforestation emissions in 2010 (each point is a 5-year average).

The mitigation activities are not adopted independently by the forest owner. The introduction of a carbon price gives an additional value to the forest through the carbon stored and accumulated in it. The increased value of forests in a regime with a carbon price alters the balance of land use change through the NPV generated by land use activities towards forestry. In general, it is therefore assumed that an introduction of carbon price leads to a decrease of deforestation and an increase of afforestation. This might not happen at the same intensity, though. Less deforestation increases land scarcity and might therefore decrease afforestation relative to a baseline. Afforestation can reduce forest management emissions in case the model uses the planted forests for wood production and thus decreases intensity of harvest of old forests. However reduction of deforestation leads to more wood extraction from forest management because less wood obtained from deforestation enters the market, therefore forest management emissions increase.

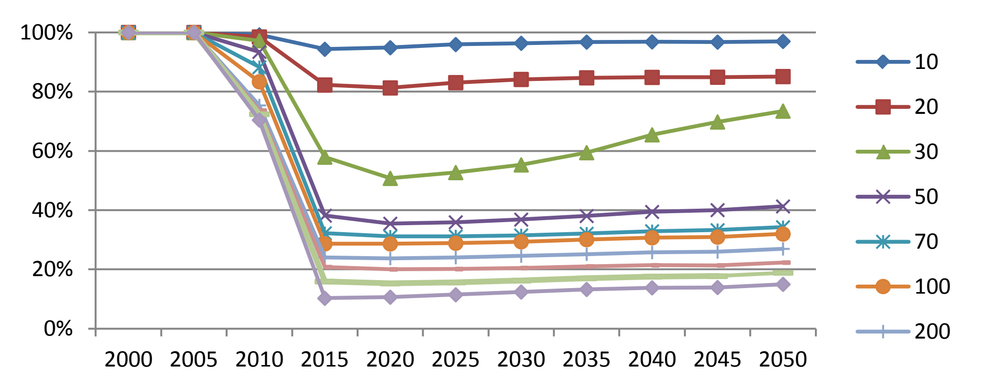

Figure 4. Development of deforestation area in different carbon price scenarios relative to the baseline. Carbon price levels are given in USD/tC (each point is a 5-year average).

The existing forest under a CO_2 price is managed with longer rotations of productive forests, and shifting harvest to less productive forest. Where possible the model increases the area of forests used for wood production, meaning a relatively larger area is managed relatively less intensively. This model paradigm implies also changes of the thinning versus final felling ratio towards more thinnings (which affect the carbon balance less than final fellings). Forest management activities can have a feedback on emissions from deforestation because they might increase or decrease the average biomass in forests being deforested. It also influences biomass accumulation in newly planted forests depending on whether these forests are used for production or not.

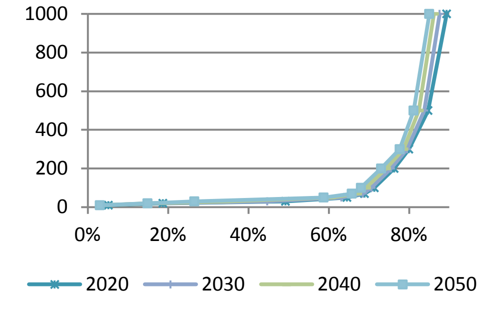

Figure 5. Relative deforestation area abatement cost curves (avoided deforestation comparing to baseline, %, horizontal axis) for carbon prices range 10-1000 USD/tC (vertical axis) in year 2020, 2030, 2040 and 2050

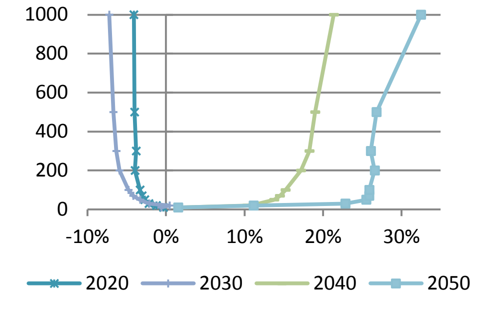

Figure 6. Relative forest management (sink) abatement cost curves (%, horizontal axis) for carbon prices range 10-1000 USD/tC (vertical axis) in year 2020, 2030, 2040 and 2050

As it is shown above emissions from deforestation, afforestation and forest management are interdependent. Therefore it is important to model them simultaneously in one system to detect “carbon leakage” from one activity to the other. Similarly, the economic model takes into account “carbon leakage” from one region to another as well as increase of competition for land if bioenergy is highly demanded.

4 CHALLENGES AND FOLLOW-UP ISSUES

There is a number of issues that can potentially improve the model projections and abatement cost estimates, both from a data point of view and regarding the linkage of models.

- Spatial land cover data used in the models [GLC 2000] are inconsistent with the [FAO 2010] especially in savannah leading to discrepancies in total forest areas and a misinterpretation of forest area change rates for the affected countries.
- G4M does not take all forest management and no transportation costs into account that might occur. For example the model assumes a stumpage wood price and does not consider specific costs for harvest type (final felling or thinning) explicitly. Also costs for expanding infrastructure to access forests not yet under management are not accounted for. Optimal decisions might change when including these.
- We face the challenge of a direct comparison of model results with observed data of historic emissions. There are in particular deviations in definitions (e.g. gross versus net deforestation, including disturbances, inclusion of regrowth) and serious data gaps that do not allow for a detailed country by country and activity by activity comparison and validation.
- Currently the number of variables that are exchanged between G4M and GLOBIOM is rather limited for reasons of practicality. Besides wood demand and wood prices also land prices are exchanged. Future studies, however, should include the exchange of more detailed driver information and area balances.

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