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Global Forestry Emissions Projections and Abatement Costs

FINAL REPORT

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Introduction

This report presents the methodology applied to generate a global dataset of forestry baseline emissions projections and associated Marginal Abatement Cost Curves (MACCs) for individual countries, based on economic, social and policy drivers. The forestry activities cover deforestation, afforestation, and forest management.

General approach

To produce consistent projections of CO_2 emissions from forestry activities at country level until 2050, two different models, an economic land use model (GLOBIOM) and a detailed forestry model (G4M) communicate as shown in the Figure 1 below. The economic land use model GLOBIOM is located in the centre of the framework. The model uses recent baseline projections based on results of the POLES energy model for future bioenergy demand and related assumptions on population growth, economic development (GDP), and technical progress rates as macro-economic drivers. GLOBIOM represents the forestry, agriculture, bioenergy and livestock sectors for in total 28 world regions.

For baseline and policy scenarios, the economic land use model projects domestic production and consumption, net exports and prices of wood and agricultural products. The sector specific information from the economic model is used by the forest model to project GHG emissions and removals for detailed land management options. The forestry model is applied to estimate emissions and removals from forest management and afforestation/reforestation activities. Based on a baseline projection it also provides abatement cost curves for the selected land use activities.

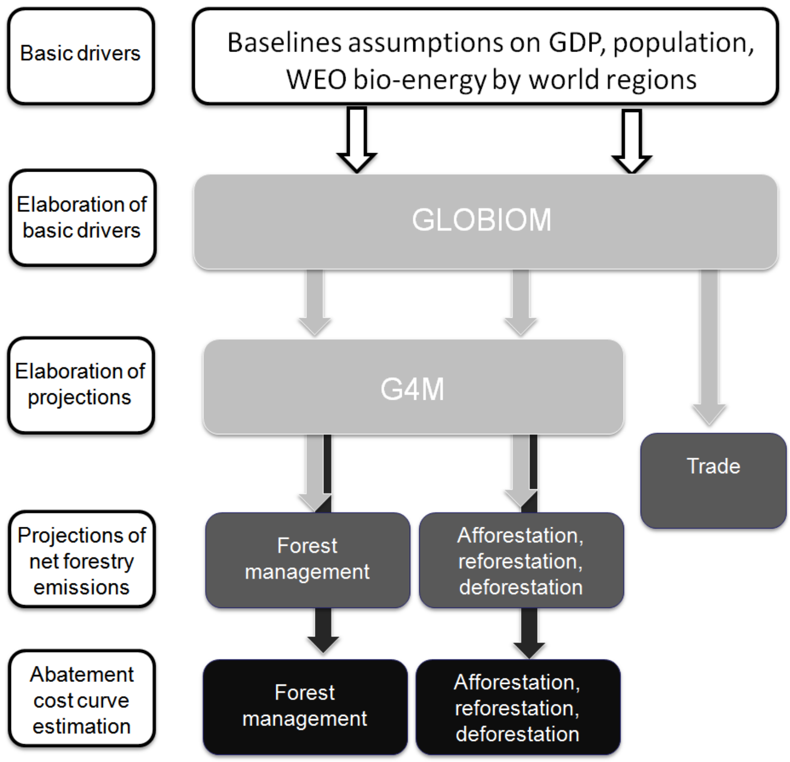

Figure 1: Overview of general modelling approach.

The models use several sources of input data some available for each grid, some by country aggregates and others are global. The data supporting the values in Table 1 are known for each grid. Some of the values are also available for time series.

Table 1: List of data sources used by the models.

Data	Year	Source
Grid level data		
Land area	2000	JRC (2000)
Forest area	2010	FAO (2010)
Forest NPP	-	Cramer et al. (1999)
Build up land	2010-2050	Tubiello and Fischer (2007)
Biomass map	2005	Kindermann et al. (2008)
Population density	1990-2050	CIESIN (2005)
Population density	1990-2050	Grubler et al. (2007)
Country level data		
PPP	2005	World Bank (2005)
Discount rates	2004	Benitez et al. (2004)
Corruption factor	2005	Kaufmann et al. (2005)
Fraction of long living products	2000–2010	FAO (2010)
Scenarios/Region level data		
WEO bioenergy scenario	2010	WEO (2010)
POLES high GDP scenario	2011	POLES (2011)
POLES low GDP scenario	2011	POLES (2011)

GLOBIOM description

General description

The Global Biosphere Management Model (GLOBIOM)[1] has been developed and is used at the International Institute for Applied Systems Analysis (IIASA). 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. It is *global* in the sense that it encompasses all world regions aggregated in a way that can be altered. GLOBIOM covers 28 (or 50) world regions.[2] *Partial* denotes that the model does not include the whole range of economic sectors in a country or region but specialises on agricultural and forestry production as well as bioenergy production. These sectors are, however, modelled in a detailed way accounting for about 20 globally most important crops, a range of livestock production activities, forestry commodities as well as different energy transformation pathways.

GLOBIOM disaggregates available land into several land cover/use classes that deliver raw materials for wood processing, bioenergy processing and livestock feeding. Figure 2 illustrates this structure of different land uses and commodities. Forest land is made up of two categories (unmanaged forest and managed forest); the other categories include cropland, short rotation tree plantations, grassland (managed grassland) and 'other natural vegetation' (includes unused grassland).

The detailed modelling of land based activities means that the GLOBIOM model relies on a detailed database containing geo-spatial information. This information is made up of different layers: geo-spatial 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. For the bulk of global crop production four management systems are available in GLOBIOM; these are 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 welfare (i.e. the sum of producer and consumer surplus) subject to resource, technological, and policy constraints. These constraints ensure that demand and supply for *inter alia* irrigation water and land meet but also impose exogenous demand constraints so as to reach, for instance, a certain biofuel target. Prices and international trade flows are endogenously determined for respective aggregated world regions (i.e. in this context for the 28 regions mentioned above). Imported and domestic goods are assumed to be identical (homogenous), but the modelling of trade does take into account transportation costs and tariffs. GLOBIOM includes accounting for greenhouse gas emissions and sinks from agricultural and forestry activities. This

[1] Documentation of the GLOBIOM model can be found at www.globiom.org.

[2] The disaggregation of the EU into 27 individual countries has been performed only recently, originally five European region are defined and used for this project (http://www.iiasa.ac.at/Research/FOR/globiom/regions.html).

includes among others accounting for N_2O emissions from fertiliser use whose intensity in turn depends on the management system.[3]

It is possible within the model to convert one land cover/use to another; the total land area spanning all the categories included remains fixed, however (this forms part of the constraints mentioned earlier). The arrows on the left-hand side of Figure 2 indicate the initial land category and therefore show the way in which land cover/use can change (i.e. unmanaged forest can be converted into managed forest or cropland). The greenhouse gas consequences from land use change are derived from the carbon content of above- and below-ground living biomass of the respective land cover classes.

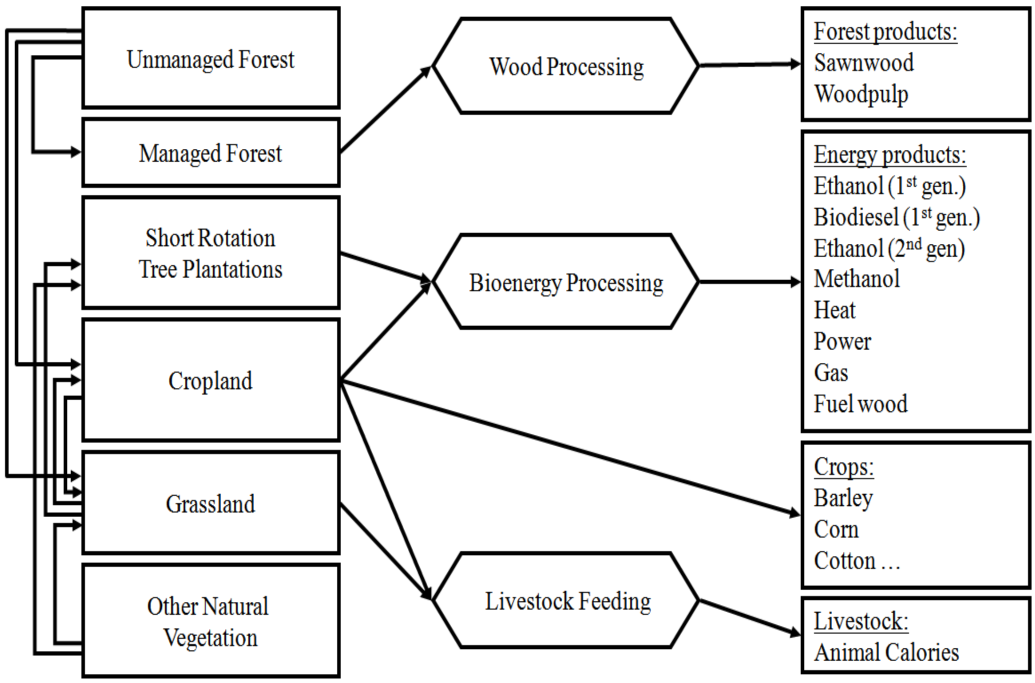

Figure 2. GLOBIOM land use and product structures (Havlík *et al*, in press). Note: The arrows on the left represent the direction where a given land use/cover type can expand given the current constraints in the model.

The model is *recursive dynamic* in the sense that changes in land use made in one period alter the land availability in the different categories in the next period. Land use change is thus transmitted from one period to the next. As GLOBIOM is a partial equilibrium model, not all economic sectors are modelled explicitly. Instead, several parameters enter the model exogenously, or are pre-determined in other words, including wood and food demand which in turn are derived from changes over time in gross domestic product (GDP), population (same projections as used in PRIMES) and food (calorie) consumption per capita (projections according to FAO 2006). Assumptions on GDP, population growth and calorie consumption per capita are the underlying driver of the model dynamics. The base year for the model is the year 2000, the model horizon is 2050. The exogenous drivers population and GDP growth have been updated to take recent economic downturns into account by relying on 2009 data. In relation to yield development,

[3] The calculation of N_2O emissions is in accordance with IPCC 1996, which does not take detailed soil characteristics into account (such as soil carbon content) that can have important implications for the amount of emissions.

GLOBIOM typically assumes 0.5 % autonomous technological progress in crop improvement[4]; in addition, the possibility to shift between management systems as well as the relocation of crops to more productive areas also provides for regional average yield changes. When it comes to 'bioenergy dynamics', projections from POLES 2010 on regional biomass demand in heat and power (BIOINEL), direct biomass use i.e. for cooking (BIOINBIOD) and liquid transport fuel use (BFP1 and BFP2 or first and second generation biofuels, respectively) over the next two decades are implemented in GLOBIOM as target demands or minimum demand constraints.

Resources for the different types of bioenergy products can be sourced from agricultural and (existing) forestry activities but also from newly planted short rotation tree plantations. First generation biofuels include ethanol made from sugarcane, corn and wheat, and biodiesel made from rapeseed, palm oil and soybeans. Biomass for second generation biofuels is either sourced from existing forests/wood processing or from short rotation tree plantations. Havlík *et al* (in press) define different scenarios for the sourcing of second generation biofuels. They also conducted an analysis to establish the scale of land available for short rotation tree plantations. Summarised in a few words, they arrive at available area by excluding areas unsuitable for their level of aridity, temperatures, elevation and population density from total arable land area (grassland, cropland, 'other natural vegetation').

Recent applications of GLOBIOM have analysed the impacts of different development scenarios in terms of population growth, economic development and technical change on global food production and consumption (Schneider *et al*, 2011) as well as the global land-use implications of first and second generation biofuel targets (Havlík *et al,* in press). The explicit inclusion of water as a resource (along with land and irrigated land) makes GLOBIOM a strong tool for analysing water related impacts of different development scenarios (Sauer *et al*, 2010).

Modifications for DECC scenarios

Main drivers and crucial parameters

The main drivers of results and crucial underlying assumptions are the following:

- Yield assumption: 0.5 % autonomous yield increase per year due to technical progress typically assumed.[5] This assumption can be easily altered in GLOBIOM to reflect latest available yield projections or to run sensitivity scenarios;
- Calorie consumption per capita derived from projections according to FAO (2006);
- Available land reserve and availability to convert grassland and 'other natural vegetation': 5 per cent of area per period (10-year periods) allowed to be converted to short rotation plantings

[4] Note that Havlík *et al* (in press) work with a different, i.e. zero per cent, yield assumption. In sensitivity analyses addressing agricultural productivity this parameter will be varied to assess impacts of different yield assumptions.

[5] Note that autonomous yield increase is only one of three components of the yield change in GLOBIOM. The other two components are management system change (intensification) and shift of the production to more or less yielding zones (re-allocation). It was found that the 0.5 value enables best to reproduce recent total yield changes according to FAOSTAT. Disaggregated data which would enable to define the autonomous yield growth in a less arbitrary and more differentiated way (by region and crop) is not available.

Baseline definition

- Projections for 2015, 2020, 2025, 2030 and 2050 (according to contract), linear interpolation of GLOBIOM steps 2010, 2020 to get to 2010 and 2020, 2030 to get to 2025
- Drivers are WEO 2010 data on
  - Population
  - GDP
  - Bioenergy production
- WEO 2010 projections only reach to 2035. Population, GDP and Bioenergy data need to extended using other (default) scenario data (POLES)
- WEO 2010 projects only biomass&waste in one category. Historic shares of biomass and waste in IEA data are used to split the two
- Details on traditional fuels (first generation) and advanced fuels (second generation) are given by WEO 2010 (see files)
- Settings
  - World energy mandates are met (WEO 2010)
  - No trade of biofuels exceeding current patterns is allowed
  - Deforestation is allowed
  - Change in livestock production systems allowed
  - Other land use change allowed

Output

To G4M

- Prices of commodities relevant for G4M (wood, land etc.)
- Wood production
- Per GLOBIOM region

Into GUI

- Consumption, production, net trade of biomass feedstocks and wood (energy and timber)
- Standard output of other variables

Table 2: Mapping to WEO bioenergy categories.

WEO		POLES	GLOBIOM
Power generation	Fuel use in electricity plants, heat plants and combined heat and power plants.	BIOINEL	Electricity, Heat and Gas from wood
Other Energy Sector	Use of energy by transformation industries and the enrgy losses in converting primary energy.	BIOINBIOD	Stove
Industry Modern Biomass	Final energy consumption in industry sector. *Wood products such as pellets and briquettes that have been made to burn efficiently, industrial biogas and bioliquids.*	BIOINBIOD	Stove
Transport	Final energy consumption in transport sector.		

Conventional biofuels	*First generation biofuels.*	BFP1	Ethanol (from sugarcane, corn or wheat), FAME (from rapeseed, palm oil or soybean)
Advanced Biofuels	*Second or third generation biofuels.*	BFP2	Ethanol and methanol from wood
Residential	Final energy consumption in buildings.	BIOINBIOD	Stove
Traditional Biomass	*Use offuelwood, charcoal, animal dung and agricultural residues in stoves with very low efficiencies.*		
Modern Biomass	*Wood products such as pellets and briquettes that have been made to burn efficiently, industrial biogas, municipal solid waste incineration and bioliquids.*		
Other TFC	Final energy consumption in buildings in services and agriculture and non energy use.	BIOINBIOD	Stove

Table 3: Mapping to WEO world regions

WEO	POLES	GLOBIOM	Countries
US	USA	USAReg	United States
CAN	CAN	CanadaReg	Canada
MEX	MEX	MexicoReg	Mexico
JPN	JPN	JapanReg	Japan
KOR	COR	South Korea	Korea
AUNZ	RJANp.	ANZ	Australia, New Zealand
OE4	ROWE + TUR	ROWE + Turkey	Iceland, Norway, Switzerland, Norway, Turkey
EU27	EU27_IDT	EU_MidWest + EU_South + EU_North+ EU_Baltic+EU_Central East	France, Germany, UK, Spain, Italy, Luxembourg, Belgium, Netherlands, Danemark, Austria, Czech Republic, Slovakia, Slovenia, Sweden, Finland, Ireland, Poland, Estonia, Latvia, Lithuania, Greece, Hungary, Portugal, Bulgaria, Cyprus, Malta, Romania
OETE	RCEU + UKR	Former_USSR + RCEU	Albania, Belarus, Bosnia Herzegovina, Croatia, Macedonia, Moldova, Serbia, Ukraine, Russia, Azerbaidjan, Kazakhstan, Turkmenistan, Uzbekistan, Armenia, Georgia, Kyrgyzstan, Tajikistan,
Russia	RUS		
CASP	RIS		
RATE			
China	CHN	ChinaReg	People's Republic of China, Hong Kong
India	NDE	IndiaReg	India
South East Asia (ASEAN)	RSEA + RSAS	RSEA_OPA + RSEA_PAC + RSAS + Pacific Islands	Indonesia, Brunei Darussalam, Cambodia, laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, Viet Nam, Bangladesh, DPR of Korea, Mongolia, Nepal, Pakistan, Sri Lanka, Afghanistan, Bhutan, Cook Islands, East Timor, Fiji, French Polynesia, Kiribati, Laos, Macau, Maldives, New Caledonia, Papua New Guinea, Samoa, Solomon Islands, Tonga, Vanuatu
Rest of Other Developing Asia			
Brazil	BRA	BrazilReg	Brazil

OLAM	RSAM + RCAM	RSAM + RCAM	Argentina, Bolivia, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Netherland Antilles, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, Venezuela, Antigua and Barbuda, Aruca, Bahamas, Barbados, Belize, Bermuda, British Virgin Islands, Cayman Islands, Dominica, Falkland Islands, French Guyana, Grenada, Guadeloupe, Guyana, Martinique, Montserrat, St Kitts and Nevis, Saint Lucia, St Pierre et Miquelon, St Vincent and the Grenadinesm Suriname, Turks and Caicos Islands
SAFR	SSAF	SouthAfrReg	South Africa, Angola, Benin, Botswana, Cameroon, Congo, Democratic Republic of Congo, Côte d'Ivoire, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Mozambique, Namibia, Nigeria, Senegal, Sudan, Tanzania, Togo, Zambia, Zimbabwe, Burkina Faso, Burundi, Cape Verde, Central African republic, Chad, Comoros, Djibouti, Equatorial Guinea, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Niger, Reunion, Rwanda, Sao Tome et Principe, Seychelles, Sierra Leone, Somalia, Swaziland, Uganda
OAFR		SubSaharanAfr + CongoBasin	
NAFR	EGY	MidEastNorthAfr	Egypt, Algeria, Libya, Morocco, Tunisia, Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen
ME	GOLF+ MEME + NOAN + NOAP		

G4M description

General description

The Global Forest Model (G4M) is applied and developed by IIASA and estimates the impact of forestry activities (afforestation, deforestation and forest management) on biomass and carbon stocks. By comparing the income of managed forest (difference of wood price and harvesting costs, income by storing carbon in forests) with income by alternative land use on the same place, a decision of afforestation or deforestation is made. As G4M is spatially explicit (currently on a 0.5° x 0.5°resolution) the different deforestation pressure at the forest frontier can also be handled. The model can use external information (like wood prices, prescribed land-use change from GLOBIOM) from other models or data bases, which guarantee food security and land for urban development or account for disturbances. As outputs, G4M produces estimates forest area change, carbon sequestration and emissions in forests, impacts of carbon incentives (e.g. avoided deforestation) and supply of biomass for bio-energy and timber.

For Europe the initial forest growing stock (aboveground biomass) per grid cell was taken from the European forest biomass map from Gallaun et al. (2010) and scaled to total biomass using the biomass map of Kindermann et al. (2008). For countries outside Europe the original forest biomass map compiled by Kindermann et al. (2008) was used.

The model handles age classes with one year width. Afforestation and disasters cause an uneven age-class distribution over a forest landscape. The model performs final cuts in a manner, that all age classes have the same area after one rotation period. During this age class harmonization time the standing biomass, increment and amount of harvest is fluctuating due to changes in age-class distribution and afterwards stabilizing.

The main forest management options considered by G4M are species selection, variation of thinning and choice of rotation length. G4M does not model species explicitly but a change of species can be emulated by adapting NPP, wood price and harvesting costs. The rotation length can be individually chosen but the model can estimate optimal rotation lengths to maximize increment, maximize stocking biomass or maximize harvestable biomass.

To initialise forest biomass the forest biomass map compiled by Kindermann et al. (2008) was used. 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 changes of temperature, precipitation or CO_2 concentration. Age structure and stocking degree are used for adjusting NAI. If stocking degree of forest modelled with a given age structure (country average) in a cell is greater than 1.05 age structure of the modelled forest is shifted iteratively by a few age classes towards older forest. If stocking degree of forest modelled in a cell is smaller than 0.5 age structure of the modelled forest is shifted iteratively by a few age classes towards younger forest. It is required that the shifts are symmetrical to keep country average age structure close to statistical value. If the age structure shift distribution within a country is skewed towards older forest, the country's average NAI is increased iteratively. If the age structure shift distribution within a country is skewed towards younger forest country NAI is decreased iteratively.

The model uses external projections of wood demand per country (estimated by GLOBIOM) to calculate total harvest iteratively. The potential harvest amount per country under a scenario of rotation lengths that maintain current biomass stocks is estimated. If total harvest is smaller than wood demand the model changes grid per grid (starting from the most productive forest) management to a rotation length that optimizes forest increment and thus allows for more harvest. This mimics the typical observation that managed forests (in some regions) are currently not managed optimally with respect to yield. The rotation length is changed at maximum by five years per time step. If harvest is still too small and unmanaged forest is available the status of the unmanaged forest will change to managed. If total harvest greater than demand the model changes management to maximum biomass rotation length, i.e. manages forests for carbon sequestration. If wood demand is still lower than potential harvest managed forest can be transferred into unmanaged forest. Thinning is applied to all managed forests. The stands are thinned to maintain a stocking degree specified. The default value is 1 where thinning mimics natural mortality along the self-thinning line. The model can consider the use of harvest residues e.g. for bioenergy purposes.

Cost curve algorithm

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 baseline is estimated assuming forest management without the carbon price incentive.

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
- Change of harvest intensity (amount of biomass extracted in thinning and final felling activity

These activities are not adopted independently by the forest owner. The model is managing land dynamically and one activity affects the other. The model is calculating the optimal combination of measures. The introduction of a CO_2 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 CO_2 price changes the balance of land use change through the net present value (NPV) generated by land use activities towards forestry. In general, it is therefore assumed that an introduction of CO_2 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.

The existing forest under a CO_2 price is managed with longer rotations of productive forests, and shifting harvest to less productive forest (see Box 1). 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.

Box 1: Abatement cost curves for forest management activities – detailed algorithm.

For the generation of cost curves for forest management a two step approach is used:

STEP 1. Every year, starting from the onset of mitigation measures, forest management in each cell is changed towards a state that maximises the orest biomass. For the forest used for wood production, where NPV estimated for the maximum biomass rotation length (NPV_{wc}) is greater than the BAU NPV (NPV_{bau}, NPV_{bau}>=0), current rotation length is increased proportionally to the (NPV_{wc}-NPV_{bau})/NPV_{bau}. If the NPV condition is not satisfied, the current rotation length is increased by five years. In all cases the maximum rotation length is not allowed to be higher than the rotation length maximising biomass. NPV for the new rotation length is estimated (NPV_c) and kept in memory. NPV in all cases is estimated for the next 50 years.

STEP 2. The production of wood to satisfy wood demand has higher priority than the carbon accumulation. After Step 1 the forest management of forests within each country is adjusted to harvest as much as the country wood production prescribed (by GLOBIOM). A precondition of the adjustment is that the new NPV multiplied by an adjustment hurdle coefficient to be greater or equal to NPV_c estimated in Step 1. The adjustment hurdle varies from 1 to 2500 and to -1. The forest management adjustment for the cells within each country starts with the hurdle=1. If the total harvest does not satisfy prescribed wood production, the hurdle is increased by 0.3 and the forest management adjustment is repeated for the forests within the country again. The last hurdle tried is minus one, allowing forest management leading to negative NPV in order to satisfy wood production.

Results prior to 2000

G4M is initialized with the 2000 year parameters in 1990. Then the model is run with fixed forest area until 2000 (afforestation and deforestation rates and respective carbon flows are estimated but forest area is forced to be constant). In this way we use the 1990-2000 time period to spin-up the model but not changing parameters like forest area that are based on the year 2000 map. This means the model is calculating and emissions can be estimated but the calculated changes are not affecting forest area.

Baseline definition

- Drivers are POLES 2011 data on
    - Population
    - Prices from GLOBIOM
    - Wood production from GLOBIOM
- Calibration to area information of latest dataset from the FAO's Global Forest Resources Assessment 2010
- Specification of how much wood is burned after deforestation
    - Latin America - 90% slash burn and 10% selling
    - Africa - 50% slash burned and 50% selling
    - The remaining area - 10% slash burned and 90% selling
- Wood products
    - Two categories, long and short living
        - Decay rate long ln(2)/20
        - Decay rate short 0.5

MACCs

- Carbon price paths according to DECC proposal
- Annual MAC curves for 2015, 2020, 2030 and 2050
- The MAC curves are based on three carbon price paths to reflect varying paths of action, to be specified by DECC

Output

- Annual projection for AR, D and FM from 1990 until 2050
- Relevant variables (see list below)
- Smoothing with running 5-year mean and fixing of initial year bumps
- Tables and maps into GUI
- Per country

Table 4: Overview of G4M model variables produced in the output files.

Variable name in model	Description
area_af hayear	Afforestation area in ha per year
biom_af tc	Afforestation biomass carbon in t carbon
cai m3ha	Current annual increment (forest productivity) in m3 per ha
area_df hayear	Deforestation area ha per year
em_af_bm mtco2year	Emissions (removals) of biomass from afforestation in MtCO2 per year
em_af_sl mtco2year	Emissions (removals) of soil from afforestation in MtCO2 per year
em_df_bm mtco2year	Emissions (biomass) from Deforestation Mt CO2 per year
em_df_sl mtco2year	Emissions (soil) from Deforestation Mt CO2 per year
em_fm_bm mtco2year	Emissions (biomass) from Forest Management in Mt CO2 per year
em_fm_ab mtco2year	Emissions (aboveground biomass) from Forest Management in Mt CO2 per year
harvest_total m3	Harvested wood in m3 per ha
area_forest_new ha	New forest area (afforested area since start of simulation) in ha
area_forest_old ha	Area of „old“ forest, i.e. forest not from afforestation
area_forest_used	Area of forest used for wood production in ha
biom_fm tc	Biomass carbon in old forest, tC
rotation_avg year	Average rotation length, year
harvest_demand m3year	Wood production to be satisfied in m3
harvest_avg m3ha	Harvested wood in m3 per ha

Scenarios

Sensitivities

Several sensitivities and additional runs to test the robustness of the results from the baseline run could be run for analysis. The following list describes sensitivity runs that are potentially available:

a. High and low socio-economic drivers, e.g. GDP, population, and bioenergy demand.
b. Agricultural productivity
c. A 'technical' potential scenario, unadjusted for any governance or institutional factors

This report covers only the description and discussion of sensitivity run a).

High and low socio-economic drivers, e.g. GDP, population, and bioenergy demand (DECC scenarios)

In this scenario global economic drivers are changing in a consistent way. Optimally results of scenarios of global future assessments (WEO) or energy models (POLES) are used as input to the GLOBIOM model. It is not recommended to vary single driver data (such as only GDP) as this would create inconsistent scenarios with unknown potential artificial side effects on model results. A consistent scenario would change GDP, population, bioenergy demand. In the WEO report, three scenarios are described: New policies scenario, Current Policies scenario and a 450 stabilisation scenario. These could be used to assess the impact of changes in global drivers on forestry emissions.

Agricultural productivity (DEA scenario)

The GLOBIOM model addresses yield improvements in three ways:

- Switches are possible between production systems, for instance for cattle one can switch from purely grassland based cattle systems to more intensive production systems.
- Furthermore, crop and livestock production can be geographically shifted to areas where the resource endowments allow for higher productivity
- By default an exogenous yield growth is assumed within a given production system for crop production of 0.5% per year. For livestock this is not assumed.

Two base runs (carbon price set to zero) will test the sensitivity of the model for alternative assumptions on exogenous yield growth. A high yield growth scenario is run that sets the exogenous yield growth to 1% per year; a low yield growth scenario is run that assumes exogenous yield growth to be 0% per year. Alternative values of a high and low yield scenario can be chosen if needed. IIASA will assist with expert judgement (GLOBIUM) as part of the DEA decision making process.

This scenario addresses the uncertainty of future yield improvements. Yield improvements are essential in the future to secure food production and at the same time allow for land allocation to additional bioenergy use. Both affect the success and costs of REDD measures.

The sensitivity of GLOBIOM has been tested in earlier projects. The sensitivity of G4M to agricultural productivity is less explored and also less straight forward because the effect is only through the GLOBIOM output (land rent, product prices, wood demand). There will be test runs to explore the sensitivity.

GLOBIOM delivers also emissions from agriculture and livestock that will be made available for analyses. They include emissions of CO2 and non-CO2 gases. However, it will not be the focus of the analysis. To extract the numbers and compare them is relatively easy and would not mean higher costs.

A 'technical' potential scenario, unadjusted for any governance or institutional factors (DEA scenario)

Three factors address governance in G4M or can be interpreted with different governance situations. There are two parameters that can be manipulated in the G4M model to assess effects of governance. There is the **corruption factor** and the economic **discount rate**.

- Discount factor = discounting revenue from land activities, taken from literature
- Corruption factor = only effective when carbon price is > 0 in the MACC runs
- Hurdle rate = calibration coefficient to match historic rate of deforestation and afforestation in the baseline

There are for example countries where the potential for REDD is almost zero even at relatively high carbon prices. The reason might be high opportunity costs (land rents and high agricultural suitability) or governance. One parameter addressing governance in G4M is the **corruption factor.** The corruption factors are interpreted as a fraction of a carbon incentive that does not reach the end user (e.g. forest owner in case of incentive payment, or governmental agency in case of tax). It determines the efficiency and effectiveness of the carbon price with respect to emission reduction. If this factor would be set to fully efficient one gets an idea on the impact of governance on the potential. The corruption factor affects the efficiency of carbon policies. A high corruption factor makes carbon payments less effective. Changing the corruption rate for certain countries has only effects on the MACC runs, not the base runs (0 C-price!). IIASA and DEA will decide on test runs (one being complete removal of corruption barriers) and after that decide how to manipulate corruption factors at country level, model setup and preparation before running the MACCs. (This is independent of the test runs on changing the risk adjusted discount factor, see below).

Discount rates are used to calculate the NPV for agriculture and forestry activities in G4M. The hurdle rates in G4M are multipliers of the forestry NPV, when the model compares internal land use change with observed (FAO). These are real discount rates but risk adjusted (see Benitez and Obersteiner, 2004 for details). GLOBIOM uses discount factors only in mitigation scenarios (e.g. when setting concrete emission or area targets) but not in the baseline.

The discount rate affects baseline management options in G4M. In a governance scenario discount rates for different countries can be changed to mimic certain policies and governance scenarios (better governance resulting decreased discount rates). However, this involves a recalibration that is quite complicated and needs time (not included in budget).

Instead IIASA will try to make test runs (base runs) on risk adjusted discount factors by only include a certain percentage (undifferentiated across countries) of the applied country risk premium. Hence, one interesting and simple extreme being using a risk free rate for all countries. However, to avoid very drastic changes in the emission profile in the short run (especially 2020) the country risk premium might be phased out gradually over time in the period from 2010-2050 (e.g. linearly).

The hurdle rates are calibration coefficients to reproduce historic rates of land use change and smooth the effect of inconsistent input data. It can, however, also be interpreted as governance quality factors. Changing those is not an option in G4M.

Results

GLOBIOM results - drivers

All three scenarios (POLES base, high and low GDP) indicate an increase in GDP globally. Together with GDP vary also bioenergy demand figures that are taken from POLES and implemented into GLOBIOM. Internally, changes in GDP affect the demand for processed wood products (sawn wood and wood pulp) in GLOBIOM. The higher the GDP, the higher will be the demand, elasticity is taken from the literature. Effect on deforestation pressure depends on the origin of additional demand. In OECD countries, the model assumes that wood demand cannot trigger deforestation. Increasing demand in developing countries, however, can increase the value of the forests compared to cropland. This might decrease deforestation rates. In GLOBIOM, food consumption is not affected by different GDP levels. Currently food demand is driven exogenously by food projections that are taken from FAO projections based on their own assumptions on GDP evolution and endogenous shifts in demand are only explained by change in relative prices.

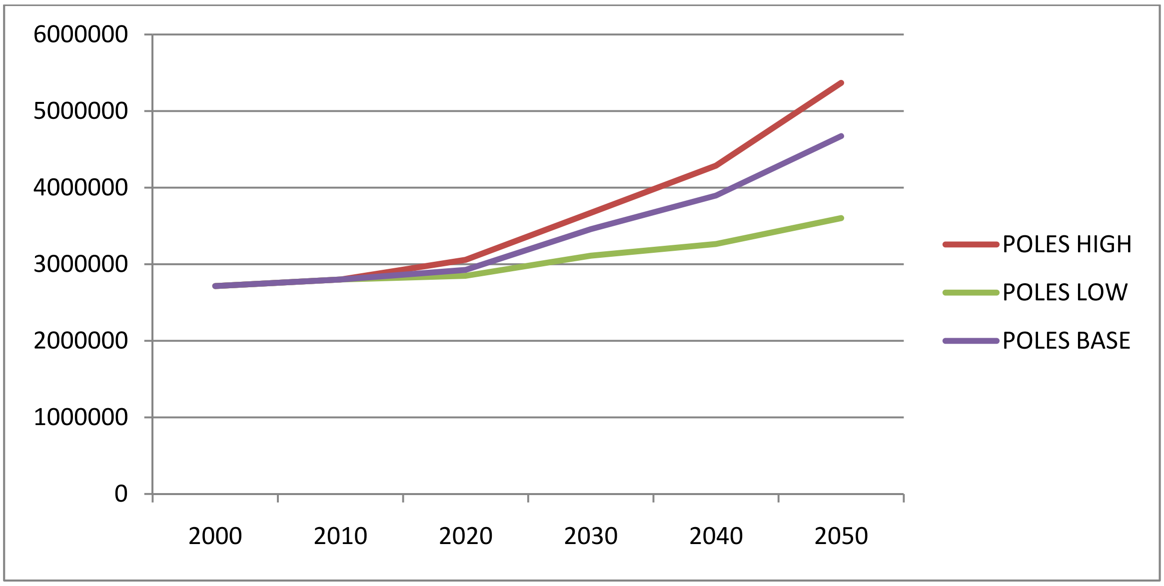

Figure 3: Total bioenergy projection in Mtoe as implemented in GLOBIOM for three base scenarios.

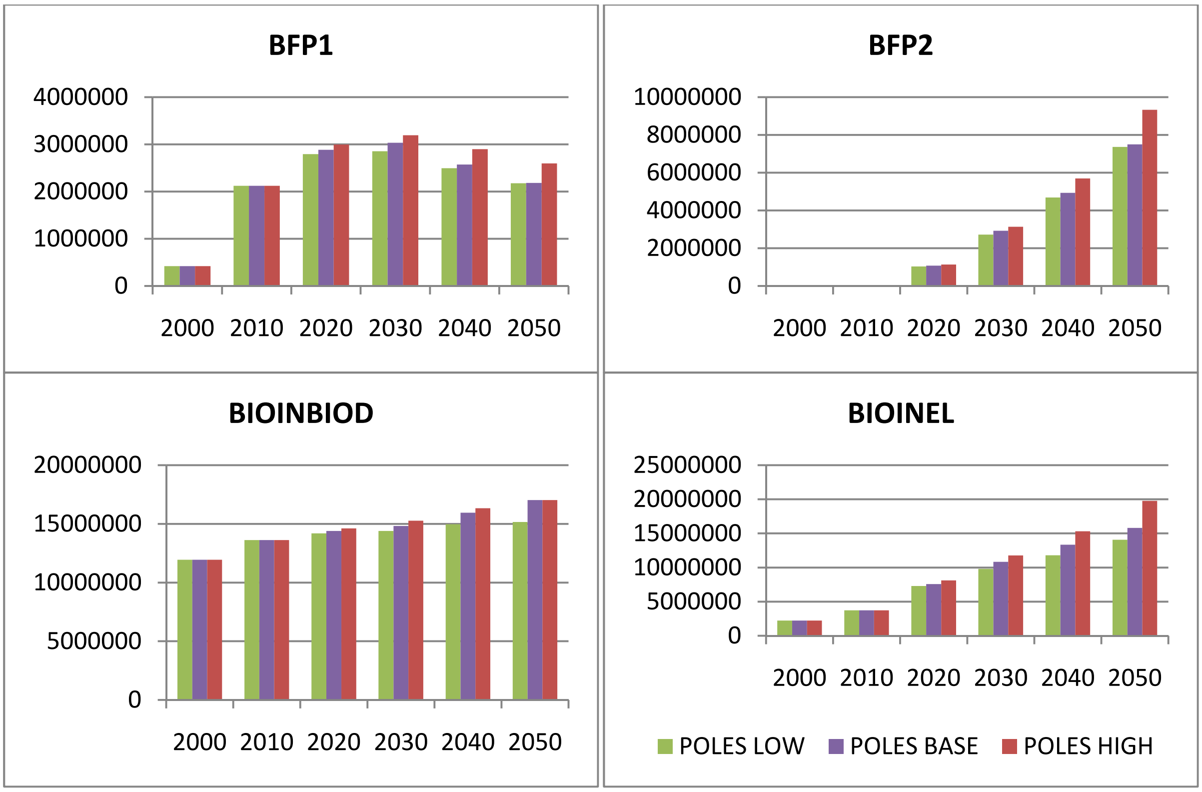

Figure 4: Development of basic bioenergy types implemented in GLOBIOM as prescribed by POLES. Bioenergy types are: biomass demand in heat and power (BIOINEL), direct biomass use i.e. for cooking (BIOINBIOD) and liquid transport fuel use (BFP1 and BFP2 or first and second generation biofuels, respectively).

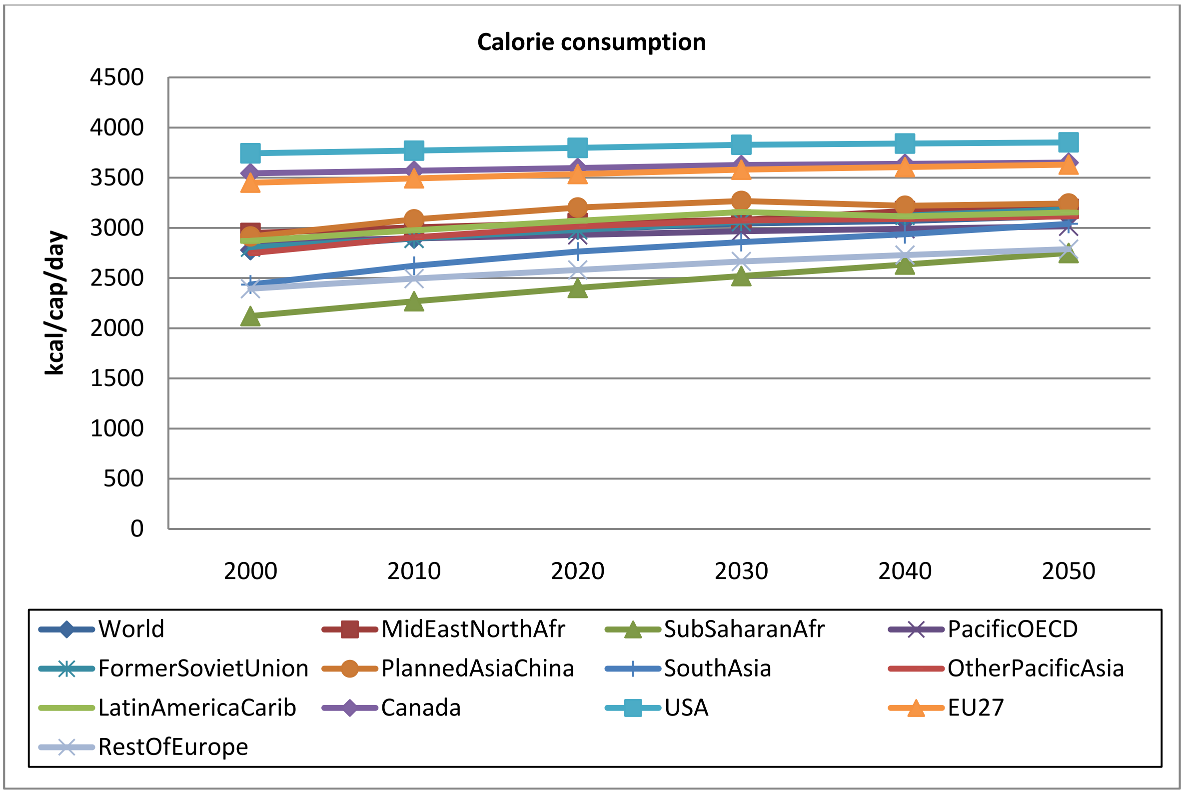

Figure 5: Baseline calorie consumption for different world regions

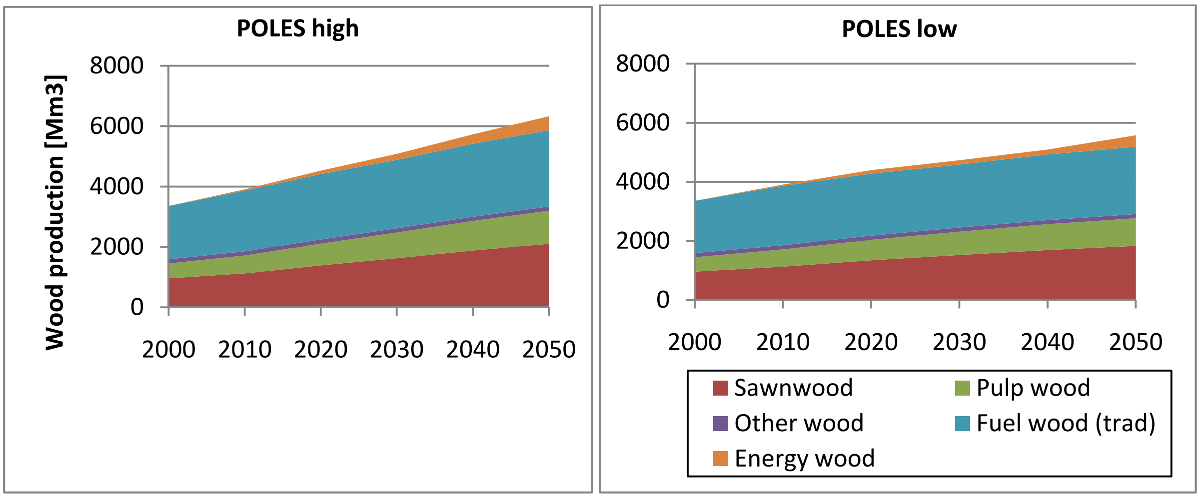

Figure 6: Comparison of wood production estimated by GLOBIOM for the high and low GDP base scenarios.

G4M results - projections

Global drivers for G4M are projections of wood demand, wood prices and land prices. The POLES base scenario translates in G4M into rather constant afforestation rates of about 7 Mha annually. The gross deforestation rate drops globally from about 20 Mha in 2000 to below 10 Mha after 2015 and reach 0.5 Mha in 2050. Net forest area globally decreases until 2015 but increases thereafter when the deforestation rate falls under the afforestation rate. Despite a net area 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. The break-even point of this balance depends very much on the onset of afforestation accounting. Compared to other sources the (net) emissions from afforestation and deforestation G4M estimates range within these.

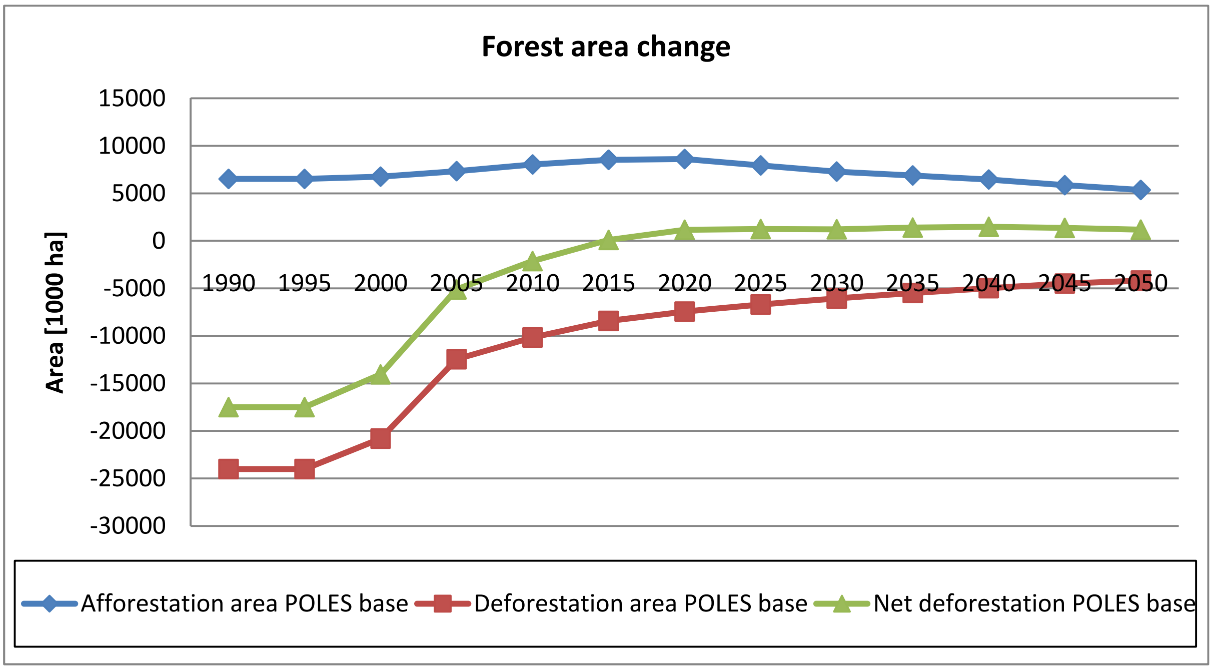

Figure 7: Global forest area change estimated by G4M. POLES base 2010 baseline bioenergy scenario.

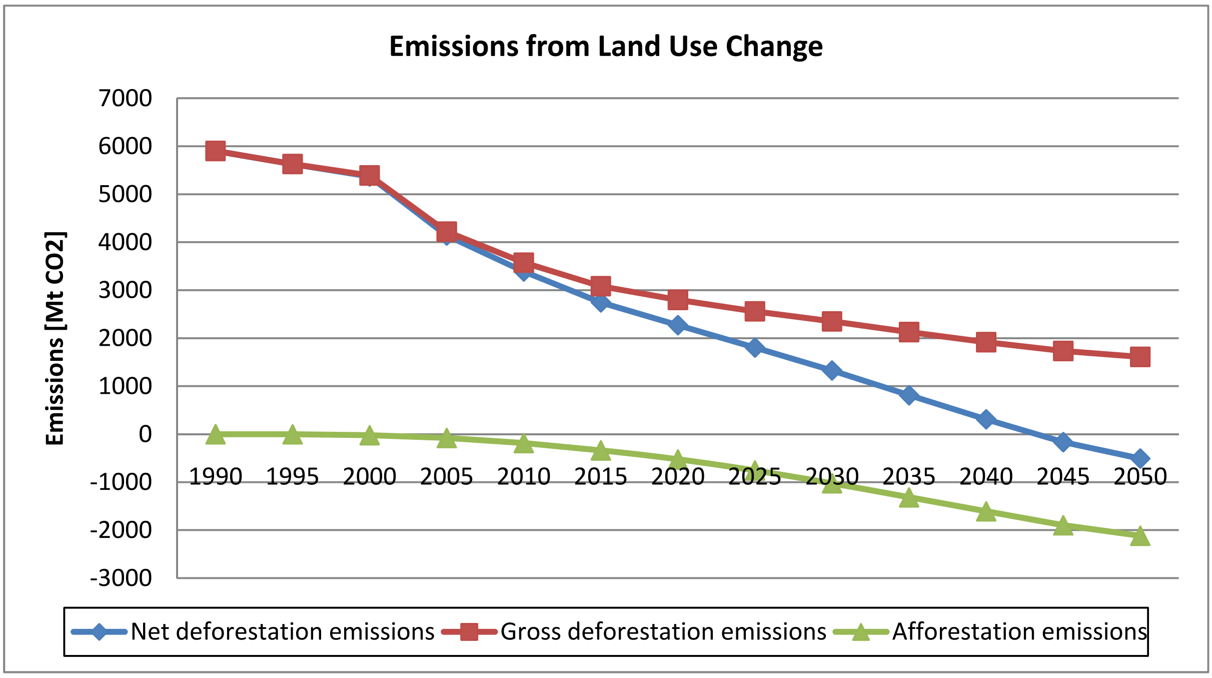

Figure 8: Global emissions from afforestation and deforestation estimated by G4M of total biomass carbon. POLES base 2010 baseline bioenergy scenario.

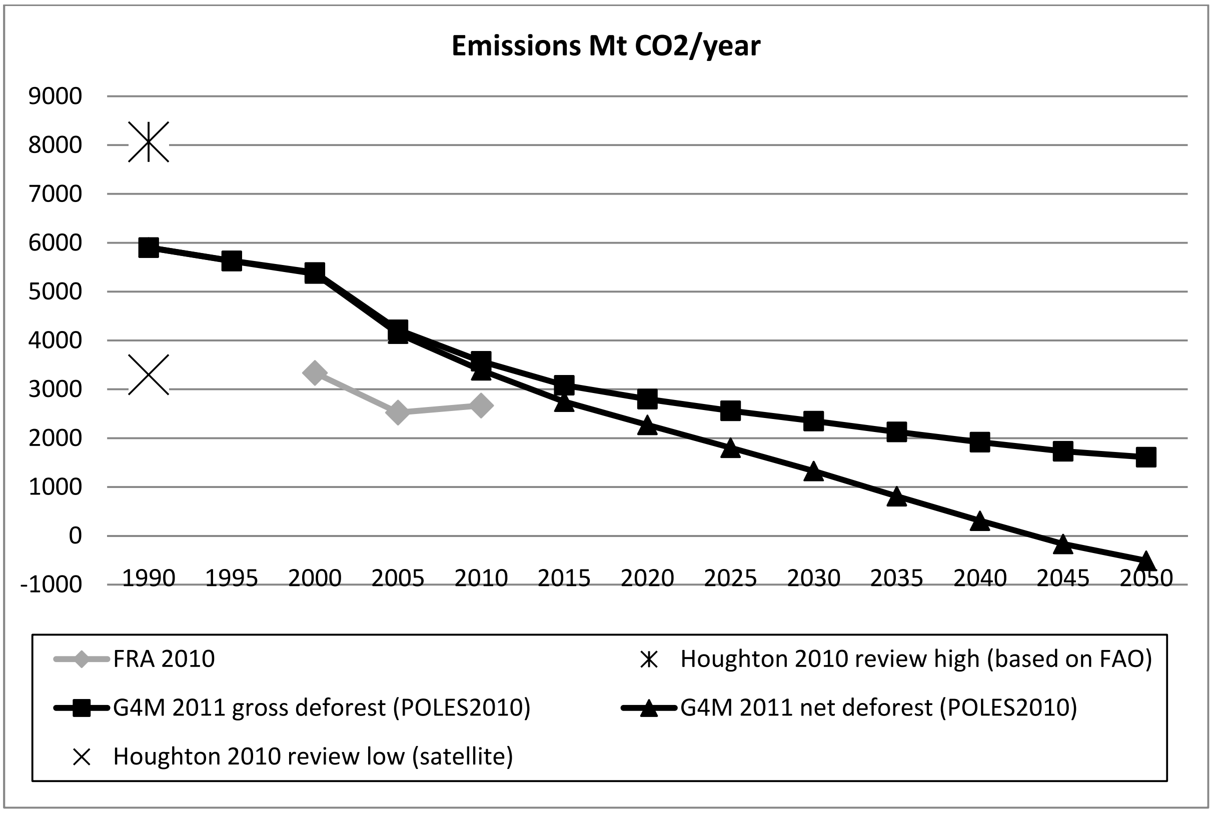

Figure 9: Comparison of G4M estimates of global gross and net deforestation emissions in Mt CO2 per year with other sources.

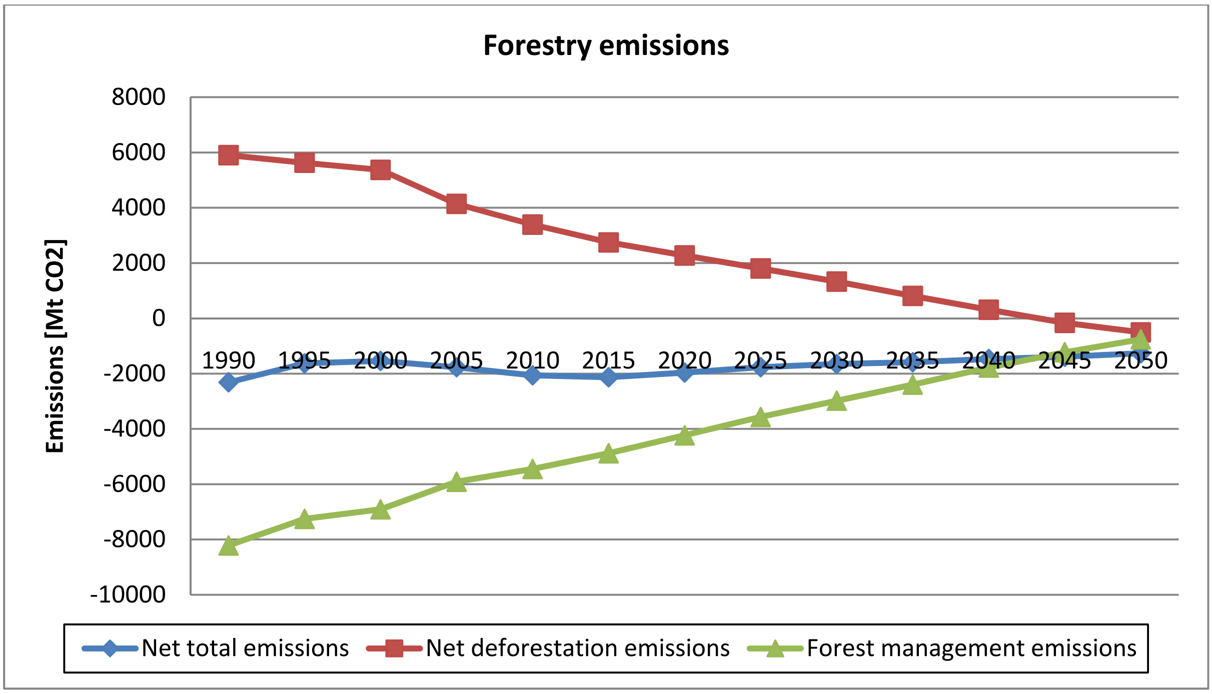

Figure 10: Global emissions from forestry (net deforestation and forest management estimated by G4M of total biomass carbon. WEO 2010 baseline bioenergy scenario.

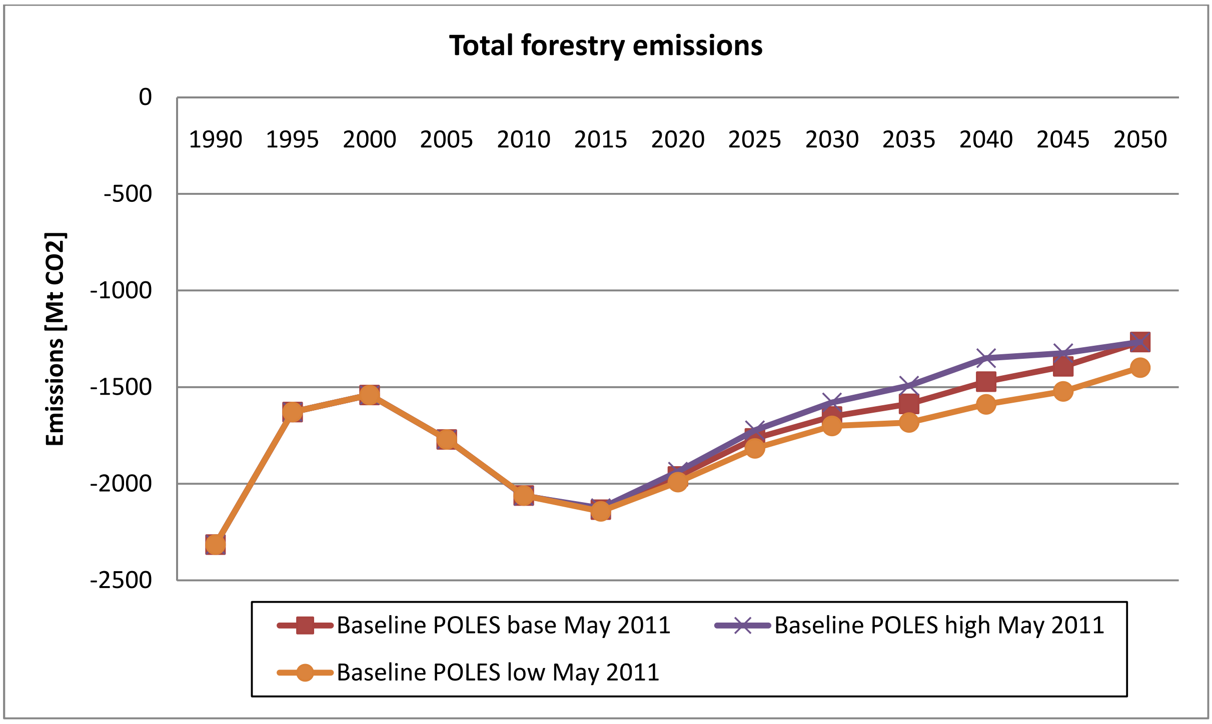

Figure 11: Global total forestry biomass emissions (afforestation, deforestation and forest management) estimated by G4M for three different POLES scenarios of GDP development.

G4M results - MACCs

The potential for increasing negative emissions through afforestation is very limited. This is mostly due to (at global average) relatively low growth rates of newly established forests and a high baseline afforestation. Further, 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. About 200 Mt CO2 per year in 2030 in Annex1 countries could be mitigated at a carbon price of 50 USD. The potential for forest management improvement is very similar. Above 200 USD the potential is clearly constrained for both options. In Non-Annex1 countries avoided deforestation can achieve about 1200 Mt CO2 per year at a price of 50 USD. The potential is less constrained compared to the potential in Annex1 countries and can grow at prices above 200 USD, achieving a potential of 1800 Mt CO2 annually in 2030 at a price of 1000 USD. The potential from afforestation is not significant in this setup of the model. Similarly to Annex1 countries, Non-Annex1 countries have a rather high baseline afforestation. Growth rates can be expected to be higher. However, as the carbon price increases linearly until the year 2030, 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.

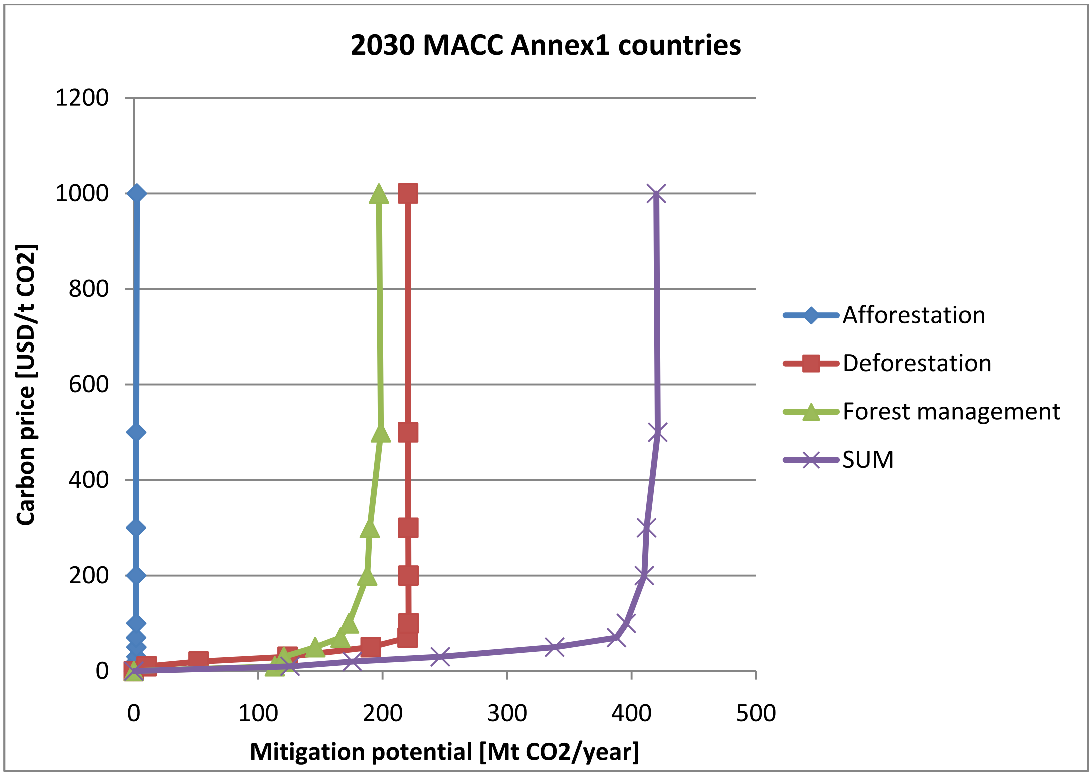

Figure 12: G4M results for POLES base 2010 baseline Annex 1 countries, linear price path, year 2030.

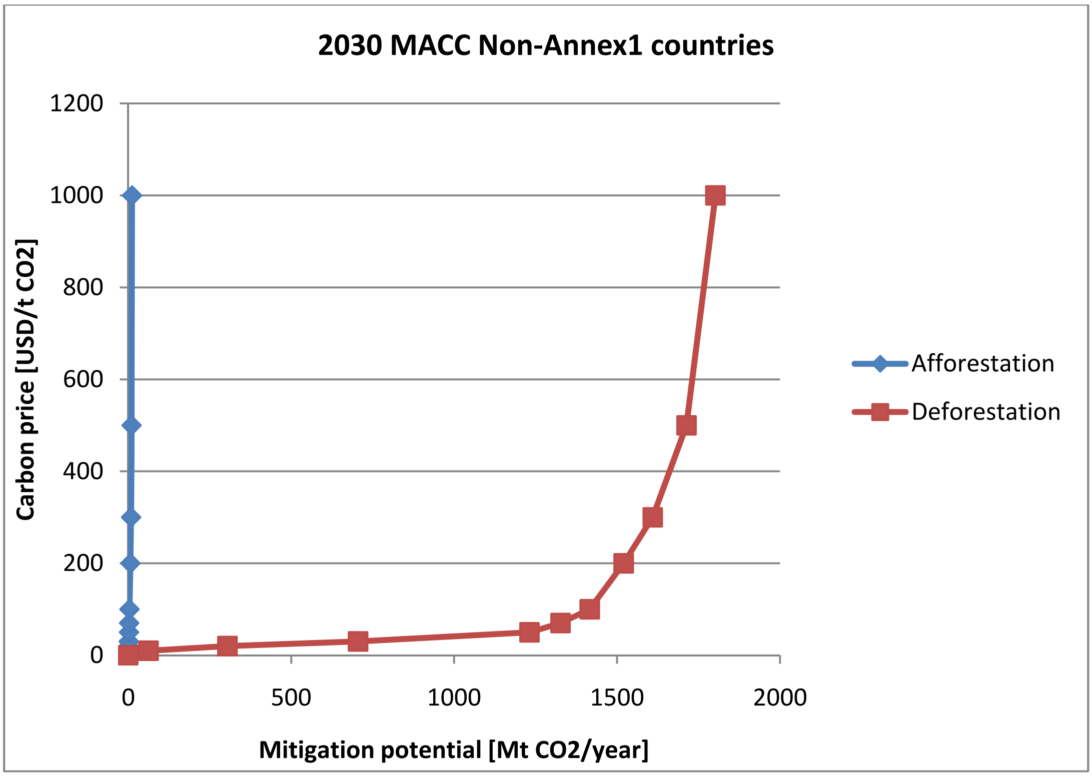

Figure 13: G4M results for POLES base 2010 baseline Non-Annex 1 countries, linear price path, year 2030.

Driver analysis - Brazil

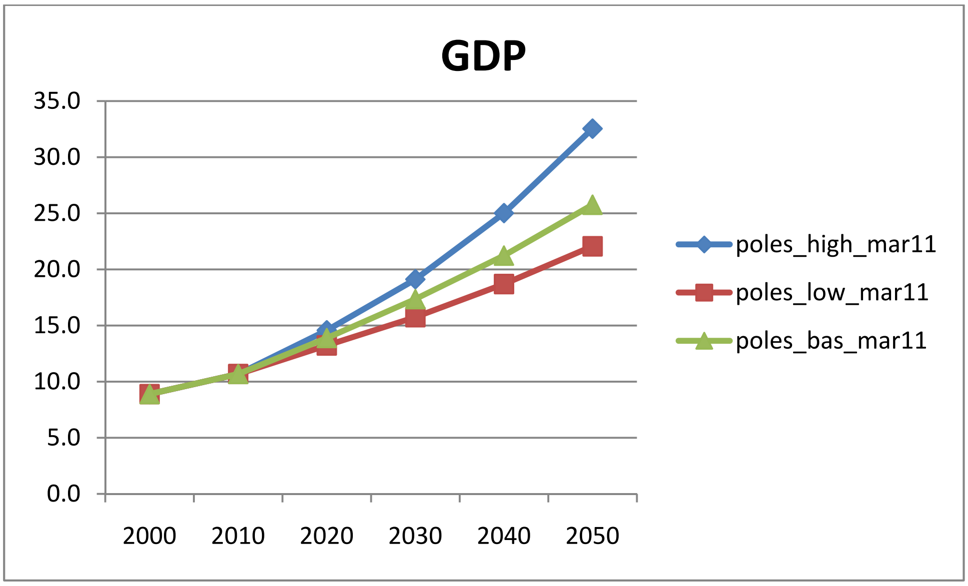

Figure 14: GDP per capita development as implemented in GLOBIOM for the region Latin America and Caribbean in 1000 USD.

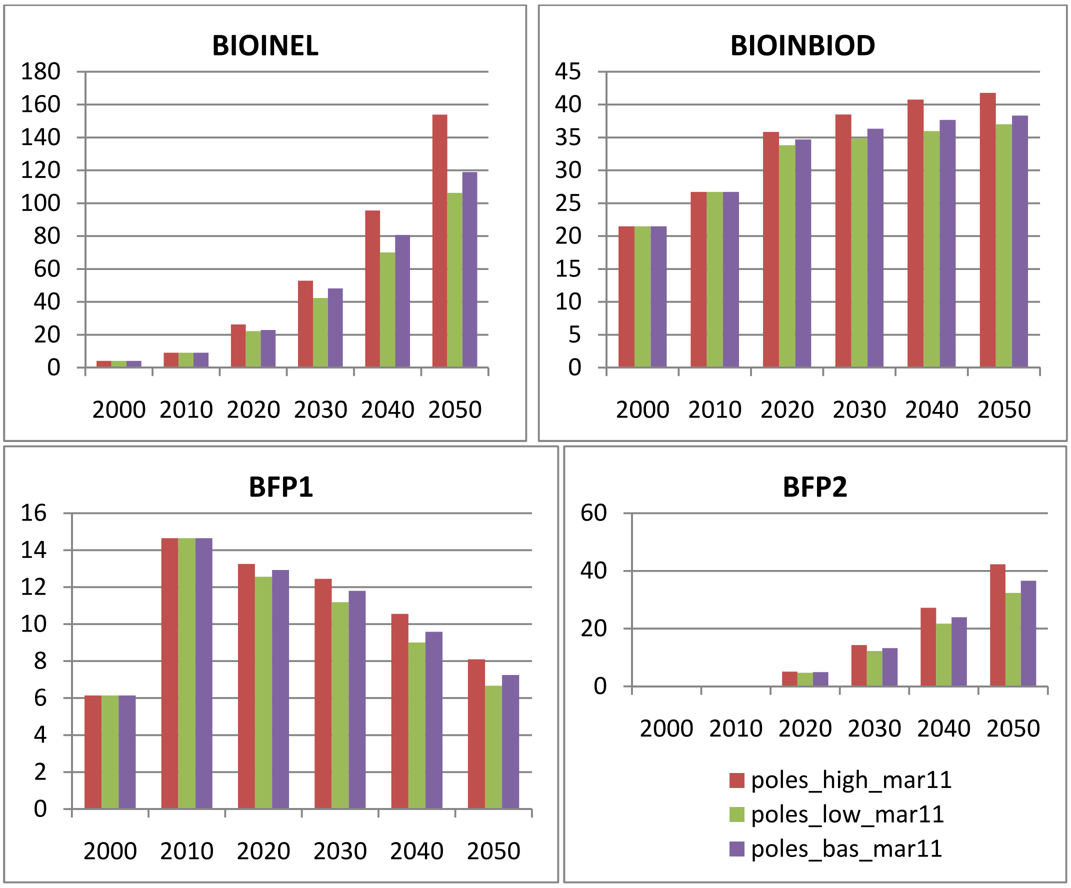

Figure 15: Development of different bioenergy products in GLOBIOM according to POLES scenarios for region Latin America and Caribbean. Units are in Mtoe. Bioenergy types are: biomass demand in heat and power (BIOINEL), direct biomass use i.e. for cooking (BIOINBIOD) and liquid transport fuel use (BFP1 and BFP2 or first and second generation biofuels, respectively).

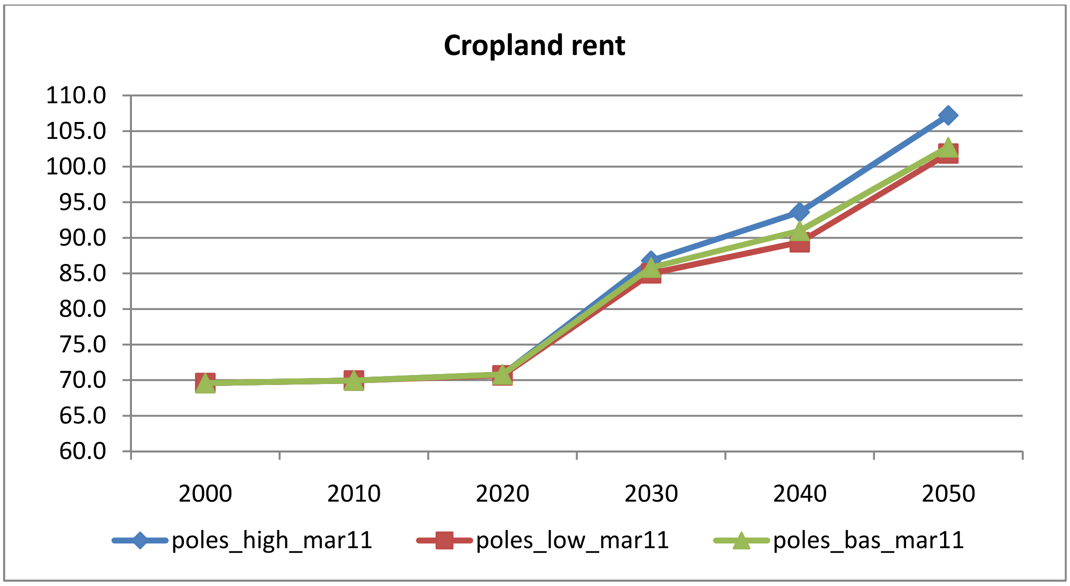

Figure 16: Development of cropland rent in USD/ha/year as a driver of deforestation in G4M for the three POLES scenarios.

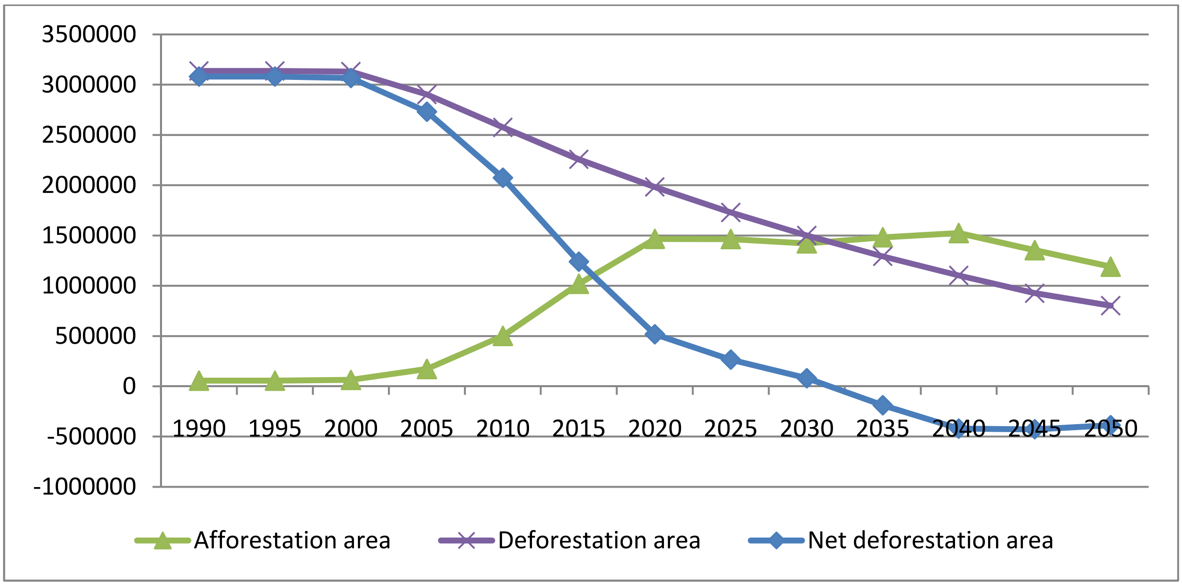

Figure 17: Brazilian deforestation and afforestation area projected by G4M for POLES base scenario in ha.

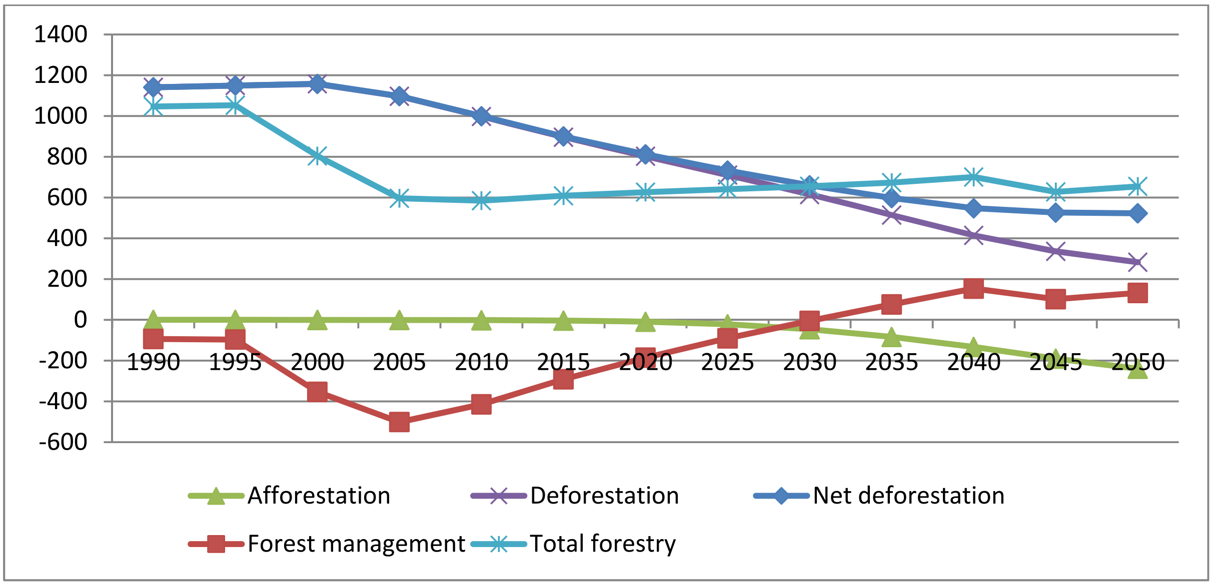

Figure 18: Brazilian emissions from afforestation, deforestation and forest management as projected by G4M in Mt CO2.

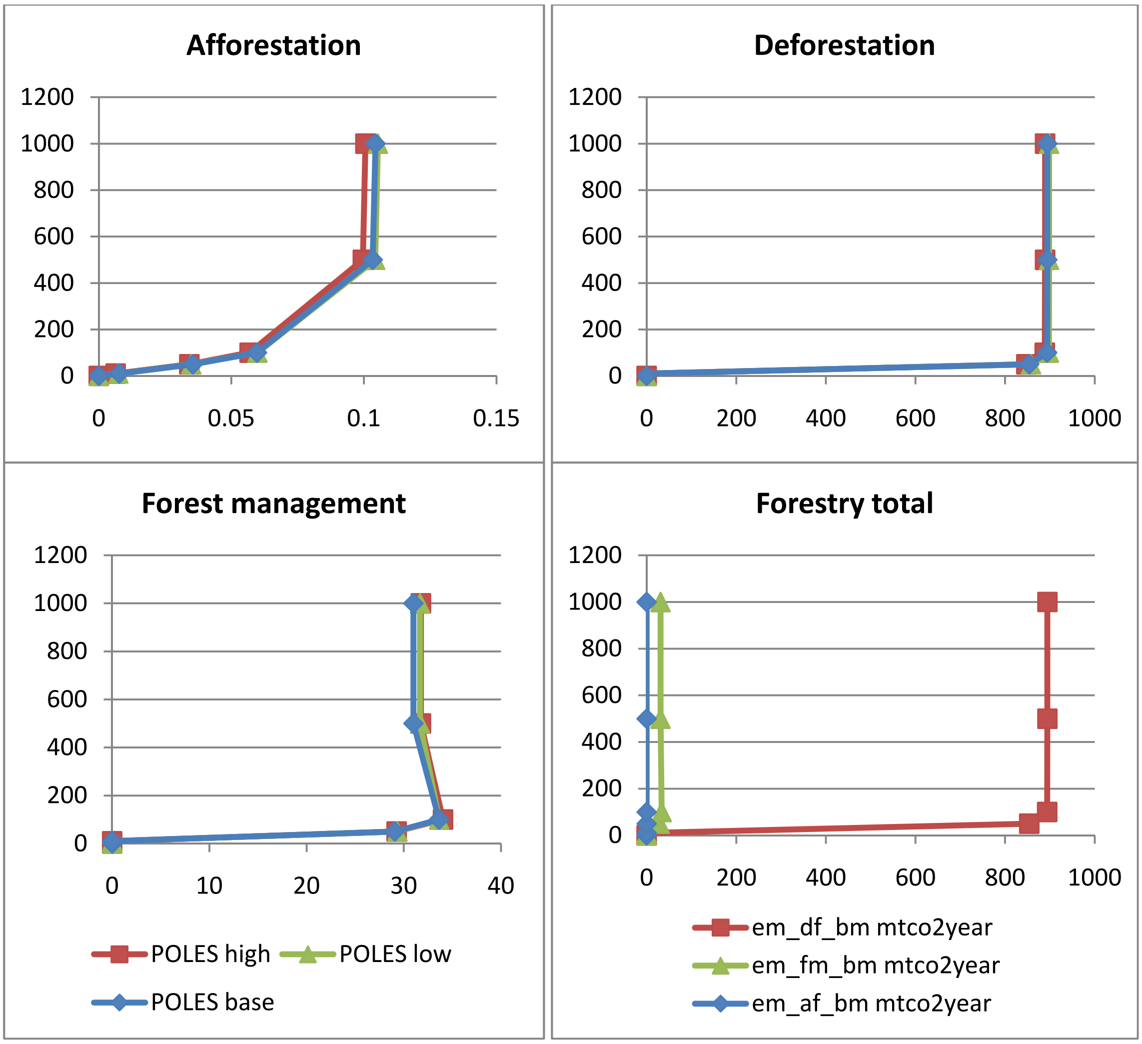

Figure 19: Abatement cost curves for Brazil fore afforestation, avoided deforestation and forest management. NOTE: forest management emissions are not optimized by reflect only the feedback from measures addressing afforestation and deforestation. Concrete forest management measures were only calculated for Annex1 countries.

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