G4M Model

Description of current model version

The Global Forest Model (G4M) is applied and developed by IIASA (Kindermann et al. 2006; Gusti et al. 2008; Kindermann et al. 2008; Gusti 2010; Gusti 2010; Gusti and Kindermann 2011) 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. (Gallaun et al. 2010) and scaled to total biomass using the biomass map of Kindermann et al. (Kindermann et al. 2008). For countries outside Europe the original forest biomass map compiled by Kindermann et al. 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, stocking biomass or harvestable biomass.

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 Cost curve algorithm

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; and
- 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 a 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 forest 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.

Governance factors

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 (i.e. the MACC runs)
- Hurdle rate = calibration coefficient to match historic rate of deforestation and afforestation in the baseline

Discount rates are used to calculate the NPV for agriculture and forestry activities in G4M. These are real discount rates but risk adjusted (Benítez et al. 2004). GLOBIOM uses discount factors only in mitigation scenarios (e.g. when setting concrete emission or area targets) but not in the baseline. GLOBIOM does not use a discount rate in the computation of the equilibrium since it is recursive dynamic (while G4M is fully dynamic). Agents in GLOBIOM do not anticipate what will happen in the next period. The solution is entirely based on information from the previous period as a starting point. Discount rates in GLOBIOM are only used in policy scenarios with emission reduction objectives e.g. to take into account the urgency of reducing emissions in the near future. However for this study, such policies have not been used in the set-up of the model.

The discount rate, however, 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 in decreased discount rates). However, this involves a recalibration making the results incomparable to previous scenarios.

Instead IIASA has done test runs (base runs) on risk adjusted discount factors by only including a certain percentage (undifferentiated across countries) of the applied country risk premium.

The hurdle rates in G4M are multipliers of the forestry NPV, when the model compares internal land use change with observed (FAO). 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.

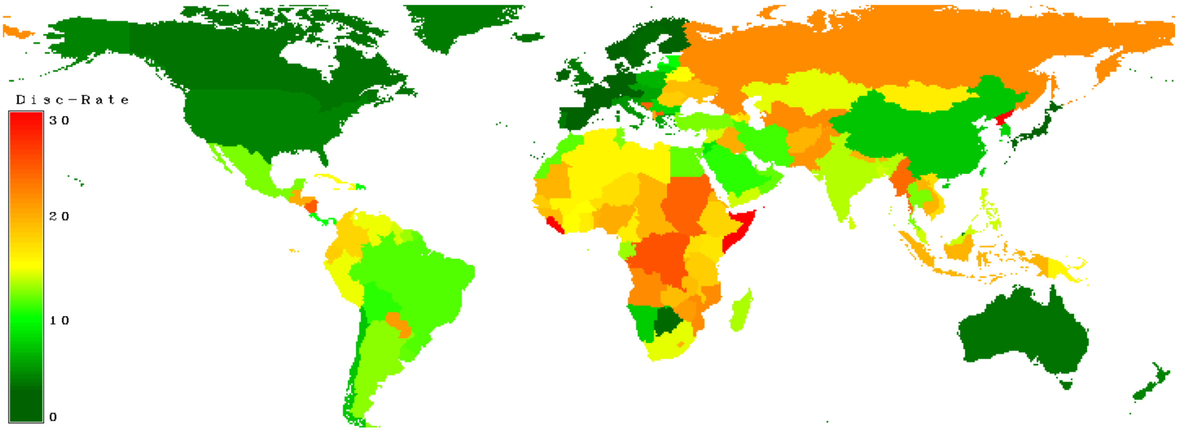

Figure 1: Discount Rate. Countries with a low discount rate are marked in dark green, moderate countries in yellow and countries with a high rate in red (Source: Kindermann et al. 2006).

The discount rate scenario is implemented in two test runs. One assumes a discount rate for all countries set to 3% for the entire simulation period (just for the reference). More interestingly an alternative scenario is calculated where the common discount rate is introduced gradually after 2010 with a linear development 2020 when the value reaches 3% for all countries, starting from original country specific values (see Figure 1 and detailed country list with values in the Annex).[1]

Earlier cost curve calculations have shown that there are 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).

[1] Ideally, to avoid very drastic changes in the emission profile in the short run (especially 2020) the country risk premium might alternatively have ben phased out gradually over time in the longer period from 2010-2050 (e.g. linearly), but this was not done in this project.

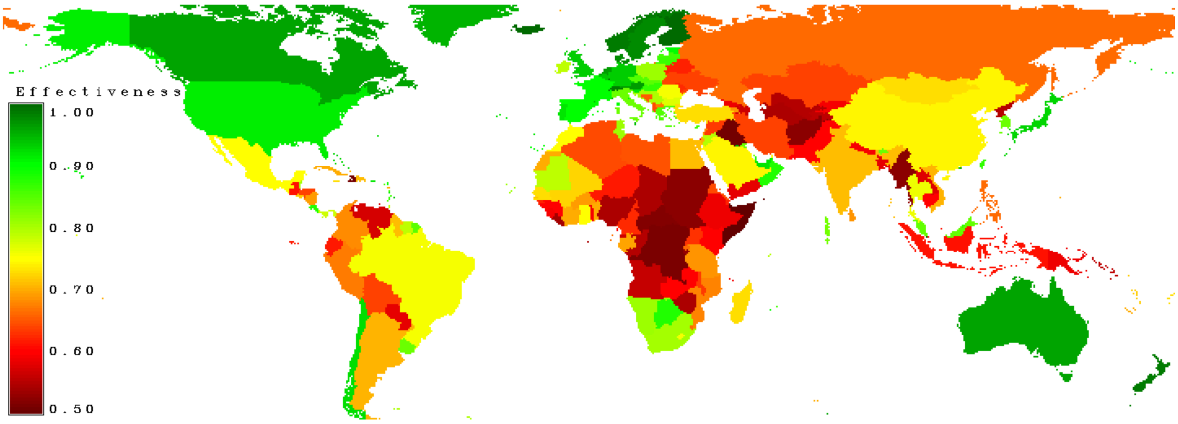

Figure 2: Effectiveness of carbon payments (Corruption rate). Countries with high values of corruption are marked in red, moderate countries in yellow and low values in green. (Source: Kindermann et al 2006).

Figure 2 describes the corruption rates applied to different countries. Values are based on governance indicators of the World Bank for the year 2005 (Kaufmann et al. 2005). A detailed list of the factors used for each country is given in the Annex.

A sensitivity scenario is implemented in which the corruption factor is set to 0 for all countries, meaning that corruption is not existing and investments into mitigation measures in the presence of a carbon tax are fully effective. The MACCs in the scenarios with corruption factor set to zero can be interpreted as a one way of approaching the 'full technical potential' in G4M. Many more factors would have to be included to estimate the technical potential more consistently, including risk adjusted discount rates and hurdle rates. All these factors affect the MACCs. However, the corruption factor is the easiest to manipulate for a sensitivity scenario as this is only affecting the MACCs but not baseline emissions. A recalibration to reported forest area changes would have to be done if factors would be included that affect the baseline emissions.

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