ALTERFOR

Milestone 6 – Global and country specific prospective scenarios

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Project Coordinator	Ljusk Ola Eriksson, Swedish University of Agricultural Sciences (SLU)
Scientific Coordinator	Vilis Brukas, Swedish University of Agricultural Sciences (SLU)
Project Administrator	Giulia Attocchi, Swedish University of Agricultural Sciences (SLU)
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Authors, organizations (short name)	Nicklas Forsell, IIASA Anu Korosuo, IIASA
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Abbreviations used

EU – European Union
MSG – Management Support Group
PA – Project Administrator
PC – Project Coordinator
SC – Scientific Coordinator
WP – Work Package
WPLs – Work Package Leader(s)

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1. Introduction

This working paper documents the scenarios to be used as a framework conditions in ALTERFOR WP1, WP3 and WP4 as well as the EU/Global analysis in WP2. It consists of two parts:

- Scenario narratives (chapter 2)
- ALTERFOR scenarios (Annex 1)

2. Scenario narratives

The scenarios described here cover a wide range of future trajectories for global development of climate change mitigation, economic growth, population development and overall use of natural resources. The scenarios are based on the scenarios analyzing policy targets for the European Union (Forsell et al. 2016), combined with the RCP-SSP framework developed for the International Panel for Climate Change (IPCC) (Fricko et al. 2016).

In this document, five scenario narratives are described: three “top-down” scenarios (REFERENCE, EU BIOENERGY, GLOBAL BIOENERGY), and two “bottom-up scenarios” (SET-ASIDES, NO POLICY). For the top-down scenarios, IIASA provides the national harvest levels and price development based on modelling efforts using the GLOBIOM model (see Annex and www.globiom.org). For the bottom-up scenario, only the scenario narrative is provided. This gives more freedom for each case study team to focus on the specific aspects found in their own country, and later in the project to provide national estimates based on the best available national data.

The scenarios are designed to vary in terms of climate mitigation efforts and the resulting climate change, as illustrated in Figure 1. In short, stronger mitigation policies restrict climate change, increase the use of biomass for energy and, consequently, increase forest harvests.

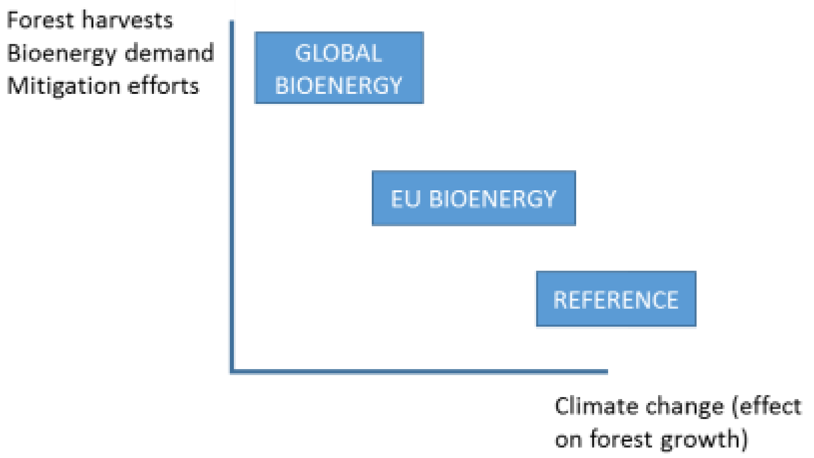

Figure 1: Top-down scenarios in ALTERFOR with respect to the climate mitigation efforts and the climate change.

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Scenario 1 – REFERENCE **Top-down**

FUTURE PATHWAYS BASED ON HISTORICAL DEVELOPMENT – Taking into account the EU policies and targets until 2020 that are in the current legislation, thereafter continuing with some development towards the climate targets, following the typical pathways experienced in the past

The starting point for the REFERENCE scenario is the EU Reference Scenario 2013 published by the European Commission[1]. In the REFERENCE scenario, biomass demand in the EU develops at first under EU bioenergy policies that aim at a 20% reduction of greenhouse gas (GHG) emissions in the EU28 by 2020. In this scenario, the proposed EU climate-energy targets for 2030 are not considered.

Within the first decades of the scenario, forest harvests are both driven by the increasing demand for bioenergy and the foreseen increasing demand for woody materials. This increases the demand for both timber and pulpwood. Short rotation coppices and energy crop plantations on agricultural land are expected to become more important as a source of biomass for bioenergy. In addition to these, also EU reliance on imported biomass feedstock increases, with in particular increasing amounts of imported wood pellets from North and South America. From 2030 to 2050, the EU domestic production of biomass stabilizes as a result of slower development of EU bioenergy demand. The largest changes in the EU28 production of biomass feedstocks for bioenergy are seen in the development of short rotation coppices which together with EU import of wood pellets are foreseen to increase considerably in the future.

After 2050, the bioenergy demand is expected to stabilize, with a slow decrease of fossil fuel dependency, but with biofuels mostly consisting of 1st generation biofuels. The global economic growth and population development are expected to be consistent with typical pathways experienced in the past. The climate change is slightly halted through additional policies on greenhouse gas emission mitigation and some development of carbon capture technologies. The global temperature will be about 3.7 degrees Celsius higher by 2100 than the pre-industrial level.

[1] http://ec.europa.eu/transport/sites/transport/files/media/publications/doc/trends-to-2050-update-2013.pdf

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Scenario 2 – EU BIOENERGY *Top-down*

RAPID DEVELOPMENT OF EU BIOENERGY SECTOR – Taking into account EU policies that aim at a 80% reduction in emissions by 2050, with some global climate policies in place

This scenario builds on the EU policy target of decreasing the GHG emissions by 80% by 2050 in the EU as well as the proposed EU climate-energy targets for 2030. The development of biomass use is assumed to follow that of the REFERENCE scenario until 2020, but thereafter, there is a considerable increase in the EU demand for biomass and, consequently, forest harvests. The increase in bioenergy demand is expected to lead to both the mobilization in wood harvest for bioenergy purposes (including residues), as well as an increasing use of forestry by-products for energy production. As a consequence, both pulpwood and timber demands increase considerably. The increased bioenergy demand is also seen as increased EU import of wood pellets and increased production of short rotation coppices and other energy crops on agricultural land.

In this scenario, the emission reduction targets in the EU for 2030 and 2050 are assumed to be fulfilled. The biomass demand for energy is assumed to remain stable thereafter in the EU. Instead the importance of woody biomass as a feedstock for material production increasing. Outside the EU, it is assumed that additional climate change mitigation policies are in effect, so that the global temperature will be ca. 2.5 degrees Celsius higher by 2100 than the pre-industrial level.

Scenario 3 – GLOBAL BIOENERGY *Top-down*

GLOBAL DEVELOPMENT TOWARD THE CLIMATE TARGETS – Climate policies are assumed to be taken into action globally, with both stringent EU policies and strong global climate mitigation

In this scenario, the economic growth and population development are consistent with typical pathways experienced in the past. Overall, it is expected that mitigation options within the land use sector are taken early on to reduce emissions, in comparison to reduction options within the energy sector. In the EU, the same targets until 2050 are in place as in the EU BIOENERGY scenario. Additionally, strong global mitigation actions are expected to be taken in all sectors and the bioenergy demand is expected to increase through the investments in CHP as well as of carbon capture technologies. On the forest sector, the high efforts in climate change mitigation are seen as an increase in the harvest levels. As the bioenergy demand is high globally, EU imports of bioenergy feedstocks will become more expensive than in REFERENCE or EU BIOENERGY. That is, the domestic harvest assortments suitable for bioenergy (logging residues, smaller-diameter pulpwood) will face a very high demand, compared to a more modest development of timber demand.

The climate policy is strict and together with alternative energy sources and strong development of carbon capture technologies leads to reaching the climate targets of global temperature increase, resulting in a temperature increase of 1.5 to 2.0 degrees Celsius by 2100, compared to pre-industrial level.

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Scenario 4 – SET-ASIDES *Bottom-up*

INCREASED AREA OF SET-ASIDES PROTECTED FROM HARVESTING – A bottom-up scenario where the national policies increase set-aside areas

This scenario is characterized by strong development of national policies to protect the environment and enhance biodiversity and/or carbon stocks in the forests through increased set-aside areas. In this scenario, the area of forest protected from harvests increases considerably, and other ecosystems services are emphasized over timber production.

As the forest characteristics and current situation of forest protection differ across the different ALTERFOR case study countries, the extent and focus of the set-asides can vary between the countries. However, to enable the upscaling and European level analyses later on in the project, no harvesting of industrial-quality timber is allowed on the areas marked as set-asides.

The case study teams are encouraged to develop a scenario that can be considered as feasible, given the expected development of ownership structure and variety of ecosystem services in the country. For the upscaling, the following variables will need to be quantified for each case study area (and upscaled to the country level):

- area of set-aside forest (in ha) and its development 2010-2100
- changes in forest species distribution 2010-2100

For this scenario, no data to describe the scenario development will be provided by IIASA, but instead the case study teams are encouraged to use the best available data and information they have themselves on the development of relevant biodiversity values in the country.

The climate development is expected to continue as in REFERENCE, and the same climate model and climate change assumptions as for REFERENCE should be used for this scenario.

Scenario 5 – NO POLICY *Bottom-up*

NO EXTERNAL DEMAND FOR WOOD TAKEN INTO ACCOUNT – A bottom-up scenario where no international drivers for forest harvests are simulated

This scenario serves as a reference for the national decision support systems: in this scenario, national wood harvests are expected to follow the current national guidelines, and the DSSs are to be used without simulating external impacts from climate change or its mitigation policies.

For the upscaling, the following variables will need to be quantified for each case study area (and upscaled to the country level):

- area of set-aside forest (in ha) and its development 2010-2100
- changes in forest species distribution 2010-2100

For this scenario, no data to describe the scenario development will be provided by IIASA, but instead the case study teams are encouraged to use the best available data and information they have themselves on the development of relevant biodiversity values in the country.

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In this scenario, no climate development is modelled.

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Annex 1

ALTERFOR scenarios (separate excel file "MS6 ALTERFOR_Scenarios.xls").

Annex 2

What is GLOBIOM?

The Global Biosphere Management Model (GLOBIOM)[2] (Havlík et al., 2014) is a global recursive dynamic partial equilibrium model of the forest and agricultural sectors, where economic optimization is based on the spatial equilibrium modelling approach (Takayama and Judge, 1971b). The model is based on a bottom-up approach where the supply side of the model is built-up from the bottom (land cover, land use, management systems) to the top (production/markets) (see Figure 2 for an overview of the model framework). The agricultural and forest productivity is modeled at the level of gridcells of 5 x 5 to 30 x 30 minutes of arc[3], using biophysical models, while the demand and international trade occur at regional level (30 to 53 regions covering the world, depending on the model version and research question). Besides primary products, the model has several final and by-products, for which the processing activities are defined.

The model computes market equilibrium for agricultural and forest products by allocating land use among production activities to maximize the sum of producer and consumer surplus, subject to resource, technological and policy constraints. The level of production in a given area is determined by the agricultural or forestry productivity in that area (dependent on suitability and management), by market prices (reflecting the level of demand), and by the conditions and cost associated to conversion of the land, to expansion of the production and, when relevant, to international market access. Trade is modelled following the spatial equilibrium approach, which means that the trade flows are balanced out between different specific geographical regions. Trade is furthermore based purely on cost competitiveness as goods are assumed to be homogenous. This allows tracing of bilateral trade flows between individual regions.

By including not only the bioenergy sector but also forestry, cropland and grazing land management, and livestock management, the model allows for a full account of all agriculture and forestry GHG sources. GLOBIOM accounts for ten sources of GHG emissions, including crop cultivation N2O emissions from fertilizer use, CH4 from rice cultivation, livestock CH4 emissions, CH4 and N2O emissions from manure management, N2O from manure applied on pasture, above and below ground biomass CO2 emissions from biomass removal after converting forest and natural land to cropland, CO2 emissions from soil carbon included cultivated organic soil (drained peatland, at country level). These emissions inventories are based on IPCC accounting guidelines.

2 See also: www.iiasa.ac.at./GLOBIOM

3 The supply-side resolution is based on the concept of Simulation Units, which are aggregates of 5 to 30 arc-minute pixels belonging to the same country, altitude, slope, and soil class (Skalsky et al., 2008).

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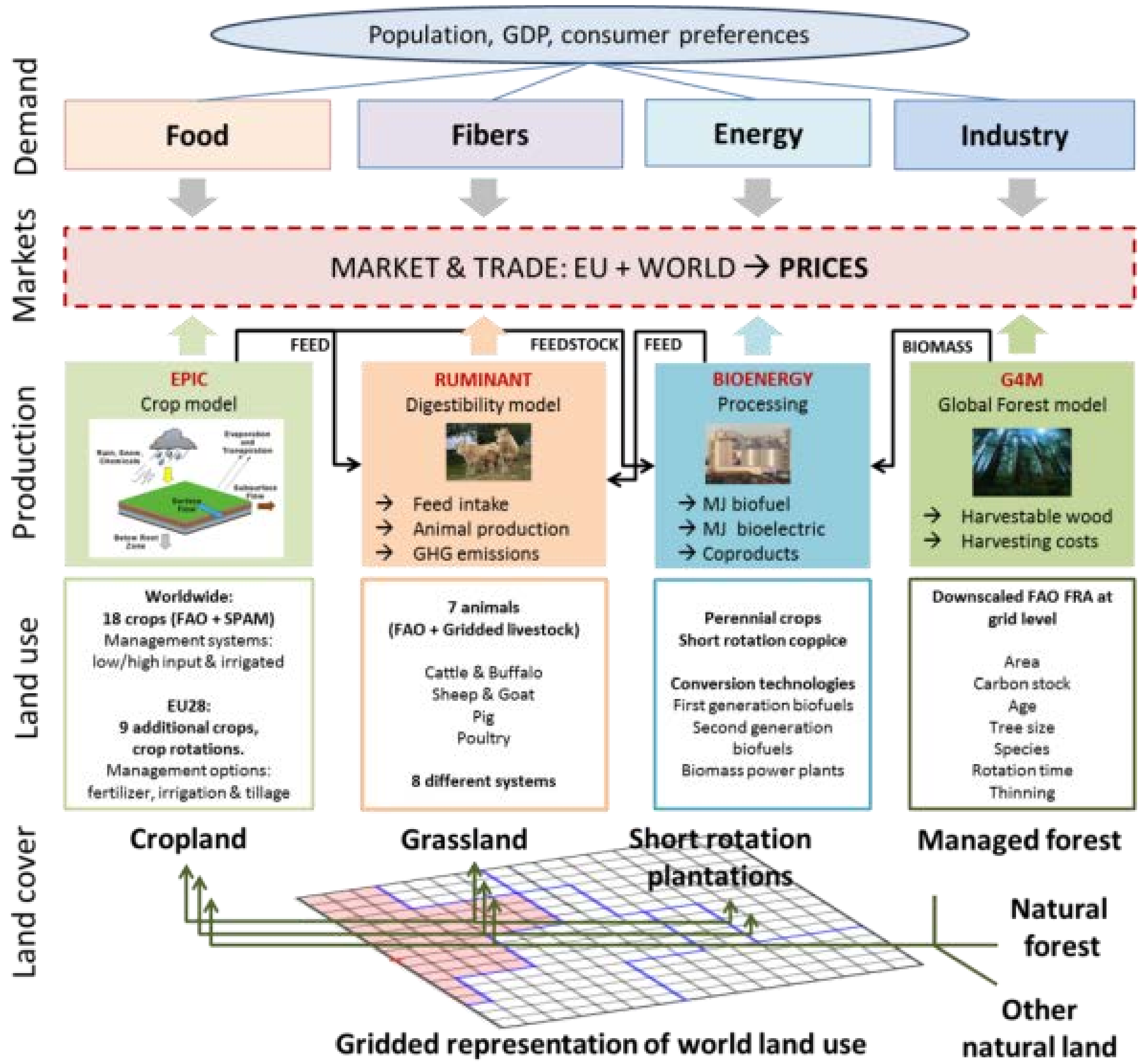

Figure 2. Illustration of the GLOBIOM model.

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Representation of land use change

The model includes six land cover types: cropland, grassland, other natural vegetation land, used forests, unused forests, and plantations[4]. Economic activities are associated with the first four land cover types. Depending on the relative profitability of primary, by-, and final products production activities, the model can switch from one land cover type to another. Land conversion over the simulation period is endogenously determined for each gridcell within the available land resources. Such conversion implies a conversion cost – increasing with the area of land converted - that is taken into account in the producer optimization behavior. Land conversion possibilities are further restricted through biophysical land suitability and production potentials, and through a matrix of potential land cover transitions (see **Error! Reference source not found.**).

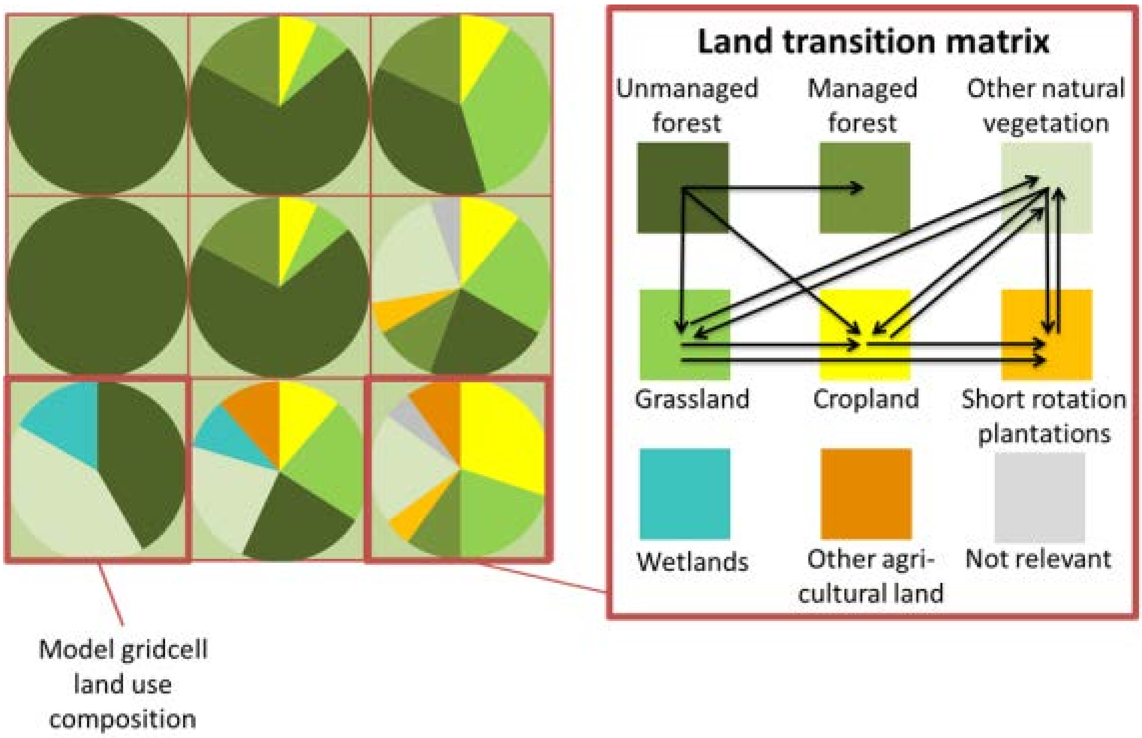

Figure 3 Land cover representation in GLOBIOM and the matrix of endogenous land cover change possibilities.

Land use change emissions

Land use change emissions are computed based on the difference between initial and final land cover equilibrium carbon stock. For forest, above and below-ground living biomass carbon data are sourced from G4M which supplies geographically explicit allocation of the carbon stocks. The carbon stocks

[4] The term "used forests" refers to all forest areas where harvesting operations take place, while "unused forests" refers to undisturbed or primary forests. There are other three land cover types represented in the model to cover the total land area: other agricultural land, wetlands, and not relevant (bare areas, water bodies, snow and ice, and artificial surfaces). These three categories are currently kept constant at their initial level.

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are consistent with the 2010 Forest Assessment Report (FRA 2010), providing emission factors for deforestation in line with that of FAOSTAT. Carbon stock from grazing land and other natural vegetation is also taken into account using the above and below ground carbon from the biomass as of Ruesch et al. (2008). When forest or natural vegetation is converted into agricultural use, the GLOBIOM approach consider that all below and above ground biomass is released in the atmosphere.

The use of detailed and reliable statistics and maps

All processes and management options are represented at a high level of regional detail and built on trustworthy databases. GLOBIOM is based on EU data regarding area, yields, production etc. at NUTS 2 level. The market balances calculated for the 53 regions worldwide rely on EUROSTAT accounts and on FAOSTAT for outside EU. Land cover is dealt with in a geographically explicit way. The land cover description for the EU28 is based on CORINE/PELCOM cover maps, which ensure a great level of detail in land cover. The land cover for the rest of the World is based on Global Land Cover 2000 (GLC 2000).

Biomass use for large-scale energy production is usually based on the POLES or MESSAGE energy sector models (Havlík et al., 2011; Reisinger et al., 2013), but other estimates can also be utilized. For forests, mean annual increments and growing stocks for GLOBIOM are obtained from G4M. For the agricultural sector, GLOBIOM draws on results from the crop model EPIC (Environmental Policy Integrated Climate Model)[5], which provides the detailed biophysical[6] processes of water, carbon and nitrogen cycling, as well as erosion and impacts of management practices on these cycles. GLOBIOM therefore incorporates all inputs that affect yield heterogeneity and can also represent a different marginal yield for different crops in a same grid cell.

Categories of biomass and biomass conversion are included in GLOBIOM

GLOBIOM represents a number of conventional and advanced biofuels feedstocks:

- 27 different crops including 4 vegetable oil types[7];
- Co-products: 3 oilseed meal types, wheat and corn DDGS;
- Perennials and short rotation plantations: Miscanthus, switchgrass, short rotation coppice;
- Used forest: 4 types of stem wood, primary forestry residues from wood harvest;
- Wood processing residues: bark, black liquor, sawdust, sawchips;
- Recovered wood products;
- Crop residues (e.g. straw).

Various energy **conversion processes** are modelled in GLOBIOM and implemented with specific technological costs, conversion efficiencies and co-products:

- Wood (forestry): sawnwood, plywood, fiberboard, pulp and paper production, combustion, fermentation, gasification;
- Lignocellulose (energy crop plantations): combustion, fermentation, gasification;

5 See also: www.iiasa.ac.at/EPIC

6 Biophysical means related to living (animals, plants) and non-living (light, temperature, water, soil etc.) factors in the environment which affect ecosystems

7 Palm oil, rapeseed oil, soy oil and sunflower oil

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- Conventional ethanol: corn, sugar cane, sugar beet and wheat ethanol processing;
- Conventional biodiesel: rapeseed oil, soybean oil, soya oil and palm oil to FAME processing;
- Oilseed crushing activities: rapeseed, soybeans, and sunflower crushing activities.

This allows ethanol, methanol, biodiesel, heat, electricity and gas to be distinguished and traced according to their feedstocks. Furthermore, competition for biomass resources as considered is also taken into account between the various sectors in term of the demand for food, feed, timber, and energy.

Agricultural production within GLOBIOM

GLOBIOM explicitly covers production of each of the 18 world major crops representing more than 70% of the total harvested area and 85% of the vegetal calorie supply as reported by FAOSTAT. Each crop can be produced under different management systems depending on their relative profitability: subsistence, low input rainfed, high input rainfed, and high input irrigated, when water resources are available. Crop yields are generated at the grid cell level on the basis of soil, slope, altitude and climate information, using the EPIC model. Within each management system, input structure is fixed following a Leontief production function. However, crop yields can change in reaction to external socio-economic drivers through switch to another management system or reallocation of the production to a more or less productive gridcell. Besides the endogenous mechanisms, an exogenous component representing long-term technological change is also considered.

Livestock sector within GLOBIOM

The GLOBIOM model also incorporates a particularly detailed representation of the global livestock sector. With respect to animal species, distinction is made between dairy and other bovines, dairy and other sheep and goats, laying hens and broilers, and pigs. Livestock production activities are defined in several alternative production systems adapted from Seré and Steinfeld (1996): for ruminants, grass based (arid, humid, temperate/highlands), mixed crop-livestock (arid, humid, temperate/ highlands), and other; for monogastrics, smallholders and industrial. For each species, production system, and region, a set of input-output parameters is calculated based on the approach in Herrero et al. (2008).

Feed rations in GLOBIOM are defined with a digestion model (RUMINANT, see (Havlík et al., 2014)) consisting of grass, stovers, feed crops aggregates, and other feedstuffs. Outputs include four meat types, milk, and eggs, and environmental factors (manure production, N-excretion, and GHG emissions). The initial distribution of the production systems is based on Robinson et al. (2011). Switches between production systems allow for feedstuff substitution and for intensification or extensification of livestock production. The representation of the grass feed intake is an important component of the system representation as grazing land productivity is explicitly represented in the model. Therefore, the model can represent a full interdependency between grazing land and livestock.

Available supply of wood biomass and types of wood

Total forest area in GLOBIOM is calibrated according to FAO Global Forest Resources Assessments (FRA) and divided into used and unused forest utilizing a downscaling routine based on human activity impact on the forest areas (Kindermann et al., 2008b). The available woody biomass resources are provided by G4M for each forest area unit, and are presented by mean annual increments. Mean annual increments for forests are then in GLOBIOM divided into commercial roundwood, non-commercial roundwood and harvest losses, thereby covering the main sources of woody biomass supply.[8] The amount of harvest losses is based on G4M estimates while the share of non-commercial species is based on FRA (2010) data on commercial and non-commercial growing stocks. In addition to stemwood, available woody biomass resources also include branches and stumps; however, environmental and sustainability considerations constraint their availability and use for energy purposes.

Available woody biomass resources from plantations

Plantations are covered in GLOBIOM in the form of energy crop plantations, dedicated to produce wood for energy purposes. Plantation yields are based on NPP maps and model's own calculations, as described in Havlík et al. (2011). Plantation area expansion depends on the land-use change constraints and economic trade-offs between alternative land-use options. Land-use change constraints define which land areas are allowed to be changed to plantations and how much of these areas can be changed within each period and region (so-called inertia conditions). Permitted land-cover types for plantations expansion include cropland, grazing land, and other natural vegetation areas, and they exclude forest areas. Within each land-cover type the plantation expansion is additionally limited by land suitability criteria based on aridity, temperature, elevation, population, and land-cover data, as described in Havlík et al. (2011).

Plantation expansion to cropland and grazing land depends on the economic trade-off between food and wood production. Hence, the competition between alternative uses of land is modeled explicitly instead of using the "food/fiber first principle," which gives priority to food and fiber production and allows plantation to be expanded only to abandoned agricultural land and wasteland (Beringer et al., 2011; Hoogwijk et al., 2009; Smeets et al., 2007; Van Vuuren et al., 2010).

Woody biomass production costs

Woody biomass production costs in GLOBIOM cover both harvest and transportation costs. Harvest costs for forests are based on the G4M model by the use of spatially explicit constant unit costs that include planting, logging, and chipping in the case of logging residues. Harvest costs also vary depending on geographical considerations such as the region and the steepness of terrain. Transport costs are on the other hand not spatially explicit but are modeled by using regional level constant elasticity transport cost functions, which approximate the short run availability of woody biomass in each region. These transport costs functions are then shifted over time in response to the changes in the harvested volumes and related investments in infrastructures.

[8] Commercial roundwood is stemwood that is suitable for industrial roundwood (sawlogs, pulplogs and other industrial roundwood). Harvest losses and non-commercial roundwood are stemwood that is unsuitable for industrial roundwood. The difference between harvest losses and non-commercial roundwood is that the former has unwanted stemwood sizes, while the latter has unwanted wood characteristics.

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Woody biomass demand and forest industry technologies

The forest sector is modeled to have seven final products (chemical pulp, mechanical pulp, sawnwood, plywood, fiberboard, other industrial roundwood, and household fuelwood). Demand for the various final products is modeled using regional level constant elasticity demand functions. Forest industrial products (chemical pulp, mechanical pulp, sawnwood, plywood and fiberboard) are produced by Leontief production technologies, which input-output coefficients are based on the engineering literature (e.g. FAO 2010). By-products of these technologies (bark, black liquor, sawdust, and sawchips) can be used for energy production or as raw material for pulp and fiberboard. Production capacities for the base year 2000 of forest industry final products are based on production quantities from FAOSTAT (2012). After the base year the capacities evolve according to investment dynamics, which depend on depreciation rate and investment costs. This implies that further investments can be done to increase production capacities or allow industries to reduce their production capacities or be closed. For further details of the modelling approach of the depreciation rates, capital operating costs, and investment costs as applies, we refer to Lauri et at 2014.

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G4M model description

What is G4M?

The Global Forest Model (G4M)[9] is applied and developed by IIASA (Gusti, 2010a; Gusti, 2010b; Gusti et al., 2008; Gusti and Kindermann, 2011; Kindermann et al., 2008a; Kindermann et al., 2006) and estimates the impact of forestry activities (afforestation, deforestation and forest management) on biomass and carbon stocks. By comparing the income of used 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), different levels of deforestation pressure at the forest frontier can also be handled. The model can use external information, such as wood prices and information concerning land use change estimates from GLOBIOM. As outputs, G4M produces estimates of forest area change, carbon sequestration and emissions in forests, impacts of carbon incentives (e.g. avoided deforestation) and supply of biomass for bioenergy and timber.

Forest management option and impacts

The available woody biomass resources is estimated by G4M for each forest area unit determined by mean annual increments, which are based on net primary productivity (NPP) maps from (Cramer et al., 1999a) and from different downscaling techniques as described in (Kindermann et al., 2008b). This information is then combined with national data sources (e.g., National Forest Inventories) to provide further and more detailed information concerning biomass stocks and forest age structure.

The main forest management options considered by G4M are variation of thinning levels and choice of rotation length. 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., 1999b) and translated into net annual increment (NAI). At present this increment map is static and does not change over time. Age structure and stocking degree are used for adjusting NAI.

The model uses external projections of wood demand per country (estimated by GLOBIOM) to calculate total harvest iteratively. In G4M, the potential harvest amount per country is estimated by choosing a set of rotation lengths that maintain current biomass stocks. If total harvests are less than the wood demand, the model changes management grid per grid (starting from the most productive forest) to a rotation length that optimizes forest increment and thus allows for more harvest. This mimics the typical observation that used forests (in many regions) are currently not managed optimally with respect to yield. The rotation length is updated for each five years' time step. If harvest is still too small and there is unused forest available, the unused forest will be taken under management. If total harvests are greater than the demand, the model will change management to maximize biomass rotation length, i.e. to manage forests for carbon sequestration. If wood demand is still lower than the harvest potential, used forest can be transferred into unused forest. Thinning is applied to all used forests, and the stands are thinned to maintain a specified stocking degree. The

9 See also: www.iiasa.ac.at/G4M

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default value is 1 where thinning mimics natural mortality along the self-thinning line. The model can also consider the use of harvest residues e.g. for bioenergy, using a cost curve algorithm.

Carbon price and forest mitigation

Introducing a carbon price incentive means that the forest owner is paid for the carbon stored in forest living biomass if its amount is above a baseline, or pays a tax if the amount of 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 forest management in G4M are:

- Reduction of deforestation area;
- Increase of afforestation area;
- Change of rotation length of existing used 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 manages land dynamically and one activity affects the other. The model then calculates 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 the forest. The increased value of forests in a regime with a CO_2 price hence changes the balance of land use change through the net present value (NPV) generated by land use activities toward 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. Moreover, less deforestation increases land scarcity and might therefore decrease afforestation relative to the baseline.

Model validation

GLOBIOM and G4M have been peer-reviewed in various European and international project, and scientific publications. With respect to the conceptual and data validation of GLOBIOM: Input data is based on official statistics, historic data, scientific studies, or remote sensing data. Parameterization of biophysical relationships for the different land use sectors relies mainly on process based simulation models like EPIC (Williams, 1995), G4M (Kindermann, 2008), and RUMINANT (Herrero et al., 2013) which aim to simulate biophysical processes in detail. Empirical validation of model output has been performed (Balkovič et al., 2013; Herrero et al., 2013; Xiong et al., 2014). The general model specification follows well established tradition of linear programming models (McCarl and Spreen, 1980; Takayama and Judge, 1971a). Validation of results remains a highly challenging exercise especially for large scale land use models such as GLOBIOM. Besides comparison of model results with historic trends, scientific publication, and other models, national experts cross-checked EU28 country level land use and GHG emission results of GLOBIOM during a consultation process. The EPIC model participated in the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) (Warszawski et al., 2014) where model results have been compared for a consistent set of climate change scenarios with ten other global gridded crop models (Rosenzweig et al., 2014). GLOBIOM participated in the AG-MIP project where the agricultural economic modeling community started to compare model projections across ten global agricultural sector models. A consistent set of scenarios was quantified in order to compare model results and thereby understand the difference in underlying

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model behaviour (Nelson et al., 2014; Schmitz et al., 2014; Valin et al., 2014; Von Lampe et al., 2014). An extensive list of peer-reviewed GLOBIOM and G4M papers is provided in the Annex.

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