

Analysis of potential and costs of LULUCF use by EU Member States

Service Contract N° 07.0307/2009/541003/SER/C5

FINAL REPORT – update September 2011

submitted to the

European Commission – DG Environment

by

IIASA and subcontractors,
the European Forest Institute (EFI) and the University of Hamburg (UniHH)

Laxenburg, September 21 2011

Authors

Name	Affiliation	
Hannes Böttcher	International Institute for Applied Systems Analysis (IIASA), Schlossplatz 1, A-2361 Laxenburg, Austria, http://www.iiasa.ac.at	 Science for Global Insight IIASA www.iiasa.ac.at
Hans Verkerk	European Forest Institute (EFI), Torikatu 34, 80100 Joensuu, Finland, http://www.efi.int/	 E F I
Mykola Gusti	International Institute for Applied Systems Analysis (IIASA), Schlossplatz 1, A-2361 Laxenburg, Austria, http://www.iiasa.ac.at	 Science for Global Insight IIASA www.iiasa.ac.at
Uwe Schneider	Sustainability and Global Change Unit, Universität Hamburg, Bundesstraße 55, D-20146 Hamburg, http://www.fnu.zmaw.de/	 UH Universität Hamburg

Disclaimer

This is an updated version of the Report “Analysis of potential and costs of LULUCF use by EU Member States” that replaces the version of May 3 2011. This update considers the results of the UNFCCC review of the Forest Management Reference Level carried out in May and June 2011 in Bonn.

Table of Content

Table of Content	iii
List of acronyms	5
1. Introduction	6
2. The modelling framework	7
2.1. General approach	7
2.2. Description of models and setup	8
2.2.1. The GLOBIOM Model	8
2.2.2. The EUFASOM Model	10
2.2.3. The EFISCEN Model	11
2.2.4. The G4M Model	13
2.3. Detailed work flow	14
2.4. Databases used	15
2.4.1. Data used by GLOBIOM and EUFASOM	16
2.4.2. Data used by EFISCEN	19
2.4.3. Data used by G4M	20
2.5. Improvements and harmonisation	21
2.5.1. Documentation of country consultations	21
2.5.2. Documentation of the UNFCCC review on Forest Management Reference Level	22
2.5.3. General harmonisation and comparison of forestry models	24
3. Scenario development	27
3.1. Projection of domestic wood production	27
3.1.1. Baseline scenario	27
3.1.2. Reference scenario	29
3.2. Projection of agricultural production	31
3.3. Sensitivity analysis for forestry models	32
3.4. Development of cost curves	32
3.4.1. Forestry	32
3.4.2. Cropland management	33
4. Results and discussion	34
4.1. Baseline scenario	34
4.1.1. Total LULUCF	34
4.1.2. Single land use activities	37
4.2. Reference scenario	38
4.3. Forest management	40
4.3.1. Model comparison	40
4.3.2. Emission from forest soils	43
4.4. Sensitivity analysis	45
4.5. Abatement cost curves	47
4.6. Uncertainties	51

4.6.1. Uncertainty of input data and economic drivers	51
4.6.2. Model limitations	52
4.6.3. Limits to harmonisation	52
5. Conclusions	53
6. Literature	54

List of acronyms

BAU	Business as usual
BOKU	University of Natural Resources and Life Sciences, Vienna
EC4MACS	European Consortium for Modelling of Air Pollution and Climate Strategies
EFI	European Forest Institute
EFISCEN	European Forest Information Scenario Model
EU	European Union
EUFASOM	European Forest and Agricultural Sector Model
GLOBIOM	Global Biosphere Management Model
Gg	Giga gram, 10^9 grams
IIASA	International Institute for Applied Systems Analysis
LULUCF	Land use, land use change and forestry
MAI	Mean annual increment
MCPFE	The Ministerial Conference on the Protection of Forests in Europe, now called FOREST EUROPE
Mt	Mega tonne, 10^6 tonnes
NAI	Net annual increment
NFI	National Forest Inventory
NPP	Net primary production
NPV	Net Present Value
UNFCCC	United Nations Framework Convention on Climate Change

1. Introduction

This report documents the modelling work undertaken for the Contract on “Analysis of potential and costs of LULUCF use by EU Member States”. The study estimated potential CO₂ emissions reductions in the LULUCF (land-use, land use change and forestry) sector for individual EU Member States and the associated costs for the time horizon up to 2020 and 2030. The objectives of this study were threefold:

- a) To make a consistent projection for the net emissions from LULUCF by 2020 and 2030 under business-as-usual (BAU) conditions.
- b) Assess the implications of alternative policy options (scenarios) for handling LULUCF emissions to support the international climate negotiations and the implementation of an international agreement at EU level for each EU Member State.
- c) Starting from the BAU projections, estimate the potential and costs for further reducing net emissions/enhancing sinks from LULUCF by 2020 and 2030 for each EU Member State.

The study estimated the emissions and removals of CO₂ for a baseline and a reference scenarios from the main LULUCF activities (forest management, afforestation/reforestation, deforestation, cropland management, grazing land management) for different carbon pools, i.e. living biomass (aboveground and belowground), dead organic matter (dead wood and litter), and soil (mineral and organic soils). This report, however, focuses on soil carbon emissions from cropland and grazing land management and total biomass emissions from forestry activities only. Furthermore, costs of mitigation measures were estimated.

With the help of this analysis, the implication of various policy options to deal with emissions and removals from LULUCF can be assessed and compared. This also will assist in comparing the costs of enhanced LULUCF use with measures to control greenhouse gas emissions in other sectors in particular CO₂ emissions from the energy sector and non-CO₂ greenhouse gas emissions. This will allow a more complete and consistent picture of the costs of various options for meeting the agreed emissions reductions at EU level for each individual Member State.

The analysis was carried out in interaction and dialogue with Member States experts (LULUCF, land-use and forest inventory, agriculture and forestry policies, greenhouse projections and emission inventories) and the Commission. In addition, model assumptions and input parameters used for estimating emissions from forest management were reviewed by international experts through the UNFCCC. The review led to a revision of input data on forest area, increment and historic harvest rates and an update of the emission projections.

This report is structured in the following way. Chapter 2 describes the general modelling approach, the applied models, harmonization efforts between models and the general set up of models. It also introduces data used to develop consistent baseline and reference scenarios. Chapter 3 describes the scenario development, i.e. how the input data were used to describe consistent scenarios of important drivers of LULUCF emissions, especially the production of forestry and agricultural products. Further, the chapter describes the methodology for estimating abatement cost curves for activities in the LULUCF sector. Chapter 4 presents results of the study including country specific CO₂ emissions and removals from the LULUCF sector under baseline and reference scenario conditions, results of a sensitivity analysis, and abatement cost curves per EU Member State and activity. Model results for different activities are compared and put into perspective of the driver data and reported emission data by Member States under UNFCCC and the Kyoto protocol. The Annex (separate document) documents in great detail the interaction and dialogue with Member States experts, the project consortium and the

Commission. This report only contains original model results¹.

2. The modelling framework

2.1. General approach

To produce consistent projections of CO₂ emissions from LULUCF activities at country level by 2020 and 2030, a number of different forest, agricultural, and economic land use models 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 by DGTREN² for future bioenergy demand (from PRIMES model for EU Member States and POLES for the rest of the world) 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 not only for EU Member States but also the rest of the world (for in total 28 world regions).

Data on potential yields and GHG emissions and removals for diverse agricultural and forest management alternatives are derived from the more detailed forestry models (G4M and EFISCEN) and the agricultural model (EPIC). For baseline and policy scenarios, the economic land use model projects domestic production and consumption, net exports and prices of wood and agricultural products for EU Member States and other world regions. The sector specific information from the economic model is used by the forest and agricultural models to project GHG emissions and removals for detailed land management options (see Figure 1 below). These detailed models cover activities in forestry (afforestation/reforestation, deforestation and forest management), cropland and grazing land management.

Two forestry models (G4M and EFISCEN) are applied in parallel to estimate emissions and removals from forest management and afforestation/reforestation activities to explore uncertainties of a potentially large contributor to carbon removals. Based on a baseline projection of emissions and removals of CO₂ from LULUCF, the models G4M (for forestry) and EUFASOM (for cropland management) provide abatement cost curves for the selected land use activities.

To achieve a high degree of consistency and to harmonise model assumptions as much as possible, there is a detailed data exchange between the models not displayed in Figure 1. The section 2.3 “Detailed work flow” after the following model descriptions documents the detailed exchange by listing shared variables and parameters per model.

¹ The projections presented in this report are not calibrated to match exactly the data reported to UNFCCC by EU member states, as done by JRC see European Commission, Joint Research Centre (JRC), JRC LULUCF tool, version (Nov 2010) http://afoludata.jrc.ec.europa.eu/index.php/models/JRC_LULUCF_TOOL

² For details of the energy baseline scenario see: http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2030_update_2009.pdf

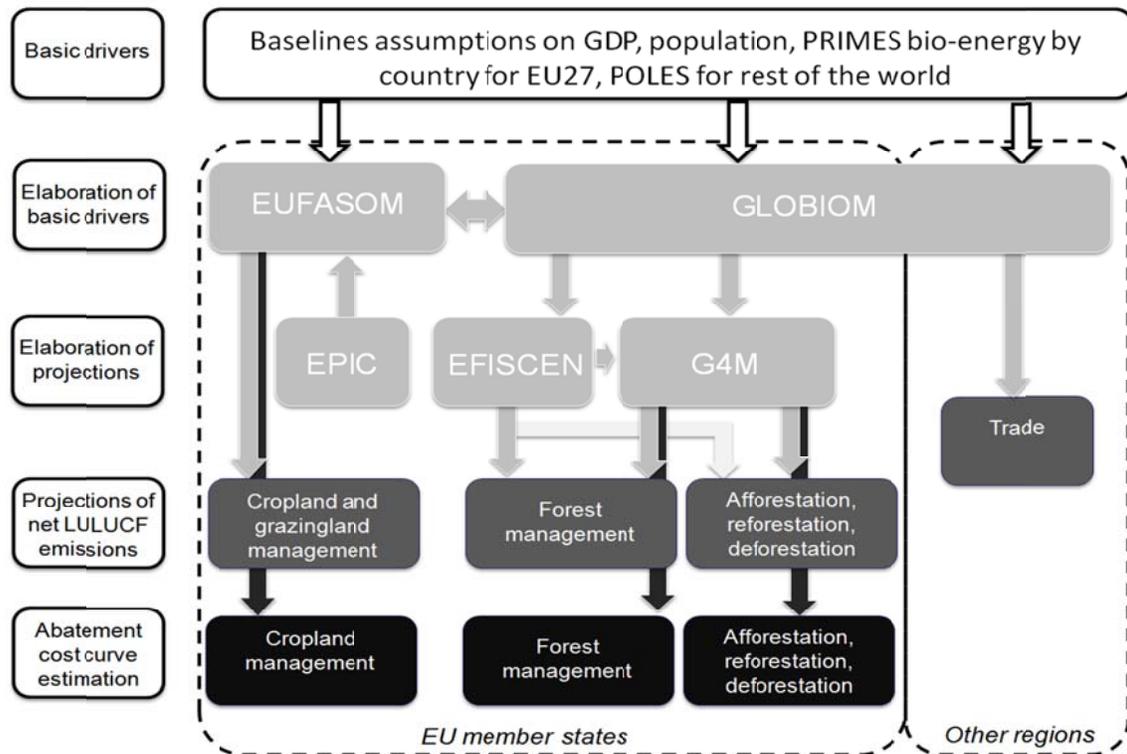


Figure 1: Overview of general modelling approach.

2.2. Description of models and setup

2.2.1. The GLOBIOM Model

The Global Biosphere Management Model (GLOBIOM)³ 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 countries of the world, aggregated to 28 world regions.⁴ 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 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).

³ Documentation of the GLOBIOM model can be found at www.globiom.org.

⁴ A disaggregation of the EU into 27 individual countries has been performed recently, originally five European regions are defined (<http://www.iiasa.ac.at/Research/FOR/globiom/regions.html>).

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.

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 can change. 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.

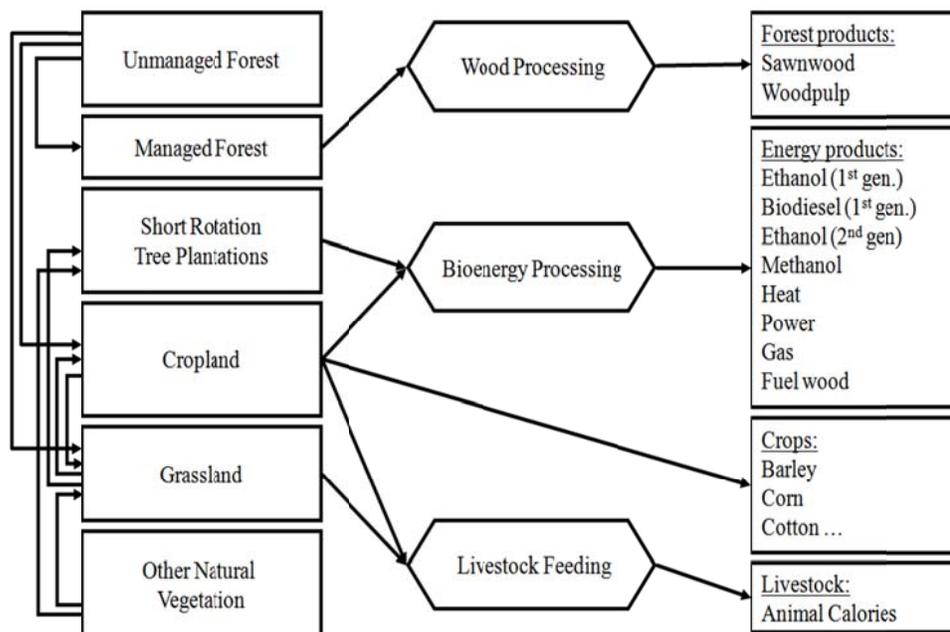


Figure 2. GLOBIOM land use and product structures (Havlík et al, in press). Note: The arrows on the left represent the direction where a given land use/cover type can expand given the current constraints in the model.

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 in this study is 2030. 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, GLOBIOM typically assumes 0.5 % autonomous technological progress in crop improvement; 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 the POLES model⁵ (for regions outside Europe) and the PRIMES model (for EU 27 countries) 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.

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 (Havlik et al, 2010).

In this study GLOBIOM is used to project total wood production and economic parameters related to land use change used by G4M for detailed emission projections and cost curves.

2.2.2. The EUFASOM Model

EUFASOM is applied by the University of Hamburg and simulates detailed land use and land management adaptations, commodity market and trade equilibrium adjustments, and environmental consequences in response to political, technical, societal, and environmental change scenarios related to agriculture, forestry, and nature conservation. The model has been applied to estimate the competitive economic potential for bioenergy production (Link et al. 2009, Schlepner and Schneider 2009). EUFASOM is a data intensive bottom-up model.

Cropland management activities in EUFASOM represent all major crops, their management alternatives related to irrigation, tillage, and residue treatment, and detailed land qualities for all EU countries except Cyprus and Malta. For each land management alternative, EUFASOM has data on the per-hectare values of production (crop and crop residue yields), input use (land, water, and labour requirements), other unspecified costs, and environmental impacts (soil carbon emission-sequestration, nutrient leaching, erosion). These data come from surveys and statistical databases (e.g. FADN, EUROSTAT, FAOSTAT), biophysical model simulations (EPIC), and the application of economic principles and engineering equations. Thus, the external data for EUFASOM provide the per-hectare impacts of all represented land management alternatives in a given location. Cost differences for specific alternative agricultural management option are computed through engineering equations or taken from the literature.

Likely land use impacts are determined through constrained welfare maximization. Particularly, the objective function maximizes the net economic surplus from all agricultural and forestry markets and includes the impact of policy incentives and disincentives. Technological opportunities, physical resource endowments, production capacities, intertemporal relationships, and political regulations form important constraints of EUFASOM. Model output consists of optimal land use allocations and

⁵ Taken from the 2010 POLES (Prospective Outlook on Long-Term Energy Systems) baseline scenario. See <http://www.enerdata.net/enerdatauk/solutions/energy-models/poles-model.php> for POLES documentation.

associated management intensities, related environmental impacts, regional resource usage, commodity supply, equilibrium market prices, and trade volumes of the agricultural and forest commodities covered in the model (Figure 3).

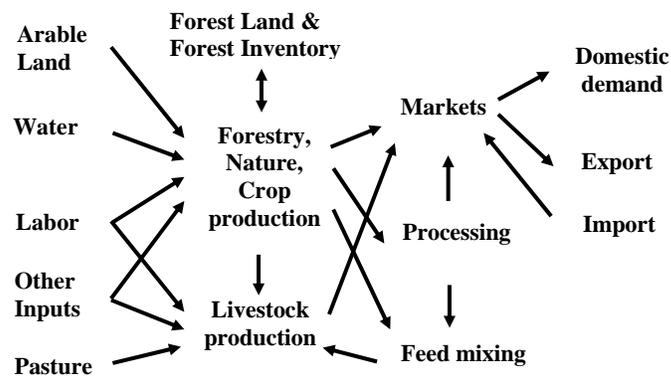


Figure 3: Resource and Commodity Flow in EUFASOM.

Crop yields, water and fertilizer requirements, and environmental impacts are simulated with the Environmental Policy Integrated Climate (EPIC) model. EPIC is applied by BOKU and integrates a large number of terrestrial biophysical processes allowing for global environmental impact assessments of alternative land use management systems (Williams, 1995; Izaurralde et al., 2006). The major components in EPIC are weather simulation, hydrology, erosion-sedimentation, nutrient and carbon cycling, pesticide fate, plant growth and competition, soil temperature and moisture, tillage, cost accounting, and plant environment control. EPIC operates on a daily time step. The representation of the carbon cycle (Izaurralde et al., 2006) is based on the CENTURY approach (Parton et al., 1994).

EPIC is used to compare (non-forest) land use management systems and their biophysical impacts on crop yields and biomass growth, hydrology, nitrogen emissions, soil organic carbon sequestration, sediment transport and on green house gas emissions.

Agricultural market data used in EUFASOM are extracted from FAOSTAT and the European New Cronos Database. Own-price-elasticities of demand are taken from Seale et al. (2003). The objective function incorporates all major drivers for these changes, i.e. cost coefficients for land use and commodity processing alternatives, adjustment costs for major land use changes, market price changes for commodities and production factors, trade costs, political incentives and disincentives, and terminal values for standing forests.

In this study, EUFASOM is used to calculate baseline emissions for cropland and grassland management and to generate cost curves of mitigation measures in cropland management.

2.2.3. The EFISCEN Model

The European Forest Information Scenario (EFISCEN) model (Sallnäs 1990; Schelhaas et al. 2007a) is developed by the European Forest Institute (EFI) and Alterra and was applied in this study by EFI. EFISCEN is a large-scale model that assesses the supply of wood and biomass from forests and projects forest resource development on regional to European scale (Nabuurs et al. 2007; Eggers et al. 2008; Ľupek et al. 2010). A detailed model description is given by Schelhaas et al. (2007a) and a schematic overview is shown in Figure 4.

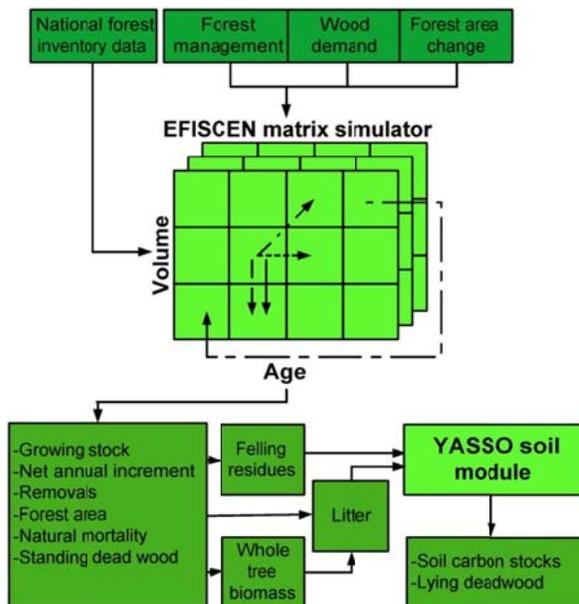


Figure 4: Schematic presentation of the EFISCEN model (Sallnäs 1990; Schelhaas et al. 2007a).

EFISCEN uses forest inventory data as an input, including:

- area (ha);
- average standing volume of growing stock (m^3/ha);
- net annual increment ($\text{m}^3/\text{ha}/\text{y}$).

These data are structured by geographical region, forest owner type, site-class, species and age-class. Based on this data, the state of the forest is described as an area distribution over age- and volume-classes in matrices. During simulations, forest area moves between matrix cells, describing different natural processes (e.g. growth and mortality) and human actions (e.g. forest management). Growth dynamics are simulated by shifting area proportions between matrix cells. In each 5-year time step, the area in each matrix cell moves up one age-class to simulate ageing. Part of the area of a cell also moves to a higher volume-class, thereby simulating volume increment. Growth dynamics are estimated by the model's growth functions whose coefficients are based on inventory data.

Management scenarios are specified at two levels in the model. First, a basic management regime defines the period during which thinnings can take place and a minimum age for final fellings. These regimes can be regarded as constraints on the total harvest level. Thinnings are implemented by moving area to a lower volume class and final fellings by moving area outside the matrix to a bare-forest-land class, from where it can re-enter the matrix. Second, the demand for wood is specified for thinnings and for final felling separately and EFISCEN may fell the demanded wood volume if available. If wood demand is high, management is intensive and rotation lengths are close to the lower limit defined in the management regimes. If wood demand is low, rotation lengths are longer, because less fellings are needed to fulfill the demand.

EFISCEN projects (i) stemwood volume, (ii) increment, (iii) age-classes and (iv) wood removals for five year time-steps. To assess biomass carbon stocks, stemwood volume is converted into carbon in stems, branches, foliage, coarse and fine roots, using basic wood densities, a generic carbon content, and age-dependent biomass distribution factors. Felling residues and litter production of trees, due to turnover and natural mortality, are used as input data for the dynamic soil model YASSO (Liski et al., 2005) and incorporated as independent module.

The soil model YASSO is used to estimate changes in the soil C pool by EFISCEN model. YASSO consists of three litter compartments and five decomposition compartments. For the soil carbon module, the litter is grouped as non-woody litter (foliage and fine roots), fine woody litter (branches and coarse roots) and coarse woody litter (stems and stumps). Each of the litter compartments has a fractionation rate determining the proportion of its contents released to the decomposition compartments in a time step. For the compartment of non-woody litter, this rate is equal to 1 which means that all of its contents is released in one time step, whereas for the woody litter compartments this rate is smaller than 1. Litter is distributed over the decomposition compartments of extractives, celluloses and lignin-like compounds according to its chemical composition. Each decomposition compartment has a specific decomposition rate, determining the proportional loss of its contents in a time step. Fractions of the losses from the decomposition compartments are transferred into the subsequent decomposition compartments having slower decomposition rates while the rest is removed from the system. The fractionation rates of woody litter and the decomposition rates are controlled by temperature and water availability and are based on litterbag data across Europe (Liski et al., 2003).

The model is especially suited for simulating managed, even-aged forests at large scales. The model has been validated for Finland (Nabuurs et al. 2001) and Switzerland (Thürig and Schelhaas 2006) by running EFISCEN on historic data. Other validations have been performed by comparing its growth functions against growth functions of other models and by comparing projections against projections of other models (e.g. Tůpek et al. 2010).

In this study, the EFISCEN model is used for projecting the net emissions due to forest management, afforestation and reforestation activities.

2.2.4. The G4M Model

The Global Forest Model (G4M) is a geographically explicit agent-based model that simulates decisions made by virtual land owners on deforestation, afforestation and forest management taking into account profitability of forestry and agriculture. The model is applied and developed by IIASA.

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 other models or data bases, which guarantee food security and land for urban development or account for disturbances. As outputs, G4M produces estimates of land-use change, carbon sequestration/emissions in forests, impacts of carbon incentives (e.g., avoided deforestation), and supply of biomass for bio-energy and timber.

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 rotation length can be individually chosen but in this study the model estimates current rotation length based on the age class structure data received from EFISCEN. To simulate changes in forest management the model then applies optimal rotation lengths to maximize either increment, stocking

biomass or harvestable biomass depending on the management objectives.

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 Europe 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.

Despite the harmonization efforts to reproduce observed data on increment, area and harvest, the forest carbon balance as described in the model might still deviate from the observed forest carbon sink or source. This might be due to differences in forest management or forest disturbances. The model cannot account for such effects. To compensate for processes affecting the carbon balance that cannot be modelled, an adjustment algorithm has been introduced. Rotation length of unmanaged forest is set to the value that yields constant biomass (equal to observed biomass in 2000). If modelled carbon sink/source from forest management (averaged over 1990-1995) is smaller/larger than reported by a country, the maximum forest age of unmanaged forest is changed to increase biomass stocks. The procedure is applied cell by cell within the country's unmanaged forest until the reported carbon stock change is matched.

In this study G4M is used to estimate baseline emissions from afforestation, deforestation and forest management. Further it is applied to derive cost curves for mitigation measures in the forestry sector.

2.3. Detailed work flow

As described already above, this analysis was built on a complex interaction of models of different sectors with different geographical resolution and degree of detail. The detailed work and data flow between the models is described in Figure 5 below. Flows of data and information are summarised in the following.

The economic backbone of the analysis forms GLOBIOM. It has (according to Figure 5) the most linkages to other models. GLOBIOM takes up data on the development of GDP and population for EU and the rest of the world from PRIMES and POLES (for EU countries and the rest of the world, respectively). The models PRIMES and POLES are not run by the consortium of this project. Output of existing runs from other projects is used. It further receives projections of bioenergy production by different feedstocks. GLOBIOM is also informed prior to baseline calculations by G4M on basic forestry parameters such as growth rates and the maximum potential supply of wood from existing forests as well as some initial economic parameters. Data exchange from EFISCEN to GLOBIOM included the theoretical harvest potential. EFISCEN delivered to G4M data on wood densities as weighted average by country and aggregated forest inventory data (age class distribution).

EUFASOM also takes up PRIMES bioenergy projections. The model has further been aligned to the

CAPRI model baseline development. It also exchanged basic assumptions on agriculture with GLOBIOM to guarantee an adequate level of consistency. Crop production at the very biophysical level is calculated in detailed crop potential maps by EPIC. The crop model also provides the economic models with look-up tables of soil carbon implications of management change for cropland management.

After baseline calculations in GLOBIOM, which integrates global competition of world regions for different commodities, the model provided country level total wood production to the two detailed forestry models G4M and EFISCEN. In addition G4M received from GLOBIOM information on the development of land and wood prices. The detailed procedure of the wood production projection is described in Chapter 3 in context of the baseline development. The model chain is concluded with G4M sending data on areas of afforestation and deforestation to EFISCEN.

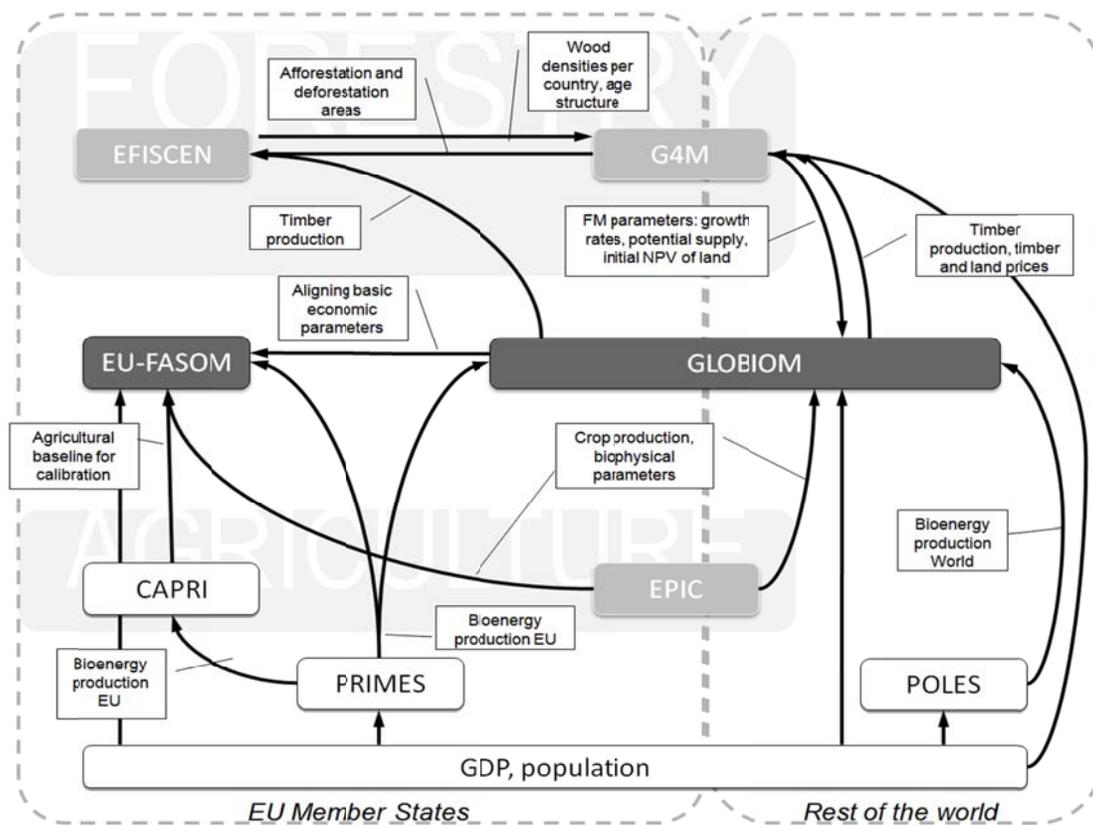


Figure 5: Schematic flowchart of the data exchange between models involved. Models of partners in the project consortium are in grey shaded boxes (economic models in dark grey, sector specific models in light grey). Arrows describe major data flows between models described in brief by call outs.

2.4. Databases used

Data for the initialisation of models and scenario development for all models is based on relevant international statistics (e.g. EUROSTAT, FAO) and publicly available databases (e.g. EFISCEN Forest Inventory Database (Schelhaas et al. 2006 a,b). The data cover the period of 1990 to 2008. Table 1 lists all important datasets that were used to develop the LULUCF baseline emissions and removals. The data and the methods applied to them are described later in this chapter.

Table 1: Summary of datasets used in LULUCF modelling approach.

Dataset name	Dataset description	Sources
Main datasets used by GLOBIOM and EUFASOM		
Population and GDP	Population and Gross Domestic Product projections	E3MLab/GEM-E3
PRIMES bioenergy production	Baseline projection of bioenergy production by different feedstocks until 2030	PRIMES biomass model, Dec 2009
	Reference scenario projection of bioenergy production by different feedstocks until 2030	PRIMES biomass model, Jul 2010
Main datasets used by G4M and EFISCEN		
Wood removals	Historic production of roundwood at country level to scale future wood production (projected by GLOBIOM)	FAO 2009; EU submission
Harvest losses	Factor to be used to convert wood removals into fellings	UNECE/FAO 2000; national correspondents
Wood density	Wood density (t dry matter/ m3 fresh volume)	IPCC GPG defaults
Main datasets used by EFISCEN		
National forest inventories	Data on area, growing stock, increment by region, owner type, site-class, species and age-class	Schelhaas et al. 2006 a,b; national correspondents and forest inventory agencies
Biomass Expansion Factors (BEF)	Species-specific and age-dependent BEFs have been developed for selected number of countries and are applied to neighbouring countries	Vilén et al. 2005; national reports
Management	Management regimes have been derived from a country-wise compilation of guidelines, handbooks and personal communication	Nabuurs et al. 2007; national correspondents
Main datasets used by G4M		
Forest biomass map	EU-wide maps of growing stock and above-ground biomass in forests based on remote sensing and field measurements	Gallaun et al. 2010
Potential NPP map	Map of potential forest net primary production based on a biophysical growth model, used by G4M	Cramer et al. 1999
Increment	Net annual increment data per country, used by G4M to scale NPP map at national level	MCPFE 2007

2.4.1. Data used by GLOBIOM and EUFASOM

The baseline scenario⁶ determines the development of the EU under current trends and policies; it includes current trends on population and economic development including the recent economic downturn and takes into account bioenergy markets. The baseline does not include the biomass demand resulting from the renewable targets agreed as part of the Climate & Energy Package. Economic decisions are driven by market forces and technology progress in the framework of concrete national and EU policies and measures implemented until April 2009.

⁶ For details of the energy baseline scenario see: http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2030_update_2009.pdf

The 2009 baseline scenario builds on macro projections of GDP and population which are exogenous to the models used. They reflect the recent economic downturn, followed by sustained economic growth resuming after 2010. This data is entering both GLOBIOM and EU-FASOM that use these scenarios to translate them into production projections for timber, bioenergy and agricultural commodities. The latest version of December 2009 was used. This dataset was also consistently used in the PRIMES biomass model that provided bioenergy projections to GLOBIOM and EU-FASOM (see below). The data for population and GDP development in EU countries for both, the base year 2007 (prior to the financial and economic crisis for comparison) and 2009 (used for this study) are displayed in Table 2.

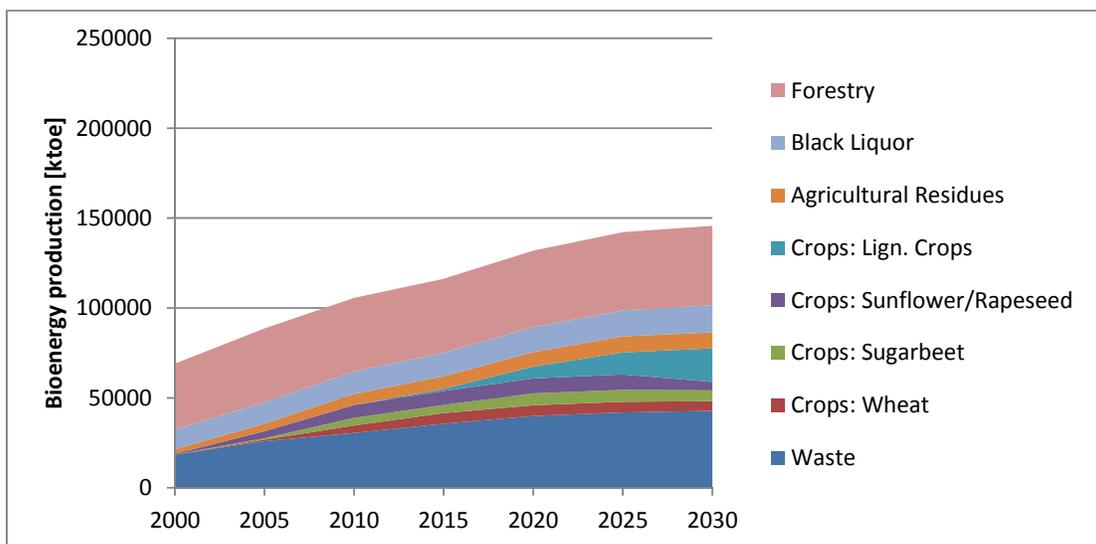
Table 2: Rate of growth of population and GDP per year in percent.

	Baseline year	1995— 2000	2000— 2005	2005— 2010	2010— 2015	2015— 2020	2020— 2025	2025— 2030
Population	2007	0.17	0.35	0.16	0.10	0.04	-0.01	-0.06
	2009	0.17	0.34	0.41	0.33	0.24	0.15	0.08
GDP	2007	2.89	1.74	2.57	2.49	2.22	1.94	1.59
	2009	2.93	1.82	0.56	2.29	2.13	1.82	1.65

Source: http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2030_update_2009.pdf

Bioenergy production data were taken from the PRIMES biomass mode⁷. The biomass system model is incorporated in the PRIMES large scale energy model for Europe. It is an economic supply model that computes the optimal use of resources and investment in secondary and final transformation, so as to meet a given demand of final biomass energy products, driven by the rest of sectors as in PRIMES model.

The primary production of biomass and waste has been linked with resource origin, availability and concurrent use (land, forestry, municipal or industrial waste etc). The total primary production levels for each primary commodity are restricted by the technical potential of the appropriate primary resource. The projection of total bioenergy production as suggested by the PRIMES biomass model (version December 2009) is displayed in Figure 6.



⁷ For a description of the model see http://www.e3mlab.ntua.gr/manuals/The_Biomass_model.pdf

Figure 6: Baseline projection of total bioenergy production in the EU as suggested by the PRIMES biomass model (version December 2009).

The bioenergy reference scenario⁸ is based on the same macroeconomic, price, technology and policy assumptions as the baseline. In addition to the measures reflected in the baseline, it includes policies adopted between April 2009 and December 2009 and assumes that national targets under the Renewable Energy Directive 2009/28/EC and the GHG Effort sharing decision 2009/406/EC are achieved in 2020.

The most relevant changes in the reference scenario compared to the baseline for LULUCF are related to bioenergy production. Figure 7 shows the original PRIMES biomass model reference scenario, Table 3 the relative difference in production of single feedstocks between baseline and reference. At EU level the reference scenario is characterized by higher production of bioenergy from waste, agricultural residues, dedicated energy crops (especially lignocellulosic crops) and forestry biomass. Overall bioenergy production in the reference scenario is about 50% higher in 2020 compared to the baseline (slightly dropping in 2030). Forestry fellings for bioenergy, relevant for the estimation of total wood production, however, are supposed to increase by 30% in 2020 compared to the baseline. It has to be noted that at an individual country level the difference between baseline and reference is very different from the EU average. For example, for France and Lithuania PRIMES projects in the reference scenario a decrease in bioenergy forestry fellings compared to the baseline.

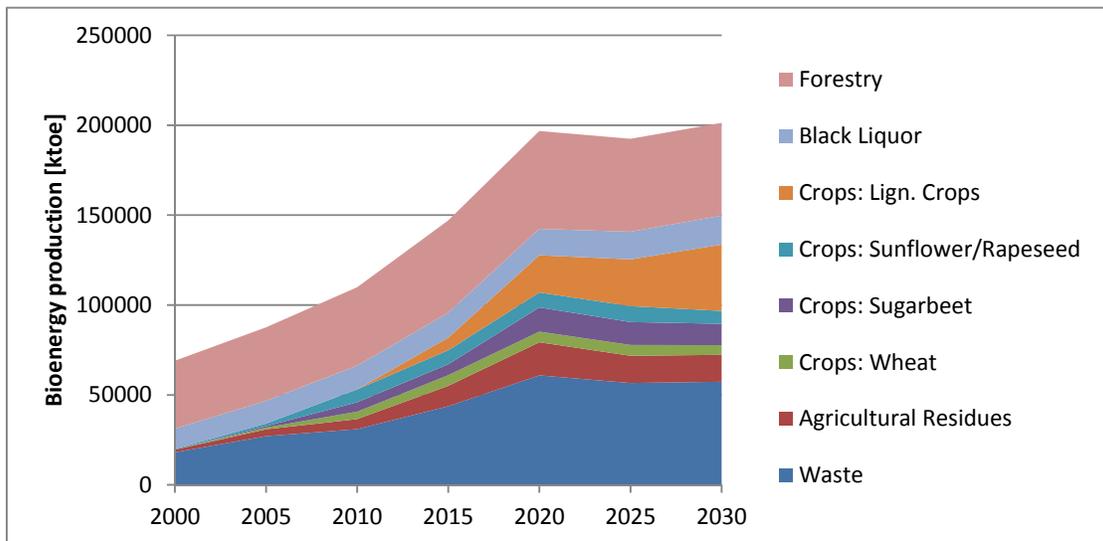


Figure 7: Reference scenario projection of total bioenergy production in the EU as suggested by the PRIMES biomass model (version July 2010).

Table 3: Difference of reference bioenergy production compared to baseline bioenergy scenario in PRIMES.

Biomass category	2000	2005	2010	2015	2020	2025	2030
Waste	-2%	5%	2%	23%	52%	35%	34%
Agricultural Residues	-42%	-10%	-9%	62%	128%	70%	68%
Crops: Wheat		0%	0%	0%	0%	0%	0%
Crops: Sugar beet		0%	22%	36%	103%	93%	99%

⁸ For details of the energy reference scenario see: http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2030_update_2009.pdf

Crops: Sunflower/Rapeseed		-63%	0%	0%	0%	3%	51%
Crops: Lignocellulosic Crops				491%	215%	113%	98%
Black Liquor	3%	6%	6%	6%	6%	6%	6%
Forestry	3%	0%	6%	25%	28%	19%	17%
- Fellings	1%	0%	5%	28%	31%	20%	18%
- Residues	15%	-2%	14%	11%	13%	14%	14%
SUM		-1%	4%	27%	49%	35%	38%

2.4.2. Data used by EFISCEN

The forest inventory data that is used to initialise EFISCEN for the 24 EU Member States in our study was collected by Schelhaas et al. (2006). New inventory data have been collected for Austria, Czech Republic, Denmark, Finland, Germany, Hungary, Ireland, Italy, Latvia, the Netherlands and Sweden and some small corrections have been made to data for Belgium and United Kingdom based on Member State consultations (Table 4). No suitable NFI data were available for Cyprus, Greece and Malta. Hence, projections could not be made for these countries.

Table 4: Original forest inventory data in EFISCEN.

Country	Year of inventory	Forest area (1000 ha) *
Austria	2001-2002	3349
Belgium	1995-1999	587
Bulgaria	2000	3646
Czech Republic	2005	2667
Denmark	2000	473
Estonia	1999-2001	2048
Finland	2004-2008	18550
France	1988-2000	13872
Germany	2001-2002	10382
Hungary	2005	1859
Ireland	2004-2005	626
Italy	2005-2008	5172**
Latvia	2004-2008	3141
Lithuania	2000	1939
Luxembourg	1989	71
Netherlands	2001-2005	360
Poland	1993	6309
Portugal	1997-1998	976
Romania	1980s	6211
Slovakia	1994	1909
Slovenia	2000	1159
Spain	1986-1995	10476
Sweden	2004-2008	22647
United Kingdom	1995-2000	2094

* The forest areas found in the original NFI data were scaled to match the areas agreed in the review.

** Area refers to even-aged forests and coppice only.

The most recent, available NFI datasets were used by EFISCEN and determine the point in time from which CO₂ emissions and removals are projected by EFISCEN. The forest area in EFISCEN generally refers to the forest area available for wood supply (FAWS), which is defined as the “forests where any legal, economic, or specific environmental restrictions do not have a significant impact on the supply of wood” (MCPFE 2007). To correct for area differences between the forest area in EFISCEN and the area for forest management (collected from Member State submissions to UNFCCC and elaborated by JRC; see section 2.5.3) a simple scaling factor was applied, assuming average forest characteristics. This was done for all Member States, except Austria, Finland, and Sweden. Instead, the area in EFISCEN in these countries refers to the forest available for wood supply. This was done based on country consultations to avoid overestimating the GHG removals from forest management.

To assess emissions and removals by afforestation/reforestation activities, the total afforested/reforested area was calculated for the period from 1990 to the year for which EFISCEN data was available. The area was then included as new forest in the first simulation step, thereby assuming that all historical afforestation took place in one year. This leads to an underestimate of the development stage of afforested/reforested area and consequently affects the projected emission/removals. Furthermore, due to lack of empirical data, it was assumed that growth of trees on afforested/reforested area was similar to the growth of young trees in already existing forests.

The amount of wood that can be felled in a time-step is controlled by a basic management regime that defines the period during which thinnings can take place and a minimum age for final harvest. Age-limits for thinnings and final fellings were based on conventional forest management according to handbooks at regional to national level (Nabuurs et al. 2007). Adjustments to these management regimes have been made for Belgium, Italy and Latvia, based on country consultations.

During harvest operations more stemwood is felled than is removed from the forest in the form of logs, due to harvest losses. The proportion of volume from thinning or final fellings being removed from the forest in the form of logs was calculated at country level, distinguishing between coniferous and broadleaved species (UNECE-FAO, 2000). Adjustments to these proportions have been made for Czech Republic, Ireland and Sweden, based on country consultations.

To assess biomass carbon stocks, stemwood volume is converted into carbon in stems, branches, foliage, coarse and fine roots, using basic wood densities, a generic carbon content (50%), and age-dependent biomass distribution factors. We used species-specific basic wood densities (IPCC, 2003), and age-dependent, species-specific biomass distribution factors for (Vilén et al., 2005; Mokany et al., 2006). Adjustments were made to basic wood densities for Italy (Romano et al et al., 2009) and to biomass distribution factors for Austria and Italy (Romano et al et al., 2009; Anderl et al. 2009), based on country consultations. Soil carbon stocks were estimated, using average climate data from the period 1971-2000.

2.4.3. Data used by G4M

An EU-wide forest/ non-forest map was used that is consistent with the national forest areas reported by MCPFE (2007) for the year 2000. For areas where CORINE land cover data are available, the CORINE dataset was aggregated from the original 100 meters to 500 meters spatial resolution. Firstly, the number of forest pixels within each 5 by 5 grid cells (one grid cell is 0.5° x 0.5° aggregation unit) was calculated. Secondly, a threshold with the minimum number of forested pixels within the aggregation units was determined for each country. This threshold was selected accordingly, to generate a forest map in agreement with the total forest area given by TBFRA 2000 at the national level. For areas not covered by CORINE data, a similar approach was applied with Vegetation Continuous Fields (VCF) data (Hansen et

al. 2003). The area covered with woody vegetation in the VCF data is given in percent. A percentage threshold of the minimum area covered by woody vegetation was defined for each country to match total forest area from TBFRA 2000.

Based on FAO data the map distinguishes between managed and unmanaged forest. Criteria of wilderness and remoteness were used to locate the unmanaged forest areas on the map. The initial growing stock per grid cell was taken from the European forest biomass map from Gallaun et al. (2010). For countries outside Europe 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 mean annual increment (MAI). At present this increment map is static but can be changed to a dynamic growth model which reacts to changes of temperature, precipitation and CO₂ concentration. Age structure and stocking degree are initialised for each grid cell. The resulting net annual increment (NAI) calculated per grid and averaged per country can then be compared to either reported NAI data to MCPFE (MCPFE 2007) or reported individual country data. For the purpose of this study the increment map was scaled at country level to match reported NAI data. 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.

2.5. Improvements and harmonisation

2.5.1. Documentation of country consultations

Adjustments were made to the models and their datasets based on bilateral consultations with Member States during the Second technical workshop on projections of GHG emissions and removals in the LULUCF sector held at the Joint Research Centre, Ispra (Varese, Italy) on 21-22 October 2009 and e-mail correspondence until June 2010. Most comments by Member States were targeted to projections by the forest models EFISCEN and G4M.

The projections developed by the models involved benefited from the comments of Member States and many were accommodated in revising the draft results, while preserving a harmonised approach to LULUCF modelling. Table 5 lists the contacts and exchanges between modelers and Member State representatives during the consultation process.

Table 5: Overview of Member States that provided comments or data during the consultations. A detailed documentation can be found in the Annex (status July 2010⁹).

Country	Policies	FM	GM	CM	Comments by country on area used	General comments by country
Austria	comments	data	data	data	comments	comments
Belgium	comments	data	data	data		comments
Czech Republic		data				

⁹ This list documents the status at the end of the consultation process. Comments from member states after the deadline were not considered.

Country	Policies	FM	GM	CM	Comments by country on area used	General comments by country
Denmark	comments	data		data		
Finland	comments	data			comments	comments
France	comments	data			comments	comments
Ireland	comments	data	data	data	comments	
Italy	comments	data	comments	comments	comments	comments
Latvia		data				
Netherlands		comments			comments	
Poland	comments	comments				
Portugal						comments
Slovakia	comments					
Slovenia		comments				
Sweden		data			comments	comments
United Kingdom	comments	data	data	data	comments	

2.5.2. Documentation of the UNFCCC review on Forest Management Reference Level

The UNFCCC coordinated a technical assessment of the submission of the European Union on its forest management reference level from 30 May to 3 June 2011 in Bonn, Germany. The review was carried out by an international group of nominated LULUCF experts (one per each country). The technical assessment resulted in a number of recommendations, mainly related to the need to improve the consistency between FM area used by models and the FM area reported by countries in GHG inventories (Table 7). All revisions considered in the update of the projection of forest management emissions that followed the review are documented in Table 6.

Table 6: Overview of the main revisions considered in the update of the projection of forest management emissions.

Country	Main reasons for change compared to April 2011 submission
Belgium	As requested by the ERT, the following changes were made: - new FM area used by models - corrected a mistake in harvest rate 2000-2005 used by models (now models use the correct harvest demand indicated previously) Based on new data from the country, a slight variation was applied in the age structure
Bulgaria	As requested by the ERT, the following changes were made: - small change to FM area used by EFISCEN (very small impact on FMRL). Given the amount of work required for adjusting the area of G4M, no correction of area was done because the difference with GHG inventory is very small (less than 4%). Given the ex-post calibration of models' results, the impact of the remaining area discrepancies on FMRL can be considered absolutely negligible.
Czech Republic	As requested by the ERT, the following changes were made: - New FM area in both models - Change the value of increment used by EFISCEN The new runs by models provide much better data (i.e. models results now are closer to GHGI), since a number of problems/misunderstanding have been solved

Country	Main reasons for change compared to April 2011 submission
Estonia	As requested by the ERT, the following changes were made: - small change to FM area used by EFISCEN (very small impact on FMRL). Given the amount of work required for adjusting the area of G4M, no correction of area was done because the difference with GHG inventory is very small (less than 1%). Given the ex-post calibration of models' results, the impact of the remaining area discrepancies on FMRL can be considered absolutely negligible. Following the ERT recommendation, we used 2010 GHG inventory as basis for calibrating models results
France	Changes of forest area after country consultation
Greece	Changes of forest area after country consultation
Hungary	As requested by the ERT, the following changes were made: - new AREA, new INCREMENT and new HISTORICAL HARVEST (from the country) used by both models New models results are better than previous one (much closer to GHGI)
Italy	Update of NFI (increment and age structure) and harvest data after country consultation
Latvia	As requested by the ERT, the following changes were made: - small change to FM area used by EFISCEN (very small impact on FMRL). Given the amount of work required for adjusting the area of G4M, no correction of area was done because the difference with GHG inventory is very small (less than 3.5%). Given the ex-post calibration of models' results, the impact of the remaining area discrepancies on FMRL can be considered absolutely negligible. - EFISCEN applied a mortality rate of 20% - slightly revised new rotation lengths were used, as provided by the country
Lithuania	As requested by the ERT, the following changes were made: - change to FM area used by both models
Luxembourg	No change in models results was done for Luxembourg - the small variation of FMRL is totally due to the use of 2011 GHGI
Netherlands	As requested by the ERT, the following changes were made: - small change to FM area used by EFISCEN (very small impact on FMRL). Given the amount of work required for adjusting the area of G4M, no correction of area was done because the difference with GHG inventory is very small (1%). Given the ex-post calibration of models' results, the impact of the remaining area discrepancies on FMRL can be considered absolutely negligible. - new data from 2011 GHG inventory was used for calibrating models' results in the period 2000-2008
Romania	Minor corrections of parameters, new data for FM area used by G4M
Slovakia	As requested by the ERT, the following changes were made: - change to FM area used by both models (rather small impact on FMRL). - new data from 2011 GHG inventory was used for calibrating models' results in the period 2000-2008. This had an impact on FMRL, which is now a small source.
Spain	As requested by the ERT, the following changes were made: - change to FM area used by both models (rather small impact on FMRL).

Table 7: Forest area, net annual increment and fellings of 2010 used by the models after the review.

	Area 1000 ha		Net annual increment m3/ha		Wood removals m3/ha	
	EFISCEN	G4M	EFISCEN	G4M	EFISCEN	G4M
Austria	3287	3775	8.1	11.4	5.9	5.2
Belgium	691	692	9.2	9.2	5.9	5.8
Bulgaria	3504	3504	4.5	6.0	1.8	1.8
Cyprus	-	75	-	1.5	-	0.3
Czech Republic	2561	2561	9.1	10.6	7.4	7.3
Denmark	533	533	9.8	14.9	5.1	5.0
Estonia	2153	2155	5.3	5.5	4.0	3.9
Finland	18479	21820	4.9	5.2	3.4	2.9

France	13422	13432	7.3	7.9	4.4	4.3
Germany	10859	10861	11.3	11.6	7.1	7.1
Greece	-	1183	-	1.4	-	1.1
Hungary	1657	1657	6.7	6.5	4.2	4.5
Ireland	457	457	9.2	9.9	6.5	5.7
Italy	7450	7450	4.9	4.3	2.1	1.8
Latvia	3129	3129	6.2	6.6	3.6	3.6
Lithuania	1914	1914	5.6	7.0	3.5	3.5
Luxembourg	85	85	11.2	10.2	3.6	4.4
Malta	-	-	-	-	-	-
Netherlands	324	325	8.1	7.1	3.7	3.5
Poland	8873	8873	5.2	8.8	4.1	4.0
Portugal	3758	3676	3.9	7.1	3.2	3.6
Romania	6696	6650	7.4	9.2	2.5	2.6
Slovakia	1975	1975	6.5	7.3	4.6	4.7
Slovenia	1186	1186	6.4	8.1	2.6	2.6
Spain	12577	12569	2.7	2.9	1.5	1.5
Sweden	22575	28188	4.8	5.4	4.0	3.2
United Kingdom	2591	2578	8.6	8.6	2.6	3.9
Sum/Avg EU	130735	141302	6.95	7.47	4.05	3.76

2.5.3. General harmonisation and comparison of forestry models

For activities related to forest management this study uses different models to simulate overlapping tasks. This approach allows a comparison of results and through this also insight into uncertainties that are beyond the uncertainties of input data and parameters. To compare results of parallel running model, however, special emphasis on the harmonisation of the models required. The observed differences in results can then be interpreted as a proxy for the uncertainty associated with the use of different approaches. A single model application ignores this type of uncertainty and delivers more precise but not necessarily more accurate results.

As described above, the modelling approach includes a parallel application of models projecting emissions and removals for forest management. To be able to compare results several assumptions in the models and common input datasets had to be harmonized. The following parameters and datasets were considered for a harmonization:

- Area covered by forests and forest definition
- Age-class structure
- Basic wood density
- Biomass Expansion Factors
- Wood removals and harvest losses

In the following, the most relevant harmonisation efforts are documented.

Forest area

The extent of forest area deviates between different international datasets (UNFCCC, FAO, NFIs, CORINE Land Cover 2000, GLC 2000 due to differences in definitions. Historical data on forest area for afforestation/reforestation, deforestation and forest management were collected from countries' submission to UNFCCC and the Kyoto Protocol (elaborated by JRC). Forest areas in G4M and EFISCEN have been scaled to match the reported areas. The values implemented in the models differ quite significantly from the reported data. For EFISCEN the forest areas for Austria, Finland, and

Sweden refer to the forest available for wood supply, reported by MCPFE (2007) based on country consultations. Deviations of areas used in G4M from reported data are larger because G4M uses forest cover maps and scaling to reported data cannot be achieved easily. Using forest maps in a geographically explicit model complicates a scaling of forest areas to data from other sources than these maps. Especially in countries were map and reported data of other sources deviate significantly (e.g. because of application of different definitions), additional area that is not recorded by the map has to created (in case the map shows less forest area) or the mapped forest area has to shrink (in the opposite case). Therefore, in some cases, deviations between the different data sources and data used by the models could not fully be resolved.

Forest inventories

National Forest Inventory (NFI) data in EFICEN database was updated with most recent inventory data for 11 Member States (Austria, Czech Republic, Denmark, Finland, Germany, Hungary, Ireland, Italy, Latvia, the Netherlands and Sweden) and corrections were made to inventory data for Belgium and United Kingdom. Aggregated forest inventory data as projected by EFISCEN were provided to G4M. Table 8 presents the relative age class distribution of EU countries in percent of total forest area for the year 2005. The data were projected by EFISCEN based on NFI data and historical roundwood removals.

For countries with significant areas under afforestation/reforestation the NFI data often does not contain enough information to form a good basis for emission projections. NFI data provide generally aggregated data on forest area and do not distinguish between different LULUCF activities, i.e. forest area under forest management and under afforestation/reforestation are not separated in NFI data.

Table 8: Relative age class distribution of EU countries in percent of total forest area for the year 2005. The data were projected by EFISCEN based on NFI data and historical roundwood removals. Age classes in years, areas in percent of total forest area. Data does not exist for Cyprus, Greece and Malta.

Country	Age classes in years							
	1-20	21-40	41-60	61-80	81-100	101-120	121-140	>140
Austria	14.3	21.5	21.2	13.9	10.3	7.5	4.7	6.6
Belgium	20.9	15.3	25.9	15.4	9.4	6.0	3.2	3.8
Bulgaria	16.2	20.6	27.8	19.3	6.3	5.1	2.6	2.1
Czech Republic	16.1	16.2	16.8	18.1	16.1	10.2	4.3	2.2
Denmark	24.0	24.9	27.4	11.4	5.2	4.7	1.9	0.5
Estonia	19.0	15.2	28.3	24.2	10.2	2.4	0.5	0.2
Finland	19.8	20.9	20.9	17.4	10.6	4.9	2.2	3.3
France	16.0	20.7	20.3	17.9	12.6	6.2	3.5	2.7
Germany	15.3	13.6	19.9	18.7	14.0	9.4	5.3	3.9
Hungary	47.6	39.0	13.4	0.0	0.0	0.0	0.0	0.0
Ireland	10.7	29.1	22.6	17.9	8.0	4.6	3.3	3.7
Italy	16.2	20.6	25.2	21.1	10.6	4.0	2.3	0.0
Latvia	13.3	13.3	25.7	28.1	15.0	3.8	0.6	0.2
Lithuania	10.9	6.7	22.4	12.1	7.4	8.7	13.4	18.4
Luxembourg	7.9	21.1	27.4	23.4	13.2	3.5	2.2	1.3
Netherlands	14.1	19.7	19.6	21.9	16.4	5.8	1.4	1.0
Poland	49.5	29.1	15.9	5.0	0.6	0.0	0.0	0.0
Portugal	14.3	19.3	18.7	16.6	12.0	19.1	0.0	0.0
Romania	24.7	7.0	15.4	21.2	19.0	10.0	2.0	0.6
Slovakia	6.1	3.5	11.8	19.0	19.3	19.6	12.7	8.1
Slovenia	27.1	13.7	15.7	15.5	9.9	3.6	2.2	12.2

Country	Age classes in years							
	1-20	21-40	41-60	61-80	81-100	101-120	121-140	>140
Spain	21.1	21.7	17.9	12.4	9.0	7.0	5.2	5.8
Sweden	19.7	24.5	33.7	12.3	4.2	2.3	2.1	1.2
United Kingdom	19.1	19.9	20.0	16.6	10.8	6.5	3.1	3.9
EU average	14.3	21.5	21.2	13.9	10.3	7.5	4.7	6.6

Biomass expansion factors and wood densities

To estimate emissions and removals by forests, volumetric data from forest inventories need to be converted to carbon estimates. This conversion depends on the country/region, tree species composition and characteristics, etc. Country-specific average wood densities were calculated by EFISCEN and provided to G4M. G4M was updated with a biomass map by Gallaun et al. (2010). This map uses EFISCEN biomass expansion factors to convert stem volume into whole-tree biomass, thereby enhancing consistency between the models.

3. Scenario development

A baseline and a reference scenario were developed using the GLOBIOM and EUFASOM models that translated existing marco-economic and bioenergy demand (from PRIMES and POLES models) into projections of production of timber, bioenergy and agricultural commodities. EFISCEN and G4M used the projections from GLOBIOM to assess future emissions and removals from forest management, whereas EUFASOM directly provided projections on cropland and grazing land.

3.1. Projection of domestic wood production

Wood production that results in wood extraction from forests is driving the forestry sector and has direct impact on the GHG balance of forests. When referring to wood production in this report we mean wood harvested from domestic forest resources. Total wood consumption in a country can be larger or smaller, depending on the trade balance. Total wood as defined in this study consists of wood for material use and energy use (see Table 9). Timber (referring to industrial roundwood according to FAO definition) comprises pulp wood, sawnwood and other wood. Wood for energy use includes traditional fuel wood use and industrial energy wood. The model GLOBIOM was used to integrate the wood production projection from different sources in the following way.

Table 9: Mapping of FAO, PRIMES biomass and GLOBIOM categories of wood to estimate total wood production at EU level.

Use group	FAO timber categories	PRIMES biomass model categories	GLOBIOM model categories
Material use	Industrial Roundwood, Pulpwood, Round&Split	-	Pulp wood (projected by GLOBIOM at EU level)
	Industrial Roundwood, Sawlogs+Veneer Logs	-	Sawnwood (projected by GLOBIOM at EU level)
	Other Industrial Roundwood	-	Other wood (assumed to be constant)
Energy use	Wood Fuel	Fellings	Fuel wood (traditional use, assumed to be constant)
		Fellings (remaining after FAO reported wood fuel has been subtracted)	Energy wood (driven by PRIMES biomass projection)
		Residues	Not included in model

Historic roundwood removals were collected from FAOSTAT and through Member State consultations and served as a basis for the projection of future total wood production. In general, data between 1985 and 2008 were collected, where available. Factors for coniferous and non-coniferous species were applied to convert wood removals into fellings (correction for harvest losses and the bark fraction). Trends of wood production were estimated by GLOBIOM by extrapolating from a base year into the future. To do so the historic data were averaged over the five year period 1998 to 2002 to estimate wood harvest in the base year 2000.

3.1.1. Baseline scenario

The PRIMES biomass model provides a projection on bioenergy production from forests (fellings and

residues). This forms the basis for the wood production for energy use expected for the EU countries in GLOBIOM. Bioenergy from fellings from PRIMES was fed into GLOBIOM as a constraint so that the GLOBIOM model reproduced at least the amount projected by the PRIMES biomass model. Other wood products however, were left to compete for the wood resource. The amount of fuel wood defined by FAO statistics and not covered by PRIMES (i.e. the difference between average 2000 FAO wood fuel and 2000 PRIMES biomass energy wood fellings) was set to be constant until 2030.

Future production of wood for material use for EU regions was taken from Rametsteiner et al (2009). The demand for wood in the GLOBIOM model can be satisfied by domestic production or imports. This is done by assuming competition and trade between EU and other world regions. Based on cost functions for the world regions and different commodities, GLOBIOM estimated domestic production and net imports for EU for different wood products. Other industrial roundwood production was set to be constant until 2030. The resulting total wood production for all EU27 countries is displayed in Figure 8. The lack of detailed projections of future wood demand per country was overcome by the current assumption that production of wood for material use in all EU countries will increase by the same factor estimated by GLOBIOM.

Projected total wood production by GLOBIOM was compared with observed harvest rates for the time 2000-2009. In general wood demand in EU27 was higher in 2005 than expected by the model. These differences can relate to short term responses that the model cannot include and also constraints that are not included. For example the model does not include the Russian tax barrier on round wood and also cannot account for constraints on forest accessibility of forest existing in some EU countries. Data for the year 2000 and 2005 were taken from historic data, estimates for the year 2020 and 2030 from the GLOBIOM projection. The year 2010 was interpolated between 2005 and 2020. Table 10 displays the wood production for wood used energy and material use for individual countries.

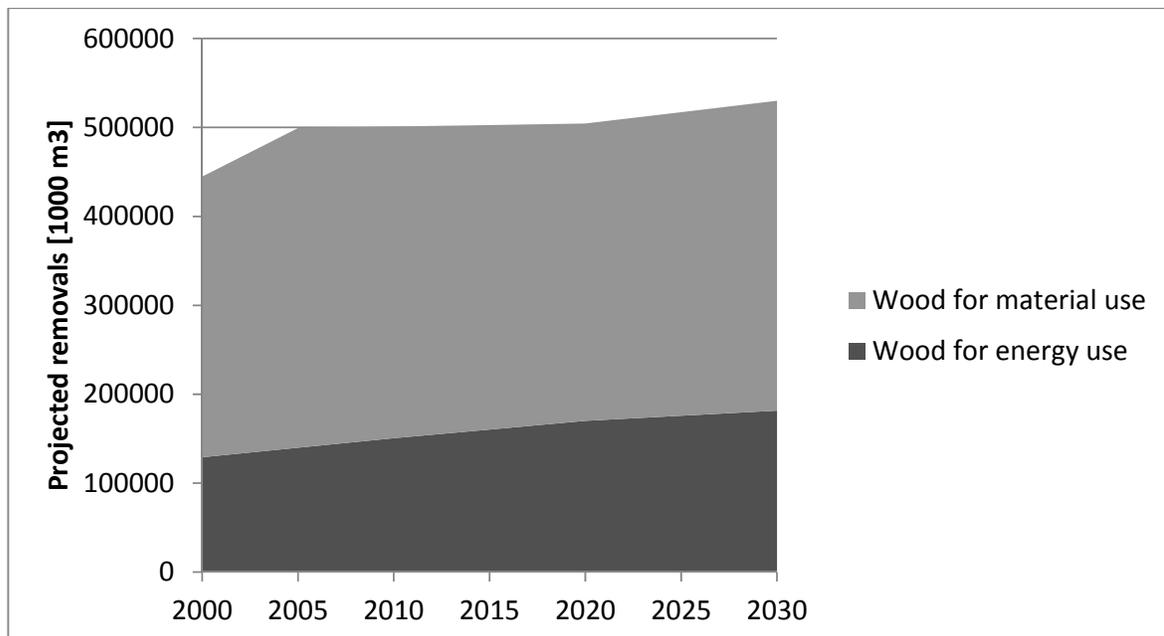


Figure 8: Baseline projection of domestic wood production for EU27 for energy wood (based on PRIMES bioenergy from fellings and traditional fuel wood) and other wood (i.e. material use including sawnwood, pulp wood and other industrial roundwood). The original GLOBIOM data were scaled by historic wood demand and adjusted in the year 2005 to correct for observed wood removals.

Table 10: Baseline projection of wood production in 1000 m³ at country level for material use (including sawnwood, pulp wood and other industrial roundwood) and energy wood (based on PRIMES bioenergy from fellings and traditional fuel wood). The original GLOBIOM data were used to extrapolate country specific historic wood production into the future.

Country	Material use					Energy wood				
	2000*	2005*	2010	2020	2030	2000*	2005*	2010	2020	2030
Austria	8444	12461	11031	8945	9320	7170	7803	8435	8924	9233
Belgium	3190	3685	3495	3380	3521	267	419	571	610	838
Bulgaria	2433	3786	3275	2577	2685	2403	2683	2962	3196	3155
Cyprus	28	13	20	30	31	0	0	0	4	6
Czech Rep.	15710	15818	14331	16643	17341	0	2329	4658	4030	5108
Denmark	980	1239	1265	1039	1082	1084	1251	1418	2031	2225
Estonia	7542	5294	6372	7990	8325	2057	2116	2176	2832	2935
Finland	48174	47356	49745	51036	53175	12434	13000	13565	18184	19529
France	36137	31538	35006	38283	39888	27500	25960	24419	24996	25247
Germany	49043	65930	59602	51956	54133	13267	15244	17222	16166	14156
Greece	275	321	474	291	303	998	987	977	1444	1567
Hungary	5044	4573	4636	5344	5568	1913	2420	2926	3358	2783
Ireland	2562	2548	2461	2714	2827	216	372	528	413	1024
Italy	6790	5610	6348	7194	7495	5930	6711	7493	9686	13110
Latvia	8730	8576	9090	9248	9636	2310	2288	2266	3092	2944
Lithuania	4144	5056	4983	4390	4574	2019	1869	1719	1866	1955
Luxembourg	298	305	309	316	329	0	0	0	0	0
Malta	0	0	0	0	0	0	0	0	0	0
Netherlands	1090	1204	1188	1155	1203	0	0	0	0	0
Poland	19499	27055	25029	20657	21523	8889	9992	11095	13620	15837
Portugal	7074	9323	8603	7494	7808	4501	4414	4327	3821	6279
Romania	6654	8208	7307	7050	7345	8172	8896	9619	9521	8759
Slovakia	6593	7225	5924	6985	7278	6	1595	3185	2703	2864
Slovenia	1227	1759	1518	1300	1355	1269	1401	1533	1533	1533
Spain	8966	9226	9246	9498	9896	8057	8529	9001	9731	8812
Sweden	56607	71899	69651	59969	62483	18273	19081	19889	26690	30046
United Kingdom	8434	9510	9555	8934	9309	294	427	561	1539	1632
EU	315669	359521	350464	334417	348435	129030	139787	150545	169993	181577

* Historic data from FAO or country submissions to UNFCCC. All other years extrapolated projections based on PRIMES and GLOBIOM.

3.1.2. Reference scenario

Figure 9 shows the PRIMES reference scenario translation into total wood production by GLOBIOM, Table 11 shows the relative differences in the wood trade balance between baseline and reference scenario in GLOBIOM. Similar to the fellings for bioenergy estimated by PRIMES (row 1), GLOBIOM shows increasing energy wood production until 2020 and then a slight drop in 2030 compared to the baseline (row 3). The difference between the scenarios for total wood production in GLOBIOM is rather small (row 2). This is because the increase in energy wood production is associated with two effects on the trade balance:

- 1) a decreased EU production of wood for material use compared to the baseline scenario (row 4) and
- 2) a decrease of wood for energy use exports (row 9).

The relatively reduced wood production for material use is not compensated by a decreased consumption (row 7), in fact material consumption is even slightly increased. The reduced production is instead met by increased imports of timber (row 10).

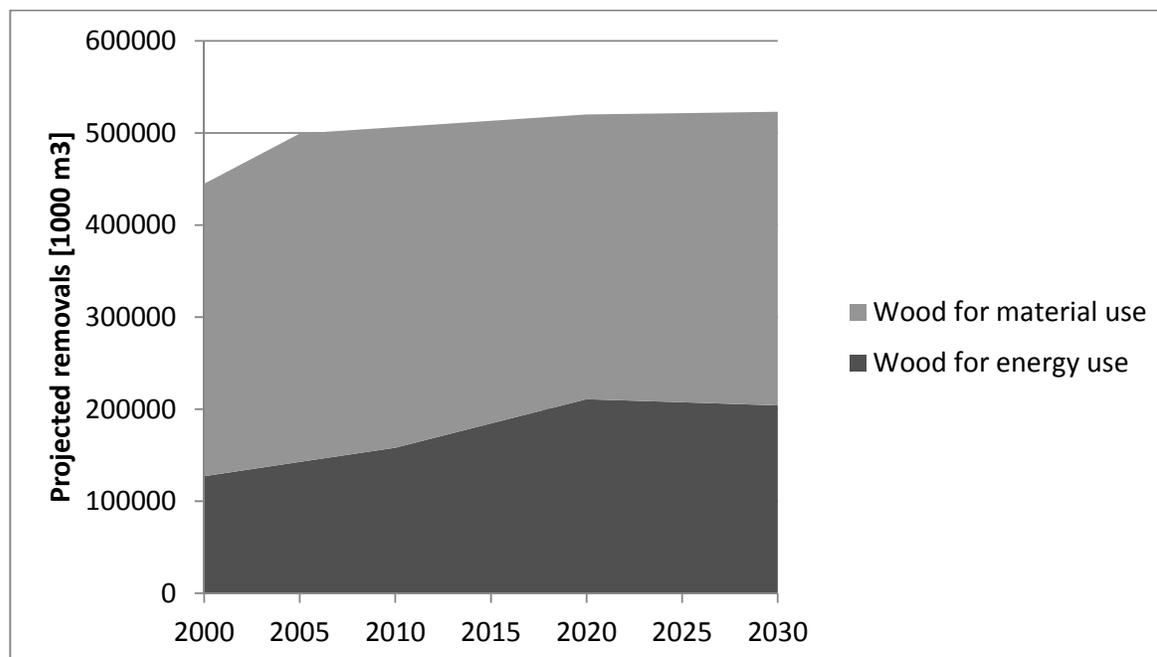


Figure 9: Reference scenario projection of domestic wood production for EU27 for energy wood (based on PRIMES bioenergy from fellings and traditional fuel wood) and other wood (i.e. material use including sawnwood, pulp wood and other industrial roundwood). The original GLOBIOM data were scaled by historic wood removals and adjusted in the year 2005 to correct for observed wood removals.

Table 11: Difference between baseline and reference scenario in the wood trade balance estimated by GLOBIOM.

Row no.	Difference to baseline	2020	2030
1	PRIMES fellings	131%	118%
2	GLOBIOM total wood production	104%	99%
3	Energy wood production	126%	112%
4	Wood for material use production	93%	92%
5	GLOBIOM total wood consumption	112%	101%
6	Energy wood consumption	131%	99%
7	Wood for material use consumption	104%	101%
8	GLOBIOM net wood trade		
9	Energy wood exports	76%	226%
10	Wood for material use imports	286%	172%

Table 12: Relative difference between baseline and reference projection of total wood production at country level for total (including wood material use, i.e. sawnwood, pulp wood and other industrial roundwood and energy wood based on PRIMES bioenergy from fellings and traditional fuel wood). The original GLOBIOM data were used to extrapolate country specific historic wood production into the future. Data for period 2000 to 2005 are identical in baseline and reference scenario.

Country	2015	2020	2025	2030
Austria	5%	7%	2%	-2%
Belgium	-8%	-13%	-7%	-2%
Bulgaria	13%	21%	16%	11%
Cyprus	-15%	-18%	-21%	-23%
Czech Republic	6%	8%	5%	2%
Denmark	-1%	-2%	-5%	-8%
Estonia	-21%	-28%	-28%	-28%
Finland	-2%	-4%	-5%	-5%
France	-1%	-2%	-7%	-12%
Germany	1%	1%	5%	8%
Greece	-5%	-7%	-18%	-29%
Hungary	5%	7%	-2%	-11%
Ireland	13%	19%	2%	-11%
Italy	62%	84%	59%	37%
Latvia	6%	8%	5%	2%
Lithuania	-3%	-4%	4%	12%
Luxembourg	-5%	-8%	-9%	-9%
Malta	-	-	-	-
Netherlands	-4%	-7%	-7%	-8%
Poland	-12%	-19%	-19%	-20%
Portugal	-7%	-12%	-19%	-24%
Romania	8%	12%	-1%	-13%
Slovakia	-2%	-2%	-5%	-8%
Slovenia	18%	28%	21%	14%
Spain	38%	55%	76%	97%
Sweden	-3%	-5%	-8%	-10%
United Kingdom	8%	12%	6%	0%
SUM	2%	3%	1%	-1%

3.2. Projection of agricultural production

The agricultural baseline of EUFASOM is based based on the same projections on macro-economic and bio-energy production for the baseline and the reference scenario as used in GLOBIOM. The EUFASOM baseline is consistent with the baseline of the CAPRI model. Baseline and links between CAPRI, EUFASOM, PRIMES and RAINS/GAINS have been developed within the EC4MACS project¹⁰. Overlapping information between CAPRI and EUFASOM includes national area, production, feed processing, and consumption for major crops and animal herd sizes and livestock production. Sub-national accounts differ because the models use different resolutions on the sub national level. While EUFASOM depicts geographically implicit altitude, slope, and soil differences, CAPRI uses geographically explicit NUTS II regions. Management system categories are also different. For baseline emission predictions, EUFASOM national agricultural production accounts are simply forced to the level

¹⁰ <http://www.ec4macs.eu>

of CAPRI accounts. For scenario analysis, the restrictions are removed and replaced by dynamic cost calibrations.

3.3. Sensitivity analysis for forestry models

Wood production and its future projection is among the most important drivers of the forestry models and potentially affects the emissions from forest management significantly. The projection is, however, associated with large uncertainties. Many influencing factors (policy, consumer trends, trade etc.) can only be considered indirectly, if at all. To investigate the likely effects of wood removals being higher or lower than the anticipated data, a sensitivity analysis is carried out with G4M and EFISCEN. Total wood production is shifted by 10% up (high scenario) and down (low scenario). A third scenario investigates the effect of constant harvest rates (values of the year 2000). Other variables remain at baseline level (*ceteris paribus*) creating inconsistencies. However, these model runs should only be regarded as sensitivity analysis to assess the effect of a single driver on model results but not as separate policy scenarios.

3.4. Development of cost curves

Both, baseline and reference scenario runs were carried out to project the likely development of CO₂ sinks and sources in LULUCF for EU countries. To assess the potential and associated costs of mitigation measures on top of the baseline and reference development, marginal abatement cost curves were calculated. These were constructed by applying management change scenarios with changing CO₂ prices. The calculations were done using G4M (forestry activities) and EU-FASOM (agricultural activities). Into both models a CO₂ price was inserted that typically affects the economic performance of forestry and agriculture and thus the behaviour of land owners to change land use. The CO₂ price was introduced as a carbon tax to be paid by land owners when emissions occur on their land. The CO₂ price is introduced in the model year 2011 and kept constant at steps of 5 EUR per tonne of CO₂ over the entire simulation time.

3.4.1. Forestry

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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ price is managed with longer rotations of productive forests, and shifting harvest to less productive forest. Where possible the model increases the area of forests used for wood production, meaning a relatively larger area is managed relatively less intensively. This model paradigm

implies also changes of the thinning versus final felling ratio towards more thinnings (which affect the carbon balance less than final fellings). Forest management activities can have a feedback on emissions from deforestation because they might increase or decrease the average biomass in forests being deforested. It also influences biomass accumulation in newly planted forests depending on whether these forests are used for production or not.

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} , $NPV_{bau} \geq 0$), 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.

3.4.2. Cropland management

Within EUFASOM the model determines how much area should be devoted to each management alternative. The levels of the endogenous land management variables are optimal when the sum of producer and consumer surplus over all regions and commodities is maximized. The product of the exogenously given per-hectare impacts times the endogenously determined area in hectares summed over all management alternatives gives the total impact of cropland management on production, input use, and environment. To generate abatement cost curves, EUFASOM is subjected to a range of carbon prices. These prices affect the revenues and costs of different land management strategies. For example, if a certain crop management increases emissions by 1 metric ton of carbon per hectare and year, a carbon price of 100 would increase the costs of this strategy by 100 Euros per hectare and year. Since different land management alternatives have different net emission values, the imposition of carbon prices leads to different costs impacts for different strategies. As a result, the optimal allocation of land management strategies increases the adoption of emission intensive strategies. Overall, the change in management then leads to reduced net carbon emissions. The following cropland management activities are considered in the model:

- Change in crop choice
- Change in crop distribution across land qualities
- Change in crop management
 - three tillage intensities (conventional, reduced, no tillage)
 - two irrigation alternatives (irrigation or rain-fed)
 - two cereal residue treatment options (no residue removal or removal of straw from cereals).

4. Results and discussion

4.1. Baseline scenario

4.1.1. Total LULUCF

Results of the models applied in this study cover measures in the following land use activities: afforestation/reforestation, deforestation, forest management, cropland management and grazing land management. The pools included in the results section are total biomass carbon for all forestry activities and mineral soil carbon for agricultural activities. Estimates for forest soil carbon have been made by EFISCEN. They are discussed in a separate section and not included in EU sums. In order to make numbers comparable among models in EU summary graphs and tables emission sums do not include values of Cyprus, Malta and Greece (if not indicated). This is because EFISCEN does not include Cyprus, Malta and Greece, G4M does not estimate values for Cyprus and Malta. For reasons of comparability original values of the G4M model (annual) were averaged to five year steps with a running mean of five year width. EFISCEN and EUFASOM produce their results in five year steps. If not indicated differently the values are presented in Gg CO₂ per year. Original results from EFISCEN do not exist for years prior to the most recent, available NFI data that was used for the analysis. This report shows only original model results and no extrapolations to fill past data were made. Hence, EFISCEN projections for the whole EU are shown from 2010 onwards, whereas there are projections for individual countries for previous years (see Table 13).

Figure 10 summarises the results of the baseline projection for LULUCF for EU-27. In total the models expect a decrease of the land carbon sink by about 10 to 35% between 2010 and 2030. The first value is based on a result of the total LULUCF sum including EFISCEN, the second an estimate including G4M as forestry model, both in combination with EUFASOM results for cropland and grassland management. EUFASOM and G4M produced results that overlap with data from UNFCCC and Kyoto reporting for the period of 2005-2008. The comparison of total reported LULUCF emissions for EU countries and modelled results is also displayed in Figure 10. Reported data were compiled by JRC¹¹ and include data reported by countries to UNFCCC and the Kyoto Protocol. Reported emissions sum up to an increasing sink between 1990 and 2005 for the included countries (EU27 excluding Cyprus, Greece and Malta). Both models, however, project a declining sink on average over the simulation period 2000 to 2030. Also the overall level of emissions differs: the model average sink is about 40% lower in 2010 compared to reported data in 2005.

The development of total LULUCF emissions for each EU Member State separated by model combinations can be found in Table 13 and Table 14. Consistently over all model combinations, Belgium, Czech Republic, Estonia, Germany, Netherlands and Poland form CO₂ sources of total LULUCF projections while all others show net sinks in the beginning of the calculation. Over the simulation time some countries are likely to change from sink to source (Denmark, Slovakia) and source to sink (Germany and Portugal in Table 14).

¹¹ European Commission, Joint Research Centre (JRC) JRC LULUCF TOOL, version (November 17, 2010)
http://afoludata.jrc.ec.europa.eu/index.php/models/jrc_lulucf_tool

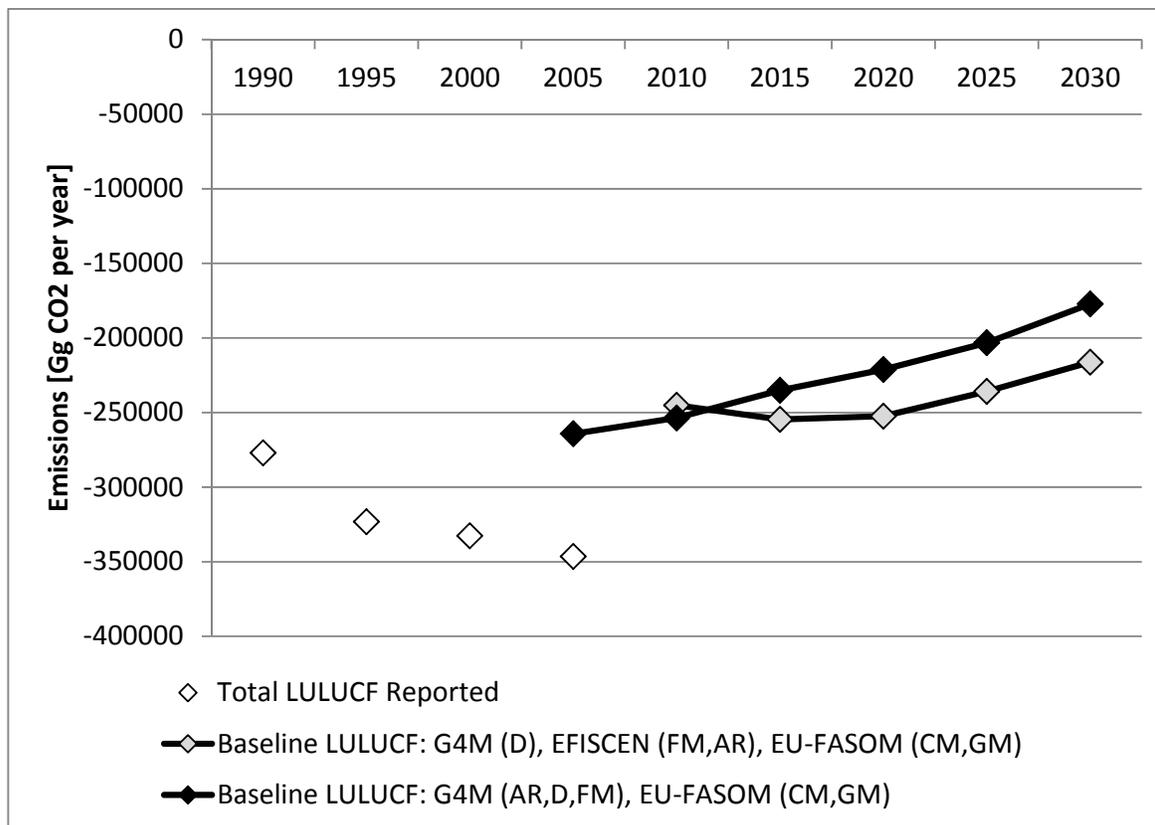


Figure 10: Baseline emission projection for different model combinations and reported data for LULUCF (sum of AR, D, FM, CM and GM). Reported data were compiled by JRC and include data reported by countries to UNFCCC and the Kyoto Protocol. Sums do not include values of Cyprus, Malta and Greece in order to make numbers comparable among models (Cyprus, Greece and Malta are not covered by EFISCEN, G4M does not estimate values for Cyprus and Malta).

Table 13: Baseline total LULUCF projection at country level as projected by G4M (AR, D, FM) and EUFASOM (CM and GM) in Gg CO₂. G4M did not estimate numbers for Cyprus and Malta. Values in Gg CO₂ per year. Positive values show sources, negative values sinks of CO₂.

G4M, EUFASOM	2005	2010	2015	2020	2025	2030
Austria	-20719	-20079	-17975	-16801	-15310	-13253
Belgium	-437	-210	496	984	850	915
Bulgaria	-16183	-16045	-15375	-13569	-13988	-12560
Cyprus	-92	-93	-90	-88	-88	-87
Czech Republic	3827	4895	7203	8264	10429	11372
Denmark	-1169	-1376	-1116	-798	-520	-64
Estonia	50	1378	3293	4576	4289	4014
Finland	-20090	-19500	-16850	-13461	-10803	-7193
France	-41623	-43527	-40655	-35556	-30280	-28865
Germany	20572	17329	13983	10424	9718	13527
Greece	-4066	-4608	-4974	-5321	-5451	-5309
Hungary	-7274	-6640	-5454	-4899	-3367	-3553
Ireland	443	-64	-291	-559	-904	-1263
Italy	-37550	-35740	-34714	-35038	-34666	-32309
Latvia	-3580	-3106	-1910	-1140	-513	-139

G4M, EUFASOM	2005	2010	2015	2020	2025	2030
Lithuania	-2494	-2765	-2580	-2726	-2403	-2082
Luxembourg	-460	-499	-172	64	191	13
Malta	0	0	0	0	0	0
Netherlands	2810	2897	3112	3271	3464	3473
Poland	7254	9924	15991	16196	21658	24298
Portugal	-8833	-11432	-14879	-17035	-17029	-16399
Romania	-74629	-68225	-62488	-57989	-44825	-50521
Slovakia	-3342	-1921	-1305	-401	-165	416
Slovenia	-6930	-6611	-5165	-4794	-4269	-3655
Spain	-14777	-15840	-18452	-19552	-21223	-22760
Sweden	-24535	-26461	-29253	-32238	-31230	-27613
United Kingdom	-10393	-11524	-10938	-10547	-9684	-9067
SUM	-264223	-259841	-240560	-228732	-196118	-178664

Table 14: Baseline total LULUCF projection at country level as projected by EFISCEN (AR, FM) G4M (D) and EUFASOM (CM and GM) in Gg CO₂. EFISCEN starts running from individual country forest inventories. This causes data gaps for those countries that have provided very recent national inventory information. There are no projections for Cyprus, Greece and Malta by EFISCEN, due to lack of suitable NFI data. Values in Gg CO₂ per year. Positive values show sources, negative values sinks of CO₂.

EFISCEN, G4M, EUFASOM	2010	2015	2020	2025	2030
Austria	-7922	-10307	-12231	-12293	-13253
Belgium	-321	-670	-777	-529	915
Bulgaria	-14375	-13826	-11437	-12429	-12560
Cyprus					
Czech Republic	4302	6293	6777	8037	11372
Denmark	-244	-587	-732	-900	-64
Estonia	-1068	1842	4136	4515	4014
Finland	-18476	-16326	-12163	-9446	-7193
France	-39581	-39977	-36865	-32603	-28865
Germany	10163	-2894	-13025	-9990	13527
Greece					
Hungary	-6851	-4898	-3924	-3845	-3553
Ireland	301	-446	-709	-627	-1263
Italy	-63039	-55144	-52130	-50658	-32309
Latvia	-6566	-4472	-2943	-2538	-139
Lithuania	-3600	-3129	-3319	-2634	-2082
Luxembourg	-204	117	178	39	13
Malta					
Netherlands	2405	2381	2389	2199	3473
Poland	36779	41987	41719	44736	24298
Portugal	-2863	-7978	-10172	-7862	-16399
Romania	-64512	-64253	-62733	-50077	-50521
Slovakia	-2518	-1272	498	561	416
Slovenia	-5564	-5773	-6047	-6035	-3655
Spain	-27850	-29702	-30145	-31454	-22760
Sweden	-21113	-29831	-35718	-33976	-27613
United Kingdom	-13897	-16109	-15235	-15377	-9067
SUM	-246614	-254974	-254607	-223188	-173269

4.1.2. Single land use activities

Figure 11 summarises the results of the baseline projection for LULUCF for EU-27 for the considered land use activities. Deforestation emissions will slowly decrease until 2030. While emissions and removals from cropland and grassland management will stay relatively stable, the sink of managed forests is going to decline quickly (to about 50% in 2030 compared to 2010). The decline in CO₂ removals from forest management is partly compensated by an increasing CO₂ sink of new forests. However, in 2030 forest management will still be the dominating term in Europe's LULUCF carbon budget.

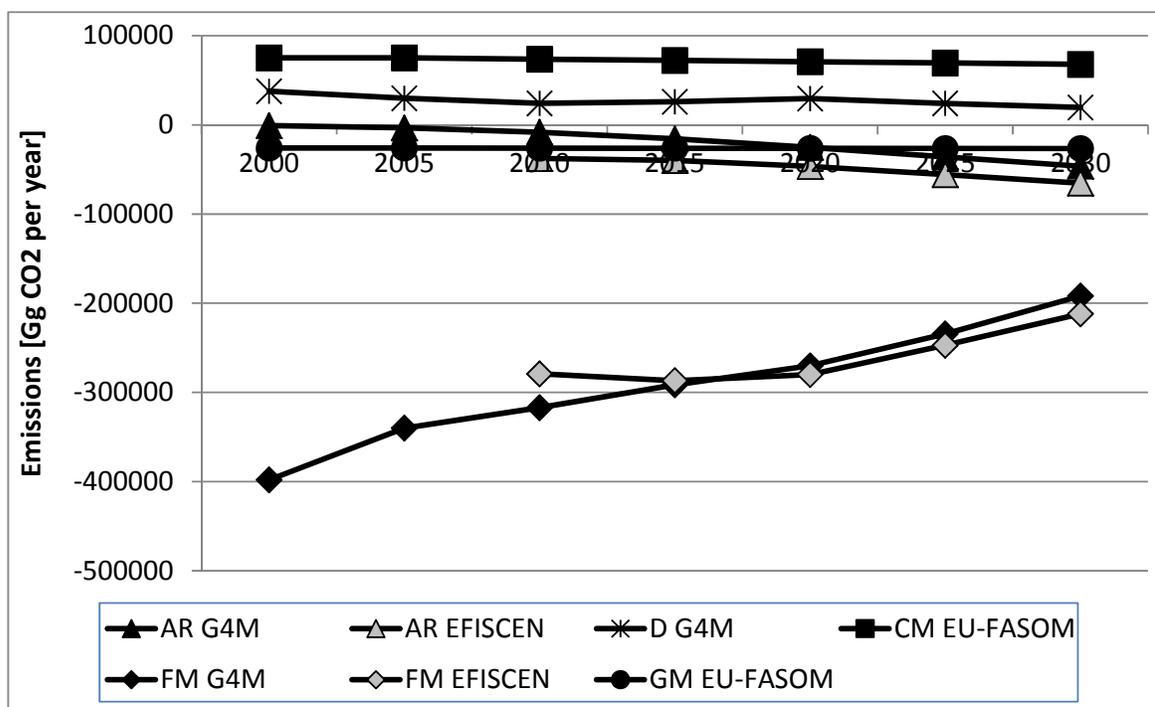


Figure 11: Projected development of emissions and removals by the different models in EU-27 for different LULUCF activities in the baseline scenario. Annual values are available in the database. For simplicity only five year steps are shown here. Sums do not include values of Cyprus, Malta and Greece in order to make numbers comparable among models (EFISCEN does not include Cyprus, Malta and Greece, G4M does not estimate values for Cyprus and Malta). Values in Gg CO₂ per year. Positive values show sources, negative values sinks of CO₂.

Table 15 provides a detailed split-up of emissions by land use activities as estimated by models and reported by countries. Where data from models and UNFCCC overlap, differences to reported cropland and grassland emissions are very small. This is due to a calibration to past emissions applied for these activities. In less agreement are the data for forestry. The negative forest management emissions (CO₂ sink) are supposed to be 25% smaller in the model estimate compared to reported data. Deforestation emissions, on the contrary are lower in reported data by a similar order of magnitude. Rather large differences occur for emissions from afforestation activities. For the year 2005 reported data differ from modelled by a factor of ten (in the case of G4M) and four (in the case of EFISCEN). Also the difference between the models is largest for this activity, e.g. compared to a relatively good model agreement for forest management.

There are several reasons for the differences between modelled and reported data. Reported data are estimated by EU Member States in very different ways. Methods differ between countries and approaches and also pools. Further, not all countries report all pools. This leads to gaps in the accounting and affects of course the total emissions at country and EU level. To the degree possible the reported data were harmonised by the JRC. Nevertheless differences occur naturally. Both, modelled data and reported data are uncertain. Uncertainty in reported data is about 35% (JRC analysis). A similar order of magnitude can be assumed for the uncertainty of model projections. This includes uncertainty of parameters entering the model. Driver uncertainty can be much larger as the model moves further into the future. This is mainly due to the uncertainty of economic projections that drive activities and markets in the LULUCF sector.

Some countries (implicitly or explicitly) include emissions from disturbances in their reports. Disturbances (like fire and storm events) are not included in the model tools. Emission data from countries where e.g. forest fires are an important source of emissions, modelled and reported data cannot be compared easily.

Table 15: Results of the baseline projection for LULUCF for EU27 for the different activities considered. Sums do not include values of Cyprus, Malta and Greece in order to make numbers comparable among models (EFISCEN does not include Cyprus, Malta and Greece, G4M does not estimate values for Cyprus and Malta). Values in Gg CO₂ per year. Positive values show sources, negative values sinks of CO₂.

Activity, model	2005	2010	2015	2020	2025	2030
Forest management						
G4M	-339953	-317113	-291505	-270091	-234387	-191888
EFISCEN		-279225	-286850	-279965	-247109	-211929
Reported	-374709					
Afforestation						
G4M	-3237	-8235	-15696	-25150	-35878	-46311
EFISCEN		-37597	-39830	-46561	-55765	-65294
Reported	-38052					
Deforestation						
G4M	29843	24089	25971	29507	24047	19563
Reported	21790					
Cropland management						
EU-FASOM	79226	77905	76584	75263	73941	72620
Reported	74480					
Grassland management						
EU-FASOM	-25943	-26055	-26167	-26278	-26390	-26502
Reported	-26849					
Total LULUCF						
G4M, EUFASOM	-260064	-249409	-281230	-265735	-246218	-218637
EFISCEN, G4M, EUFASOM		-240883	-250291	-248034	-231275	-211543

4.2. Reference scenario

The most relevant changes in the reference run compared to the baseline for LULUCF are related to bioenergy production. The PRIMES reference scenario projects a higher production of bioenergy from waste and woody energy crops. Also forestry biomass is increasing through increased fellings and use of

residues. The effect on the LULUCF CO₂ emissions and removals can be observed in Figure 12. The reference scenario leads to a smaller sink of LULUCF in EU27 compared to the baseline. However, the effect is rather small and by the year 2030 only observable by comparing the accumulated emissions and removals as the annual emissions and removals in 2030 are the same for baseline and reference. Differences between baseline and reference are most pronounced for forest management activities.

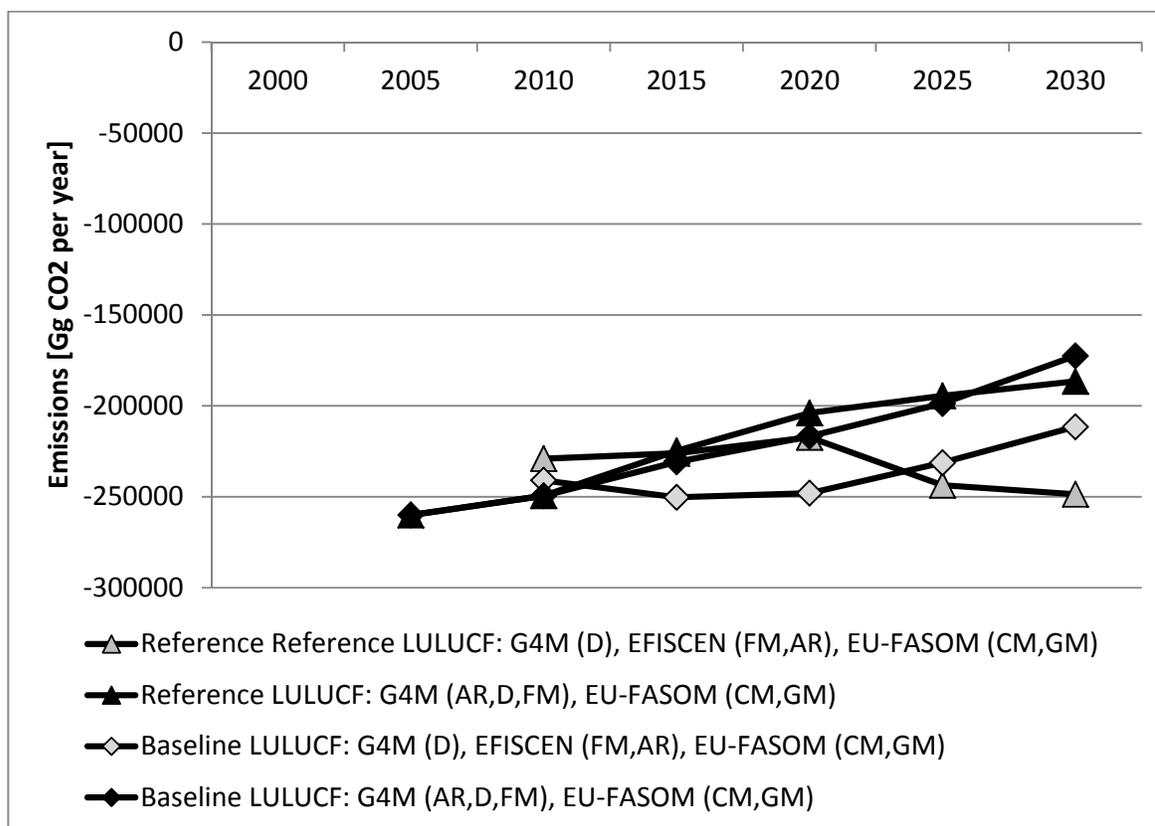


Figure 12: Projected development of emissions and removals in EU-27 for total LULUCF in the baseline and reference scenario by different model result combinations. Sums do not include values of Cyprus, Malta and Greece in order to make numbers comparable among models (EFISCEN does not include Cyprus, Malta and Greece, G4M does not estimate values for Cyprus and Malta).

Table 16: Total LULUCF emissions and removals under the reference scenario projection at country level as projected by different model combinations. Left side of the table: G4M (AR, D, FM) and EUFASOM (CM and GM). Right side of the table: EFISCEN (AR, FM), G4M (D) plus EUFASOM (CM and GM).

	G4M, EUFASOM					EFISCEN, G4M, EUFASOM				
	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030
Austria	-21523	-18206	-16127	-15120	-14386	-7963	-8925	-9889	-11641	-11022
Belgium	-502	139	275	265	641	-637	-980	-1156	-469	215
Bulgaria	-15624	-16273	-16842	-16703	-15214	-11056	-10964	-9900	-10595	-9665
Cyprus	59	3516	5418	4010	2851					
Czech Rep.	6988	7373	9556	11316	11711	7642	7428	8670	9196	9338
Denmark	663	1489	1749	1791	1886	2277	2776	2852	2401	2214
Estonia	1516	1975	1551	1796	1625	-1802	-356	457	1476	1780
Finland	-19793	-18103	-16064	-14219	-11459	-19355	-18190	-15253	-13655	-12301

	G4M, EUFASOM					EFISCEN, G4M, EUFASOM				
	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030
France	-50827	-48376	-43510	-39961	-43124	-45182	-44200	-39045	-38594	-40005
Germany	17605	13889	11488	12862	17536	14459	868	-8744	-2363	3627
Greece	-4095	-4493	-4876	-5034	-4941					
Hungary	17315	19349	23486	19543	14273	18596	21836	26627	21205	15330
Ireland	23976	25642	28919	23118	18195	25045	26611	30470	24419	20678
Italy	-35868	-30146	-23924	-26891	-28457	-41839	-27088	-14103	-16322	-16593
Latvia	-3570	-1733	-500	-45	315	-5316	-3179	-1315	-1086	-963
Lithuania	-2832	-3010	-3251	-2273	-1322	-2709	-2587	-2687	-1037	267
Luxembourg	-968	-941	-773	-460	-365	-644	-667	-679	-615	-522
Malta	0	0	0	0	0					
Netherlands	2476	2760	2939	3112	3087	2503	2601	2696	2818	2963
Poland	9772	8418	2780	8674	12780	35012	33659	28661	33611	35165
Portugal	-13780	-15619	-18561	-19729	-20700	-3908	-6742	-9158	-8246	-7631
Romania	-70384	-64568	-58843	-48337	-56298	-65350	-64791	-62430	-53047	-61864
Slovakia	-2059	-1631	-1015	-857	-713	-2585	-1584	59	-248	-226
Slovenia	-6719	-4960	-4274	-3726	-3204	-5268	-5122	-4974	-5275	-5401
Spain	-16562	-12741	-8364	-6016	-6185	-18018	-12668	-9736	-27224	-27722
Sweden	-29198	-33153	-37638	-37748	-36697	-24880	-34803	-42377	-43769	-46855
UK	-12044	-10741	-9590	-9296	-9094	-12928	-13627	-12370	-13197	-12808
SUM	-225977	-200143	-175989	-159930	-167261	-163908	-160692	-143325	-152256	-162001

4.3. Forest management

4.3.1. Model comparison

This report puts a special emphasis on forest management activities as they contribute to a large degree to the LULUCF CO₂ budget, the projection for forest management is supposed to be rather dynamic compared to other activities, and results of two different models can be used to compare these dynamics and to explore uncertainties.

Figure 13 presents (as an example) a comparison of the EU27 forest management CO₂ sink reported by EU Member States between 1990 and 2009 and projections of the two forestry models applied in this study for the two scenarios applied. Both models suggest a substantial decrease of the forest sink in EU27 in 2030 compared to 2010 by about 20-50%.

The G4M model provides data for the time period 2000-2009 for which also reported data exist. The EFISCEN model has no overlap with reported data for some EU Member States, due to the use of recent NFI data. It is striking that the average sink estimated by the model for 2000 to 2009 is about 80% of the forest management sink reported by EU Member States in the same time frame. Further, the reported data show hardly any trend during the period, while the models suggest a rapid decline of the sink. Modelled and reported data have very different origins; therefore a comparison has to be interpreted with care. Between countries the methods in countries to estimate emissions and removals differ a lot. While some countries apply complex tools and can build their estimates on detailed empirical data bases, other countries lack specific data and derive estimates more indirectly. Such a comparison should therefore be done on a case by case basis and by comparing details of assumptions and boundary conditions. It is obvious that a consistent method (as applied in this study by using two harmonised forestry models) cannot reproduce results of different individual country approaches.

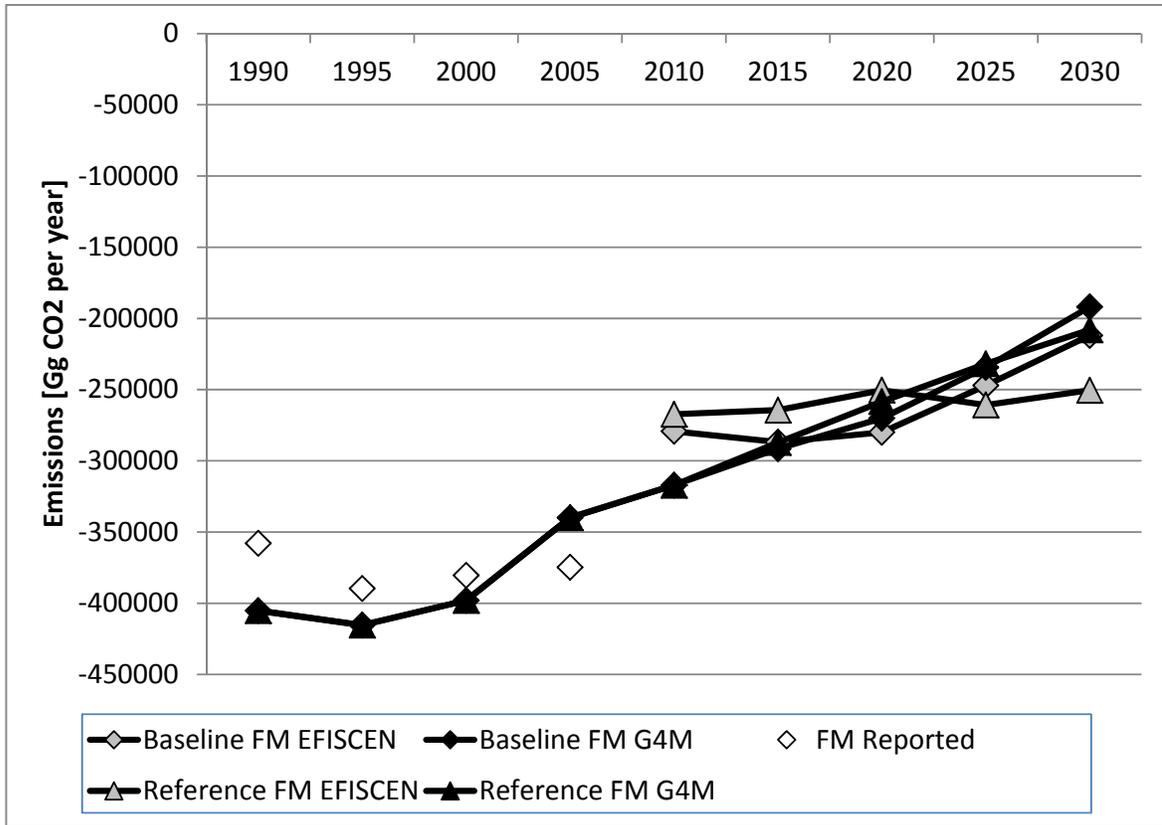


Figure 13: Comparison of model baseline results to UNFCCC reported data showing most recent (end of 2010) submissions by countries, collected by JRC for forest management activities. Explanations of differences and interpretation are given in the text. Sums do not include values of Cyprus, Malta and Greece in order to make numbers comparable among models (EFISCEN does not include Cyprus, Malta and Greece, G4M does not estimate values for Cyprus and Malta).

Figure 13 further reveals that the difference between the two models is, despite their different approaches, not very large, given the variability of reported data for different submissions (countries revised their estimates over the course of the last years resulting in significant changes of reported emissions). The similarity between the models is especially observed for the trend of future emissions from forest management. Despite the similar trend, projections still differ by about 40 Gg CO₂ by 2030.

There are various reasons for differences between the models. For example, rotation lengths in EFISCEN are based on national recommendations, whereas they are estimated in G4M. Also the distribution of harvest over thinning and final fellings is different between the models. Schelhaas et al. (2007b) showed that it is possible to increase the European forest sink substantially if longer rotations are applied and/or more wood is harvested from thinning, without compromising the total harvest level. Another difference is due to the datasets used by the models. For example, EFISCEN uses increment functions derived from NFIs. Whereas G4M uses forest NPP calibrated with increment NAI data from MCPFE (2007). This can lead to different growth rates, as shown in the projections of NAI by the two models (Table 17).

But also harvest routine in the models differs and may lead to different interpretations of the prescribed wood production projection by GLOBIOM. Table 18 shows total wood removals realised in EFISCEN and G4M compared to projected wood production by GLOBIOM in percent. Hardly any year the exact number prescribed by GLOBIOM is harvested. This is due to the spatial (grid cell) resolution of G4M

and age class widths used in EFISCEN that do not allow a perfect match. These deviations are rather small (about 10%). However, on average over the simulation time the GLOBIOM prescribed harvest is realised for most countries. In some cases (Czech Republic, Ireland, Italy, Latvia, Slovakia and UK) both models show an undersupply of wood, where obviously the GLOBIOM prescribed wood could not be harvested within the country borders and the simulated time frame. There is a mismatch between the forestry models G4M and EFISCEN for Belgium, where G4M harvest volumes are considerable higher compared to EFISCEN results. These differences are partly because of differences in harvest execution algorithms but also remaining inconsistencies that should be addressed in future updates of the data.

The bioenergy production estimated by PRIMES was used to generate a reference scenario that is characterised by slightly increased domestic wood production, according to the PRIMES model. Consequently, the effects on forest management emissions and removals are rather small, compared to the baseline (see Figure 13). However, the two models react differently and reveal different levels of sensitivity (to be assessed further in the next section). This holds for the magnitude of the effect of the reference scenario on the forestry sink and also the timing.

Table 17: Net annual increment rates as projected by EFISCEN and G4M ($\text{m}^3 \text{ha}^{-1} \text{yr}^{-1}$).

Country	EFISCEN					G4M				
	2000	2005	2010	2020	2030	2000	2005	2010	2020	2030
Austria		7.7	8.1	8.4	8.3	11.7	11.8	11.4	10.3	9.3
Belgium	8.5	8.8	9.2	9.0	8.7	11.1	9.5	9.2	8.6	8.6
Bulgaria		4.5	4.5	4.5	4.4	5.9	6.0	6.0	5.7	5.1
Cyprus						1.5	1.4	1.5	1.6	1.5
Czech Republic			9.1	9.3	9.3	10.8	10.7	10.6	10.2	9.8
Denmark		8.9	9.8	11.0	11.6	14.1	14.8	14.9	14.1	12.6
Estonia		5.6	5.3	5.1	4.9	5.6	5.6	5.5	5.4	5.4
Finland			4.9	5.2	5.3	4.9	5.1	5.2	5.2	5.1
France	6.4	7.0	7.3	7.3	7.0	7.9	8.0	7.9	7.3	6.8
Germany		10.7	11.3	11.5	11.3	11.9	11.8	11.6	11.0	10.4
Greece						1.4	1.4	1.4	1.4	1.4
Hungary			6.7	6.9	6.8	6.1	6.3	6.5	6.6	6.5
Ireland			9.2	10.9	9.7	9.3	9.7	9.9	10.2	9.9
Italy			4.9	4.6	4.3	4.6	4.5	4.3	4.0	3.7
Latvia			6.2	6.0	5.6	6.6	6.6	6.6	6.4	6.0
Lithuania		5.7	5.6	5.3	5.0	7.1	7.1	7.0	6.5	6.0
Luxembourg	11.0	11.0	11.2	11.5	10.4	9.7	10.0	10.2	8.9	6.5
Malta										
Netherlands			8.1	8.1	8.0	8.5	7.6	7.1	6.1	5.4
Poland	5.0	5.0	5.2	4.9	4.7	9.4	9.2	8.8	8.1	7.4
Portugal	4.1	4.0	3.9	4.1	4.1	5.8	6.5	7.1	7.9	8.1
Romania	7.5	7.4	7.4	7.4	6.7	9.8	9.8	9.2	7.9	6.9
Slovakia	6.7	6.5	6.5	6.1	6.4	7.7	7.5	7.3	7.0	6.7
Slovenia	6.3	6.3	6.4	6.4	6.4	8.5	8.4	8.1	7.4	6.5
Spain	2.3	2.6	2.7	2.7	2.7	2.6	2.8	2.9	3.3	3.4
Sweden			4.8	5.2	5.4	5.1	5.2	5.4	5.5	5.4
United Kingdom	7.7	8.1	8.6	8.7	8.1	8.5	8.6	8.6	8.3	7.6

Table 18: Total wood removals realised in EFISCEN and G4M on FM area compared to projected wood production by GLOBIOM in percent. for the baseline scenario.

Country	EFISCEN*				G4M			
	2005	2010	2020	2030	2005	2010	2020	2030
Austria	100%	100%	100%	100%	99%	100%	101%	101%
Belgium	100%	100%	100%	100%	99%	98%	101%	98%
Bulgaria	100%	100%	100%	100%	99%	102%	109%	98%
Cyprus					138%	100%	88%	81%
Czech Republic		100%	100%	100%	102%	99%	99%	98%
Denmark	100%	100%	100%	100%	101%	99%	100%	100%
Estonia	100%	100%	100%	100%	100%	99%	98%	98%
Finland		100%	100%	100%	99%	99%	99%	99%
France	100%	100%	100%	100%	100%	98%	98%	98%
Germany	100%	100%	100%	100%	98%	101%	102%	102%
Greece					100%	94%	79%	73%
Hungary		100%	100%	100%	101%	99%	100%	98%
Ireland		100%	100%	93%	93%	87%	100%	92%
Italy		100%	100%	100%	101%	99%	99%	99%
Latvia		100%	100%	99%	100%	100%	100%	99%
Lithuania	100%	100%	100%	100%	100%	101%	101%	99%
Luxembourg	100%	100%	100%	100%	124%	120%	213%	93%
Malta								
Netherlands		100%	100%	100%	98%	95%	97%	101%
Poland	100%	100%	100%	100%	99%	99%	102%	99%
Portugal	100%	100%	100%	100%	101%	101%	102%	100%
Romania	100%	100%	100%	100%	99%	102%	102%	101%
Slovakia	100%	100%	100%	100%	100%	101%	100%	99%
Slovenia	100%	100%	100%	100%	97%	102%	101%	100%
Spain	100%	100%	100%	100%	99%	102%	100%	102%
Sweden		100%	100%	100%	98%	101%	101%	99%
United Kingdom	100%	100%	100%	90%	99%	99%	99%	99%

* Wood removals are prioritised by EFISCEN on FM area. If wood removals are less than the wood production according to GLOBIOM, the remaining removals are allocated to AR area.

4.3.2. Emission from forest soils

Emissions or removals from forest soils have been estimated by EFISCEN and its soil module YASSO. The emission/removals by forest soils represent include the following pools: dead organic matter (incl. litter and lying deadwood, excl. standing deadwood), mineral soils and organic soils (for Finland organic soils have been excluded, based on country consultations). The results of the baseline projection are summarised in Figure 14 and Table 19 for EU-27 excluding Cyprus, Greece and Malta (due to lack of suitable forest inventory data). Projections are available for all countries from 2015 onwards, due to the use of recent forest inventory data and initialisation of the soil carbon stock within EFISCEN/YASSO.

The sink in forest soils for FM activities is about 14% of the sink in forest biomass in 2015. However, the development of the sinks in biomass and soil is different; whereas the sink in forest biomass for FM

activities is projected to decline, the sink for forest soils is projected to increase. This is due to (1) increasing wood harvests, which leads to more litter (harvest losses, branches, foliage, stumps, roots) entering the soil, and (2) increasing stocks of forest biomass, which leads to enhanced natural litter production (branches, foliage, stumps, roots).

Table 19: Projected development of emissions and removals from forest soils by EFISCEN and its soils module YASSO in EU-27 (excl. Cyprus, Greece and Malta) for Forest Management (FM) and Afforestation/Reforestation (AR) activities in the baseline scenario. Values in Gg CO₂ per year. Positive values show sources, negative values sinks of CO₂.

Country	2005	2010	2015	2020	2025	2030
Austria		-224	-436	-874	-1768	-1940
Belgium	-314	-175	-274	-368	-561	-560
Bulgaria		188	-290	-661	-829	-938
Czech Republic			-237	-755	-1188	-1078
Cyprus		-860	-1167	-1280	-1128	-1218
Denmark		-1322	-1576	-1420	-669	-409
Estonia			-9331	-11742	-11583	-12125
Finland*	447	-5153	-6250	-7498	-8034	-7535
France		1478	-147	-3743	-6061	-8013
Germany			-388	-514	-425	-578
Greece			-472	-350	-650	-480
Hungary			-3282	-4964	-6202	-6311
Ireland			-1603	-1916	-1969	-1260
Italy		-1137	-787	-882	-980	-1159
Latvia	-82	-96	-99	-115	-118	-110
Lithuania			-292	-363	-541	-578
Luxembourg		-224	-436	-874	-1768	-1940
Malta	-314	-175	-274	-368	-561	-560
Netherlands		188	-290	-661	-829	-938
Poland	-2997	192	1059	831	-658	-244
Portugal	-1664	692	-52	-1205	-2555	-2613
Romania	-10250	-8890	-8786	-8678	-8341	-8249
Slovakia	-2212	-1749	-1611	-1258	-1314	-897
Slovenia	-653	-557	-657	-802	-970	-998
Spain	-3476	-4952	-6050	-5725	-6968	-6982
Sweden			-7414	-9997	-12507	-14591
United Kingdom	-2788	-763	-2073	-1832	-2313	-2159
SUM			-52214	-66112	-78332	-81024

*EFISCEN projections for Finland only refer to emissions from mineral soils, based on country consultations. Organic soils are excluded from the analysis.

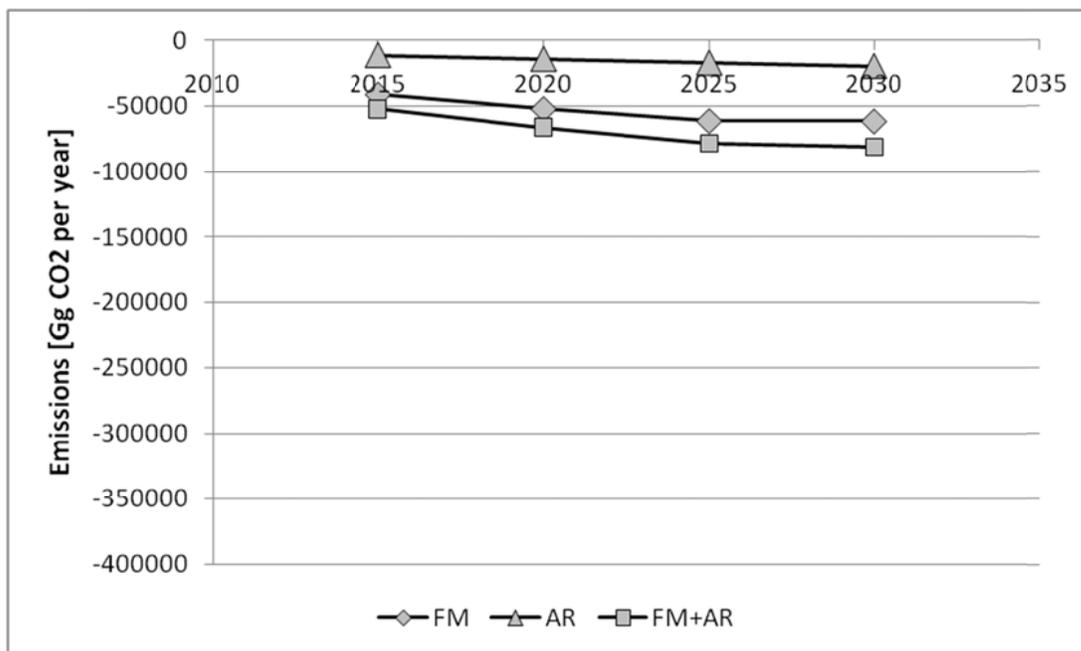


Figure 14: Projected development of emissions and removals from forest soils by EFISCEN and its soils module YASSO in EU-27 (excl. Cyprus, Greece and Malta) for Forest management (FM) and Afforestation/Reforestation (AR) activities in the baseline scenario. Values in Gg CO₂ per year. Positive values show sources, negative values sinks of CO₂.

A full comparison of EFISCEN/YASSO projections with reported data by member states is not possible, because (1) estimates are not available from EFISCEN/YASSO for all member states for 2005, and (2) not all member states reported data for all pools (dead organic matter, mineral soils and organic soils). Reported and estimated emissions/removals are likely to deviate substantially due to different methods and data that are applied to estimate emission/removals from these pools.

The increase of the sink in forest soils for FM activities is stronger for the reference scenario as compared to the baseline scenario until 2020 (Table 20). This is because more wood is harvested, leading to more input to the soil. However, less wood is harvested in the reference scenario in later time-steps, which result in a smaller soil sink in 2025 and 2030.

Table 20: Projected development of emissions and removals from forest soils by EFISCEN and its soils module YASSO in EU-27 (excl. Cyprus, Greece and Malta) for Forest Management (FM) activities only in the baseline scenario. Values in Gg CO₂ per year. Positive values show sources, negative values sinks of CO₂.

Scenario	2015	2020	2025	2030
Baseline	-40853	-51868	-61121	-61380
Reference	-44123	-54313	-50881	-56855

4.4. Sensitivity analysis

To explore sensitivities of the forestry models further, a systematic sensitivity analysis was carried out by

feeding both models with two additional scenarios of wood demand, being 1) 10% higher and 2) 10% lower compared to the baseline. The effects on the projected forest sink are displayed in Figure 15. It is striking that the two models react with different sensitivities. While a 10% reduction of harvest levels increases the sink by more than 30% in EFISCEN compared to the baseline, G4M produces a moderate shift by about 20%. The same applies for an increase in harvest levels.

The sensitivity of the projected sink in both models is not symmetrical over the entire period. Especially in the years 2020 to 2030 the reduction effect of increased harvest is less than the increase effect of decreased harvest.

The scenario case of constant harvest rates from 2000 to 2030 reveals the different drivers of the decreasing sink. Despite constant harvest rates the sink further diminishes in both models (less pronounced in EFISCEN) indicating the role of forest aging.

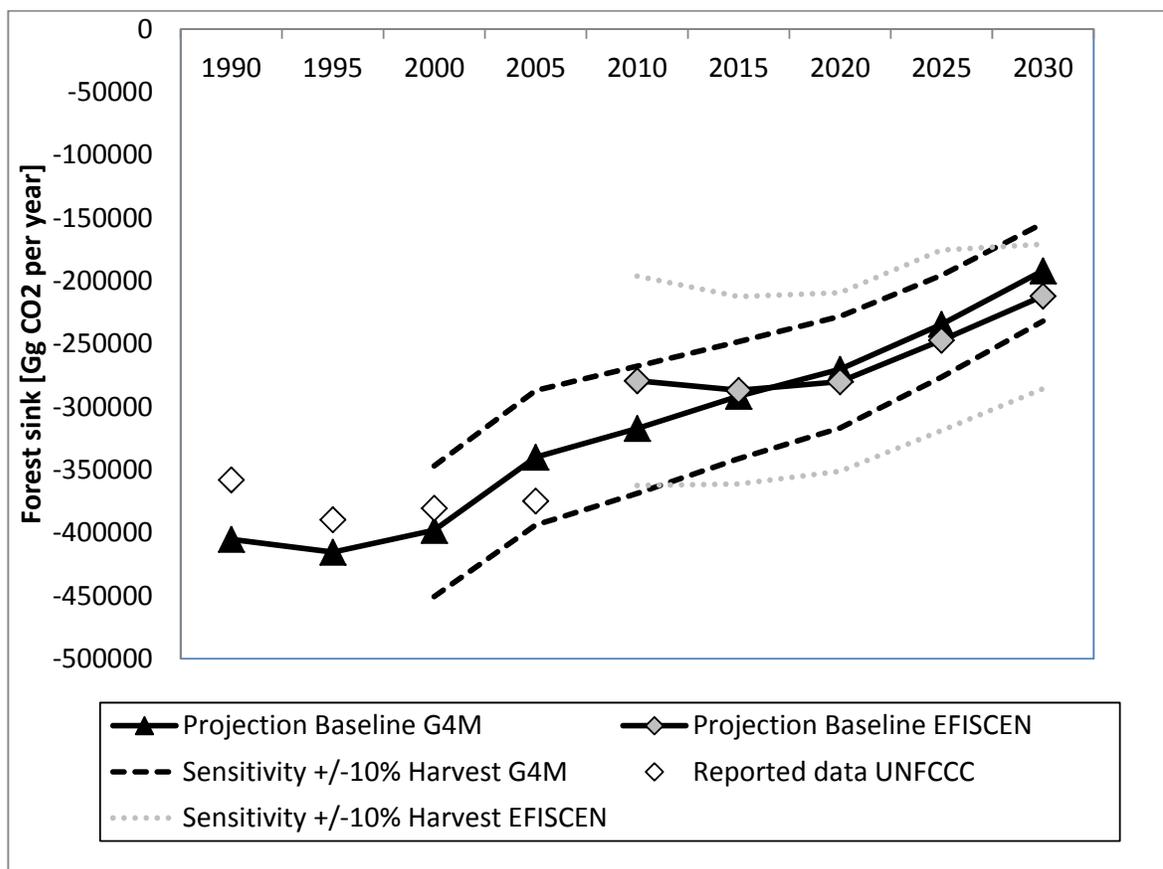


Figure 15: Projection of baseline emissions and removals of forest management activities for EU27 and estimates of 10% higher and lower total wood demand compared to the baseline. A third scenario prescribes constant harvest rates. Sums do not include values of Cyprus, Malta and Greece in order to make numbers comparable among models (EFISCEN does not include Cyprus, Malta and Greece; G4M does not estimate values for Cyprus and Malta).

The sensitivity analysis gives also an indication of the effect of underlying uncertainties. The projection of future harvest is highly uncertain and depends on many parameters that cannot be modelled explicitly. However, the sensitivity analysis shows the likely effects of changes in the driver wood demand. It also shows that both models produce robust results

4.5. Abatement cost curves

Based on the baseline projection for the 27 EU Member States, the models G4M and EUFASOM were used to estimate the potential for emission abatement and sink enhancement as well as associated costs. These were assessed for the years 2020 and 2030. The models cover abatement potential of afforestation, avoided deforestation and forest management (G4M) and cropland management (EUFASOM).

Figure 16 and Figure 17 present the abatement cost curves for different land use activities for the year 2020 and 2030, respectively. The curves show additional removals and reduced emissions compared to the baseline in the respective year in the presence of a carbon price.

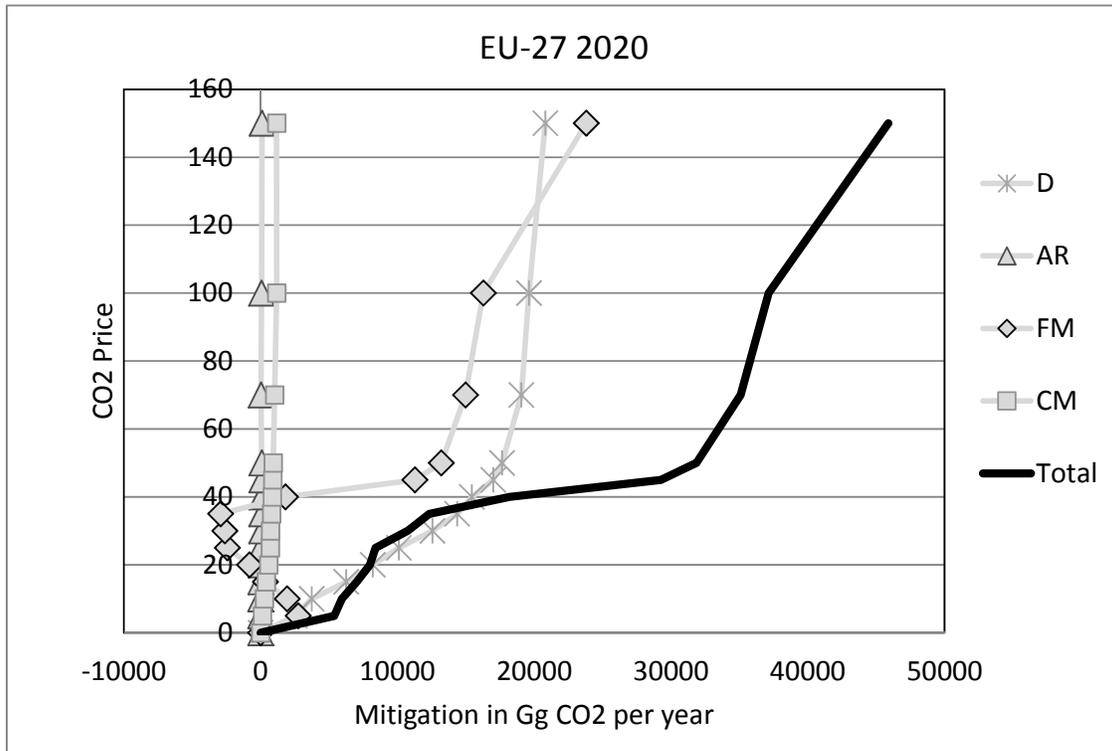


Figure 16: Abatement cost curves for different land use activities for the year 2020. AR, D and FM curves were produced by G4M, CM by EUFASOM. Sums include all 27 EU countries. Values of forestry activities for Cyprus and Malta were not estimated and set to zero.

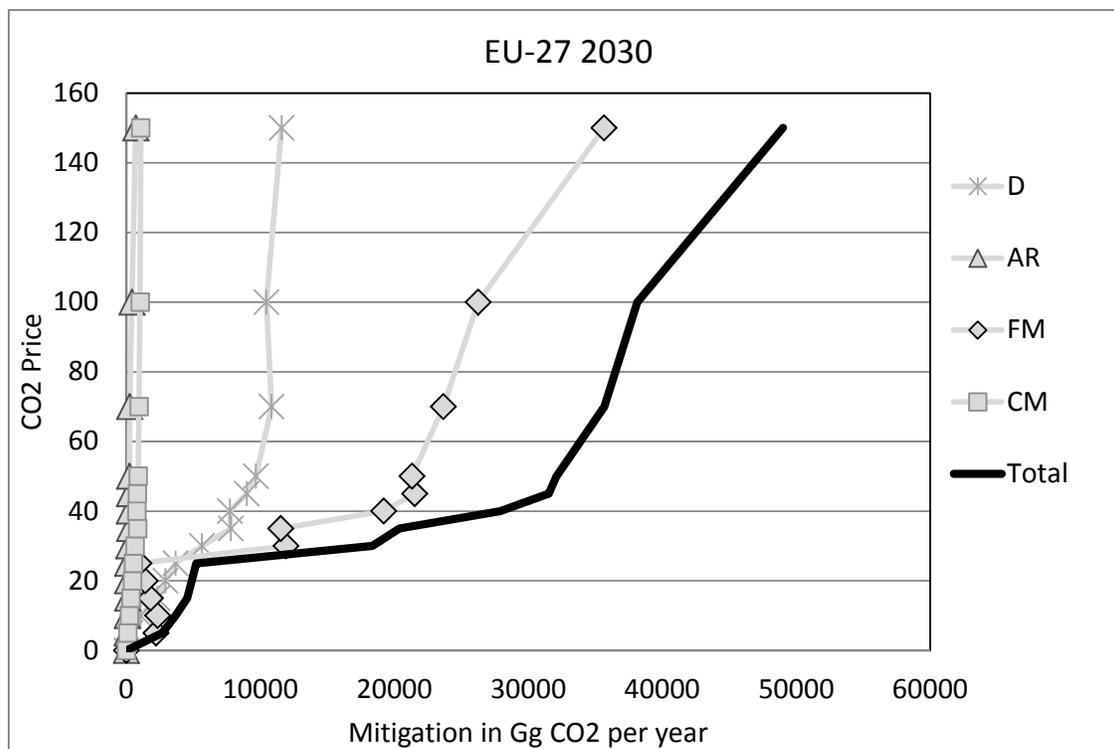


Figure 17: Abatement cost curves for different land use activities for the year 2030. AR, D and FM curves were produced by G4M, CM by EUFASOM. Sums include all 27 EU countries. Values of forestry activities for Cyprus and Malta were not estimated and set to zero.

Table 21: Abatement potential in Gg CO₂ for total LULUCF (FM, AR, D, CM) for different countries in the year 2020. AR, D and FM curves were produced by G4M, CM by EUFASOM. Values of forestry activities for Cyprus and Malta were not estimated.

Country	Marginal costs in EUR per tonne of CO ₂							
	5	10	15	30	50	70	100	150
Austria	0	0	0	202	202	202	202	787
Belgium	0	0	0	136	136	136	217	1488
Bulgaria	1276	1276	1276	2390	2760	3510	3510	3648
Cyprus	0	0	0	0	0	0	0	0
Czech Rep.	331	363	378	378	378	378	378	378
Denmark	55	55	58	110	111	111	115	212
Estonia	735	735	735	854	1205	1205	2270	2270
Finland	1339	1339	1941	2279	2279	2279	2887	2887
France	262	262	636	636	978	978	978	3644
Germany	0	0	0	545	545	545	545	1928
Greece	0	0	0	0	0	0	0	7
Hungary	55	55	55	358	517	541	541	553
Ireland	0	0	0	0	0	12	12	14
Italy	480	480	480	480	1208	1550	1550	2024
Latvia	225	273	323	323	385	407	407	407
Lithuania	187	187	187	187	280	280	280	289
Luxembourg	0	0	0	0	0	0	0	0
Malta	0	0	0	0	0	0	0	0

Country	Marginal costs in EUR per tonne of CO ₂							
	5	10	15	30	50	70	100	150
Netherlands	0	0	0	0	0	0	0	63
Poland	0	0	24	232	1334	2178	2178	3250
Portugal	41	41	41	149	152	392	501	501
Romania	8	486	486	486	486	979	979	1522
Slovakia	193	193	193	288	357	852	861	1050
Slovenia	0	0	0	0	93	93	93	330
Spain	86	86	86	86	452	452	452	452
Sweden	0	0	15	389	17762	17762	17762	17762
UK	116	116	116	234	248	248	428	428
SUM	5387	5945	7030	10742	31868	35090	37145	45891

Table 22: Abatement potential in Gg CO₂ for total LULUCF (FM, AR, D, CM) for different countries in the year 2030 in percent AR, D and FM curves were produced by G4M, CM by EUFASOM. Values of forestry activities for Cyprus and Malta were not estimated.

Country	Marginal costs in EUR per tonne of CO ₂							
	5	10	15	30	50	70	100	150
Austria	0	0	0	43	46	529	529	729
Belgium	0	0	0	16	16	33	33	1386
Bulgaria	813	1165	1492	2328	2531	3019	3019	3044
Cyprus	1	1	1	2	2	1	1	1
Czech Rep.	346	346	346	448	451	451	451	451
Denmark	0	0	0	103	103	103	103	238
Estonia	491	491	491	491	1070	1070	1872	2015
Finland	63	63	172	1557	2000	2000	2004	2868
France	135	135	135	1836	2197	2998	3393	8728
Germany	1386	1386	1386	1386	1386	1417	1950	1950
Greece	0	0	0	0	0	0	0	4
Hungary	4	30	85	298	522	753	784	837
Ireland	0	0	0	7	7	125	162	171
Italy	241	241	241	241	773	1257	2037	2983
Latvia	294	294	294	609	625	670	670	670
Lithuania	0	77	77	77	103	103	170	170
Luxembourg	0	0	0	0	0	0	0	0
Malta	0	0	0	0	0	0	0	0
Netherlands	32	32	32	32	32	32	32	32
Poland	0	528	721	721	1942	1942	1942	2931
Portugal	2	2	2	31	33	53	53	64
Romania	10	20	90	156	1137	1137	1137	1137
Slovakia	223	223	223	223	318	774	789	789
Slovenia	0	0	0	53	74	384	431	793
Spain	0	0	0	0	0	0	0	0
Sweden	0	8	118	8732	17708	17708	17708	17897
UK	13	13	13	355	413	537	823	1070
SUM	4055	5055	5920	19745	33491	37098	40094	50960

Table 23: Abatement potential in Gg CO₂ for total LULUCF (FM discounted by 85%, AR, D, CM) for different countries in the year 2020. AR, D and FM curves were produced by G4M, CM by EUFASOM. Values of forestry activities for Cyprus and Malta were not estimated.

Country	Marginal costs in EUR per tonne of CO ₂							
	5	10	15	30	50	70	100	150
Austria	0	0	0	11	11	11	11	135
Belgium	0	0	0	10	10	10	22	220
Bulgaria	1463	2135	2974	5168	5224	5336	5336	5357
Cyprus	0	0	0	0	0	0	0	0
Czech Rep.	48	64	65	183	451	483	501	501
Denmark	7	7	7	14	14	17	17	150
Estonia	636	636	636	636	659	659	792	841
Finland	200	200	289	332	332	332	446	446
France	0	0	0	0	0	0	0	477
Germany	0	0	0	45	45	45	45	306
Greece	0	0	0	0	0	0	0	7
Hungary	0	0	136	922	1552	1552	1552	1590
Ireland	0	0	0	0	0	11	11	12
Italy	148	148	148	148	225	269	269	397
Latvia	111	194	369	376	389	392	392	392
Lithuania	191	220	220	220	223	223	223	242
Luxembourg	0	0	0	0	0	0	0	0
Malta	0	0	0	0	0	0	0	0
Netherlands	0	0	0	0	0	0	0	8
Poland	0	232	1275	3545	5108	5231	5231	5432
Portugal	6	6	6	21	21	57	73	73
Romania	1	72	72	266	1729	2486	2486	2568
Slovakia	25	25	43	111	206	283	284	341
Slovenia	0	0	0	0	93	115	126	172
Spain	1	1	1	1	15	15	15	59
Sweden	0	0	0	48	2618	2618	2618	3476
UK	1	1	1	1	1	55	160	300
SUM	2839	3942	6243	12060	18926	20201	20611	23503

Afforestation rates in EU in the near future are estimated to be already quite high, additional afforestation removals rather low. This is in part due to the methodology employed. We used reported data to calibrate the model G4M to reproduce past rates of afforestation implicitly assuming the continuation of historical support measures. Given the high reference afforestation (in terms of area) this leads to a situation where even high carbon prices do not trigger additional afforestation. Additional afforestation is programmed to start in 2010. Carbon mitigation through afforestation is supposed to have a potential that is realized only after some time, the trees take to grow and reach a high level of productivity. Therefore, in the short run (looking at 2020 and 2030), in some countries even a price of 50 EUR per t CO₂ does not induce additional afforestation removals. By the years 2020 and 2030, at maximum 10 and 20 years after implementation, afforested areas are still relatively weak sinks. Longer term projections (until 2050) will very likely show a much higher potential at similar carbon price levels, simply due to the increasing productivity of newly planted forests.

Moreover, the assumptions on the afforestation contract matters and how payments are done. Here we assume that a land owner is paid once a lump-sum compensation that sums the discounted carbon

accumulation over time. In addition, we assume permanence to achieve consistency with the permanence of mitigation in the energy sector. The owner has to keep the carbon stock forever. In fact this is not a very attractive model to implement afforestation. Issuing temporary credits would probably mobilize more afforestation. As discussed in the baseline: we apply rather conservative (low) growth rates for afforestation mimicking the use of natural vegetation. One could imagine that additional afforestation (trees planted only for carbon sequestration) would use faster growing species on more productive land. This is not considered. In addition, a conservative calculation also accounts for possible disturbances.

The deforestation potential is dominated by Poland, Portugal and Romania where relatively high rates of deforestation can be reduced relatively cheaply. In contrary to afforestation, avoided deforestation mitigation potential is decreasing over time because of decreasing baseline deforestation. This explains the reduction of its relative share of total LULUCF mitigation in 2030 compared to 2020.

It is important to mention that the methodology to estimate cost curves for forest management implies no changes of wood removals. The high potential of forest management often described in the literature is in many cases derived from a change in average rotation length and thus harvest rates (but see Schelhaas et al. 2007b). However, this would have considerable market effects and leakage to surrounding forests is very likely. Here, we assume harvest removals forced to be close to the baseline removals when the carbon price is increasing. This reduces the potential of forest management for a single country that could reduce harvest of domestic forests and import more wood if economically favorable. Assuming that harvest rates will not be affected is realistic and also pragmatic because otherwise mitigation in one country would affect trade with implications for mitigation potential in the countries involved.

The harvest rates remain as in the baseline, however, the geography of harvest changes. The model searches for opportunities to change forest management parameters such as rotation length, amount of wood extracted through thinning etc. in different locations of the forest but secures the prescribed supply of wood. This shifts harvest to more expensive and less productive sites.

It is important to note that CO₂ price was only used to assess changes in forest management practices. An increasing CO₂ price could also lead to investment in new harvesting technology allowing more efficient harvesting (less harvest losses). However, these potential impacts of CO₂ prices were not investigated.

4.6. Uncertainties

4.6.1. Uncertainty of input data and economic drivers

The approach applied in this study is to a large degree data-driven. Hence, the quality of the results presented depends heavily on the quality of the datasets that were used. An effort was made to harmonise data on forest area, basic NFI data (area, age-class structure, growing stock, increment), wood density, biomass expansion factors and wood removals between models and where possible with member states. Harmonisation with datasets used by member states was not possible in all cases and differences between datasets can explain differences in reported and projected emissions and removals. As an example, historical roundwood removals (excl. harvest losses) were used to initialize the forest models and to estimate the future roundwood removals. Comparison of FAOSTAT data on historical wood removals (FAOSTAT 2009) with national statistics included in the EU submission to UNFCCC showed significant differences. For example, for France annual roundwood removals deviated up to 22 million m³ per year (after converting FAOSTAT data from underbark to overbark volume)¹². The sensitivity analysis showed that the projections were rather sensitive to the assumed harvest rates. Hence, such differences can have substantial impacts on the projected CO₂ emissions or removals.

The future roundwood production is based on projections by GLOBIOM and PRIMES. The projection by these two models depends on the same macro-economical developments. Furthermore, it was ensured

¹² FAOSTAT data have been updated afterwards

that GLOBIOM reproduced the same numbers on bioenergy production. However, the development of the forest sector was not harmonized between the models. This could lead to discrepancies in the availability of e.g. black liquor and/or wood waste between GLOBIOM and PRIMES. Further harmonization between PRIMES and GLOBIOM could improve the projections of CO₂ emission or removals by forests.

4.6.2. Model limitations

The GLOBIOM model projected future wood production for the entire EU and it was assumed that production of wood for material use in all EU countries will increase by the same factor. However, the rate is likely to vary between countries (see e.g. Mantau et al. 2010). For some countries “ceilings” on maximum wood removals should be built in to constrain the GLOBIOM model. Current ceilings are based on forest increment, but do not take into account environmental, technical, social and economical constraints that further limit the potential wood supply (see e.g. Verkerk et al. 2011).

The models EFISCEN and G4M have been developed mainly for even-aged forests and application of the models to situations other than even-aged forests should be done with great care. For shorter periods, simulation of increment and growing stock are probably reasonable, but the age-class distribution will be unreliable and this will influence growth rates and growing stocks at the longer term (Schelhaas et al. 2007a).

Finally, the impact of growth changes and large-scale disturbances due to environmental and/or climate change on the estimated CO₂ emissions and removals were not included. It is expected that growth may decrease in Southern Europe due to reduced water availability, whereas growth in Northern regions may increase much more (Lindner et al. 2010). Changes in growth will reflect in changes in future CO₂ removals and emissions (Eggers et al. 2008). In addition, disturbances were also not included in the analysis, but could have an important impact. The impact of growth changes and large-scale disturbances on the development of the LULUCF sector is difficult to model and would require further investigation.

4.6.3. Limits to harmonisation

The use of different models has also certain limitations to harmonisation. These are merely due to the fact that the models use different approaches. This explains differences in, e.g. the increment and forest area data as discussed above. There are more parameters that are essential for projections of forest management and resulting carbon emissions and removals. The rotation length, a sensitive parameter for projecting the carbon balance of managed forests, for example, is implemented in very different ways. G4M calculates the rotation length internally. It is used as calibration parameter to match observed forest removals. Thus it is not a parameter that can be adjusted and harmonised from the outside. EFISCEN instead uses rotation lengths from national recommendations and regulations, which set limits to the amount of wood that can be harvested. The rotation length estimated by the model is depending on the demand for wood: if wood demand is high, rotation lengths are close to the lower limit defined in the management regimes. If wood demand is low, rotation lengths are longer.

5. Conclusions

- The projected LULUCF net CO₂ sink for the EU is expected to decline under the baseline scenario. It is reduced on average by 30% in 2020 compared to 2000.
- Forest management is and will stay the main contributor as a net sink at EU level. It is also the main reason for the decline in the LULUCF sink.
- The drivers explaining the forest management sink decline are, on the one hand, the demand for wood for energy and material use that is projected to increase further in the future and on the other hand, shifts in the age classes towards an older forest structure that lower the strength of forest carbon accumulation.
- The reference scenario that was applied includes the national renewable targets of EU Member States for 2020 to meet the EU target of a share of 20% renewable energy sources in energy consumption in 2020 as well as the 20% reduction in GHG emissions compared to 1990. The effect of this is a further decrease in the LUCUCF sink compared to the baseline.
- The mitigation potential for EU27 countries was estimated to amount to around 20% of baseline emissions in 2020 and some 40% in 2030 compared to the baseline in the same period at costs of 100 EUR per tonne of CO₂.

6. Literature

- Alig, R. J., D. M. Adams and B. A. McCarl, 1998. Impacts of Incorporating Land Exchanges Between Forestry and Agriculture in Sector Models. *Journal of Agricultural and Applied Economics*. 30: 389-401.
- Britz, W. and P. Witzke, 2008. CAPRI model documentation 2008: Version 2.
- Cramer W, Kicklighter D.W, Bondeau A, Moore III B, Churkina G, Nemry B, Ruimy A, Schloss AL, and the participants of the Potsdam NPP Model Intercomparison (1999). Comparing global models of terrestrial net primary productivity (NPP): Overview and key results. *Global Change Biology* 5(S1), 1-15.
- Cramer, W., D. W. Kicklighter, et al. (1999). "Comparing global models of terrestrial net primary productivity (NPP): overview and key results." *Global Change Biology* 5: 1-15.
- Eggers, J., Lindner, M., Zudin, S., Zaehle, S., Liski, J., 2008. Impact of changing wood demand, climate and land use on European forest resources and carbon stocks during the 21st century. *Global Change Biology* 14, 1-16.
- European Commission, Joint Research Centre (JRC), JRC LULUCF tool, version (Nov 2010) http://afoludata.jrc.ec.europa.eu/index.php/models/JRC_LULUCF_TOOL
- FAO (2006). World agriculture: towards 2030/2050. Prospects for food, nutrition, agriculture and major commodity groups. Food and Agriculture Organization of the United Nations, Rome, Italy.
- FAOSTAT (2009). ForesStat. Roundwood production quantity. FAO statistics division, <http://faostat.fao.org/site/626/default.aspx#ancor> (accessed 14.10.2009)
- Franklin, O., E. Moltchanova, M. Obersteiner, F. Kraxner, R. Seidl, H. Böttcher and D. Rokityiansky: A European scale forest growth and thinning model -deducing productivity and stand density from inventory data. *Annals of Forest Science* accepted.
- Gallaun, H., G. Zanchi, et al. (2010). "EU-wide maps of growing stock and above-ground biomass in forests based on remote sensing and field measurements." *Forest Ecology and Management* 260(3): 252-261.
- Gallaun, H., G. Zanchi, G., J. Nabuurs, G -J., Hengeveld, G., M. Schardt, M., and P. J. Verkerk, (in press) P.J., (2010.) EU-wide maps of growing stock and above-ground biomass in forests based on remote sensing and field measurements. *Forest Ecology and Management* 260, 252-261.
- Hansen, M., R.S. DeFries, J.R.G. Townshend, M. Carroll, C. Dimiceli, and R.A. Sohlberg (2003), "Global Percent Tree Cover at a Spatial Resolution of 500 Meters: First Results of the MODIS Vegetation Continuous Fields Algorithm", *Earth Interactions*, Vol 7, No 10, pp 1-15.
- Havlík, P, Schneider, U A, Schmid, E, Böttcher, H, Fritz, S, Skalský, R, Aoki, K, De Cara, S, Kindermann, G, Kraxner, F, Leduc, S, McCallum, I, Mosnier, A, Sauer, T and Obersteiner, M (2010). Global land-use implications of first and second generation biofuel targets. *Energy Policy*.
- Havlík, P., U. A. Schneider, E. Schmid, H. Boettcher, S. Fritz, R. Skalský, K. Aoki, S. de Cara, G. Kindermann, F. Kraxner, S. Leduc, I. McCallum, A. Mosnier, T. Sauer, and M. Obersteiner 2009, Global land-use implications of first and second generation biofuel targets, submitted to *Energy Policy*, in March 2009.
- IPCC, 2003: Good practice guidance for land use, land-use change and forestry. IPCC national

- greenhouse gas inventories programme. In: Penman, J., Gytarsky, M., Hiraishi, T., Krug, T., Kruger, D., Pipatti, R., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., Wagner, F. (Eds.). Institute for Global Environmental strategies for the IPCC, Hayama, Kanagawa.
- Izaurrealde R.C., J.R. Williams, W.B. McGill, N.J. Rosenberg, and M.C. Quiroga Jakas 2006. Simulating soil C dynamics with EPIC: Model description and testing against long-term data. *Ecological Modeling* 192:362-384
- Kindermann G., Obersteiner M., Rametsteiner E. and McCallum I. (2006). Predicting the Deforestation-Trend under Different Carbon-Prices. *Carbon Balance and Management*, 1:15; doi:10.1186/1750-0680-1-15.
- Kindermann, G.E., McCallum, I. and S. Fritz 2008. "A global forest growing stock, biomass and carbon map based on FAO statistics." *Silva Fennica*. Forthcoming.
- Kindermann, G.E., Obersteiner, M., Rametsteiner, E. and I. McCallum 2006. "Predicting the deforestation-trend under different carbon-prices." *Carbon Balance and Management* 1: 15.
- Leduc, S., D. Schwab, E. Dotzauer, E. Schmid, M. Obersteiner (2008). "Optimal Location of Wood Gasification Plants for Methanol Production with Heat Recovery." *International Journal of Energy Research*, IGEC-III special issue.
- Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., Garcia-Gonzalo, J., Seidl, R., Delzon, S., Corona, P., Kolström, M., Lexer, M.J., Marchetti, M., 2010. Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. *Forest Ecology and Management* 259, 698-709.
- Link, P.M., C.I. Ramos, U.A. Schneider, E. Schmid, J. Balkovič and R. Skalský 2008, The interdependencies between food and biofuel production in European agriculture - an application of EUFASOM, submitted to *Biomass and Bioenergy*.
- Liski, J., Nissinen, A., Erhard, M., Taskinen, O., 2003. Climatic effects on litter decomposition from arctic tundra to tropical rainforest. *Global Change Biology* 9, 575-584.
- Liski, J., Palosuo, T., Peltoniemi, M., Sievanen, R., 2005. Carbon and decomposition model Yasso for forest soils. *Ecological Modelling* 189, 168-182.
- Mantau, U., Saal, U., Prins, K., Steierer, F., Lindner, M., Verkerk, H., Eggers, J., Leek, N., Oldenburger, J., Asikainen, A., Anttila, P., 2010. EUwood - Real potential for changes in growth and use of EU forests. Final report to the European Commission DG TREN. University of Hamburg, Hamburg. http://ec.europa.eu/energy/renewables/studies/bioenergy_en.htm
- McCarl, B.A. and T.H. Spreen 1980. "Price Endogenous Mathematical Programming as a Tool for Sector Analysis." *American Journal of Agricultural Economics* 62: 87-102.
- MCPFE (2007). State of Europe's Forests 2007. The MCPFE Report on Sustainable Forest Management in Europe. Warsaw, Ministerial Conference on the Protection of Forests in Europe: 247.
- MCPFE, 2007. State of Europe's Forests 2007: The MCPFE Report on Sustainable Forest Management in Europe, Ministerial Conference on the Protection of Forests in Europe, Liaison Unit Warsaw, Warsaw, Poland
- Meyer, J., Vilén, T., Peltoniemi, M., Faubert, P. Thürig, E., Lindner, M., 2005. Uncertainty estimate of the national level biomass and soil carbon stock and stock change (Deliverable 6.3). CarboInvent Project Report, http://www.joanneum.at/carboinvent/D_6_3.pdf. European Forest Institute, Joensuu, 64 pp.
- Mokany, K., Raison, R.J., Prokushkin, A.S., 2006: Critical analysis of root: Shoot ratios in terrestrial

- biomes. *Global Change Biology* 12, 84-96.
- Nabuurs, G., Pussinen, A., van Brusselen, J., Schelhaas, M., 2007. Future harvesting pressure on European forests. *European Journal of Forest Research* 126, 391-400.
- Nabuurs, G.J., Schelhaas, M.J., Pussinen, A., 2000. Validation of the European Forest Information Scenario Model (EFISCEN) and a projection of Finnish forests. *Silva Fennica* 34, 167-179.
- National Technical University of Athens (NTUA, 2005), The PRIMES Energy System Model: Summary Description, Athens, Greece.
- Parton W.J., D.S. Ojima, C.V. Cole, and D.S. Schimel (1994). A general model for soil organic matter dynamics: Sensitivity to litter chemistry, texture and management. In: Bryant RB and Arnold RW (eds) *Quantitative modeling of soil forming processes*. SSSA, Madison, 147-167
- Peltoniemi, M., Palosuo, T., Monni, S., Makipaa, R., 2006. Factors affecting the uncertainty of sinks and stocks of carbon in Finnish forests soils and vegetation. *Forest Ecology and Management* 232, 75-85.
- PRIMES biomass model (http://www.e3mlab.ntua.gr/manuals/The_Biomass_model.pdf) Dec 2009
- Rametsteiner E, Nilsson S, Boettcher H, Havlik P, Kraxner F, Leduc S, Obersteiner M, Rydzak F, Schneider U, Schwab D, Willmore L (2007). "Study of the Effects of Globalization on the Economic Viability of EU Forestry. Final Report of the AGRI Tender Project: AGRI-G4-2006-06
- Romano D., C. Arcarese, A. Bernetti, A. Caputo, R.D. C ndor, M. Contaldi, R. De Lauretis, E. Di Cristofaro, S. Federici, A. Gagna, B. Gonella, R. Liburdi, E. Taurino, M. Vitullo 2009: Italian Greenhouse Gas Inventory 1990-2007. National Inventory Report 2009. ISPRA - Institute for Environmental Protection and Research, Rome. 353 pp.
- Russ, P., T. Wiesenthal, D. van Regenmorter, and J. C. Ciscar (2007), *Global Climate Policy Scenarios for 2030 and beyond - Analysis of Greenhouse Gas Emission Reduction Pathway Scenarios with the POLES and GEM-E3 models*, JRC Reference Reports, Joint Research Centre - Institute for Prospective Technological Studies, Seville, Spain.
- Salln s, O., 1990. A matrix model of the Swedish forest. *Studia Forestalia Suecica* 183, 23.
- Sauer, T, Havl k, P, Schneider, U A, Schmid, E, Kindermann, G and Obersteiner, M (2010). Agriculture and resource availability in a changing world: The role of irrigation. *Water Resources Research* 46 (6), W06503.
- Sauer, T., Havl k, P., Kindermann, G., and Schneider, U.A. (2008). "Agriculture, Population, Land and Water Scarcity in a changing World - the Role of Irrigation". Paper prepared for the 2008 Congress of the European Association of Agricultural Economists in Gent, Belgium.
- Schelhaas, M.J., Eggers, J., Lindner, M., Nabuurs, G.J., P ivinen, R., Schuck, A., Verkerk, P.J., van der Werf, D.C.v.d., Zudin, S., 2007a. Model documentation for the European Forest Information Scenario model (EFISCEN 3.1.3). Alterra report 1559 and EFI technical report 26. In. Alterra and European Forest Institute, Wageningen and Joensuu, p. 118.
- Schelhaas, M.J., Cienciala, E., Lindner, M., Nabuurs, G.J., Zanchi, G., 2007b. Selection and quantification of forestry measures targeted at the Kyoto Protocol and the Convention on Biodiversity. Alterra report 1508. Alterra, Wageningen.
- Schelhaas, M.J., van Brusselen, J.v., Pussinen, A., Pesonen, E., Schuck, A., Nabuurs, G.J., Sasse, V., 2006. Outlook for the development of European forest resources. A study prepared for the European forest sector outlook study (EFSOS). Geneva timber and forest discussion paper 41.

- ECE/TIM/DP/41. UNECE/FAO Forestry and, Timber Section, Geneva, New York, p. 118 pp.
- Schelhaas, M.J., Varis, S., Schuck, A. and Nabuurs, G.J., 2006, EFISCEN Inventory Database, European Forest Institute, Joensuu, Finland, http://www.efi.int/portal/virtual_library/databases/efiscen/
- Schleupner, C. and U.A. Schneider (2008), Evaluation of European wetland restoration potentials by considering economic costs under different policy options, FNU-158, Hamburg University and Centre for Marine and Atmospheric Sciences, Hamburg.
- Schneider U.A., J. Balkovic, S. De Cara, O. Franklin, S. Fritz, P. Havlik, I. Huck, K. Jantke, A.M.I. Kallio, F. Kraxner, A. Moiseyev, M. Obersteiner, C.I. Ramos, C. Schleupner, E. Schmid, D. Schwab, R. Skalsky (2008), The European Forest and Agricultural Sector Optimization Model - EUFASOM, FNU-156, Hamburg University and Centre for Marine and Atmospheric Science, Hamburg. http://www.mi.uni-hamburg.de/fileadmin/fnu-files/publication/working-papers/wp156_eufasom.pdf
- Schneider, U A, Havlík, P, Schmid, E, Valin, H, Mosnier, A, Obersteiner, M, Böttcher, H, Skalský, R, Balkovi, J, Sauer, T and Fritz, S (2011). Impacts of population growth, economic development, and technical change on global food production and consumption. *Agricultural Systems* 104 (2), pp204-215.
- Schneider, U.A., B.A. McCarl, and E. Schmid (2007). "Agricultural sector analysis on greenhouse gas mitigation in US agriculture and forestry." *Agricultural Systems*. 94:128-140.
- Schwab D.E., R.C. Izaurralde, W.B. McGill, J.R. Williams, and E. Schmid (2009). A stoichiometric model of nitrification in soils and the production of Nitrous Oxide und partly anaerobic conditions. *Biogeochemistry*. in review
- Skalsky, R., Z. Tarasovi?ová, J. Balkovi?, E. Schmid, M. Fuchs, E. Moltchanova, G. Kindermann, and P. Scholtz (2008). GEO-BENE global database for bio-physical modeling v. 1.0 - concepts, methodologies and data. The GEO-BENE database report. International Institute for Applied Systems Analysis (IIASA), Austria, pp. 58.
- TBFRA 2000; Forest Resources of Europe, CIS, North America, Australia, Japan and New Zealand (industrialized temperate/boreal countries). UN-ECE/FAO Contribution to the Global Forest Resources Assessment 2000. 2000, New York and Geneva: UNITED NATIONS PUBLICATION. 467.UN-ECE/ FAO, 2000. Forest Resources of Europe, CIS, North America, Australia, Japan and New Zealand, Contribution to the Global Forest Resources Assessment 2000. New York and Geneva, UN.
- Thürig E., Schelhaas M. J. (2006). Evaluation of a large scale forest scenario model in heterogeneous forests: a case study for Switzerland. *Canadian Journal of Forest Research*, 36 (3): 671-683.
- Ťupek, B., Zanchi, G., Verkerk, P.J., Churkina, G., Viovy, N., Hughes, J.K., Lindner, M., 2010. A comparison of alternative modelling approaches to evaluate the European forest carbon fluxes. *Forest Ecology and Management* 260, 241-251.
- Verkerk, P.J., P. Anttila, J. Eggers, M. Lindner, A. Asikainen. The realisable potential supply of woody biomass from forests in the European Union. *Forest Ecology and Management* (in press).
- Vilén, T., Meyer, J., Thürig, E., Lindner, M., Green, T., 2005: Improved regional and national level estimates of the carbon stock and stock change of tree biomass for six European countries, (Deliverable 6.1). Improved national estimates of the carbon stock and stock change of the forest soils for six European countries (Deliverable 6.2). CarboInvent Project. European Forest Institute, Joensuu, p. 31.
- Williams, J.R. (1995). "The EPIC Model. In *Computer Models of Watershed Hydrology*" (Ed.: V.P. Singh). Water Resources Publications, Highlands Ranch, Colorado, 1995, pp 909-1000.