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

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**FINAL REPORT**

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*by*

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# 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 $CO_2$ 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 $CO_2$ 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 $CO_2$ emissions from the energy sector and non-$CO_2$ 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.

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 $CO_2$ 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 results[1].

[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

# 2. The modelling framework

## 2.1. General approach

To produce consistent projections of $CO_2$ 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 DGTREN[2] 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 $CO_2$ 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.

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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

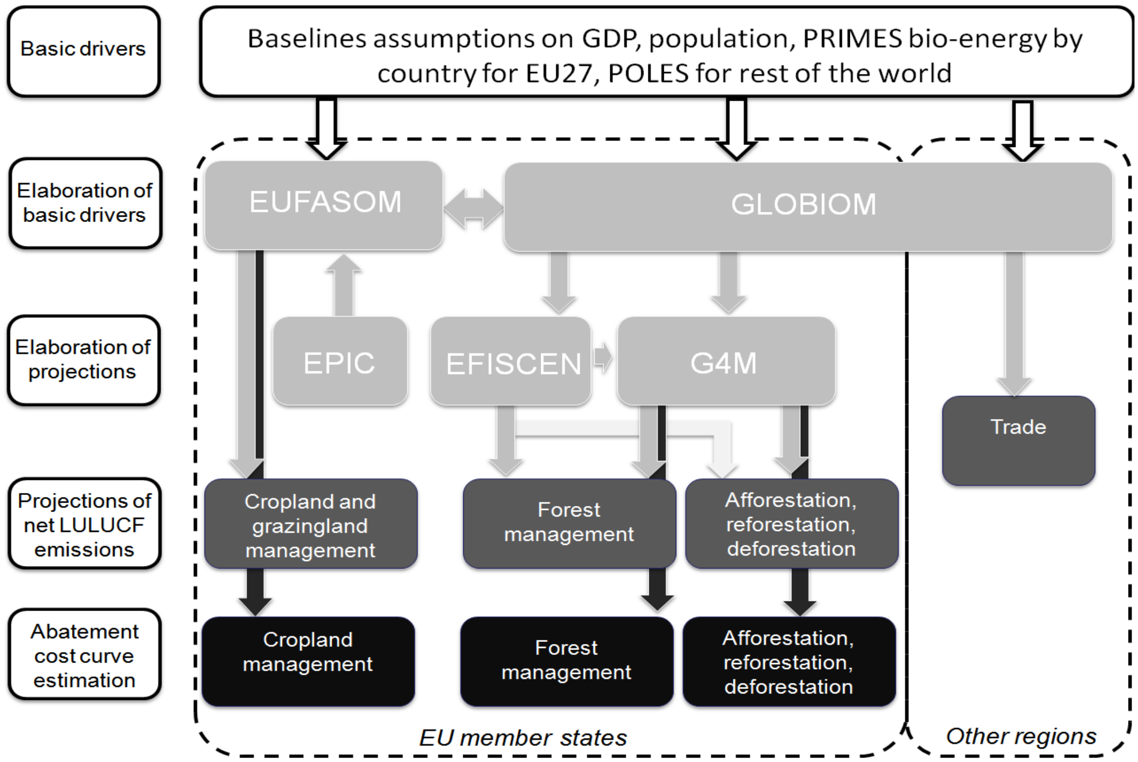



Figure 1: Overview of general modelling approach.

## 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.

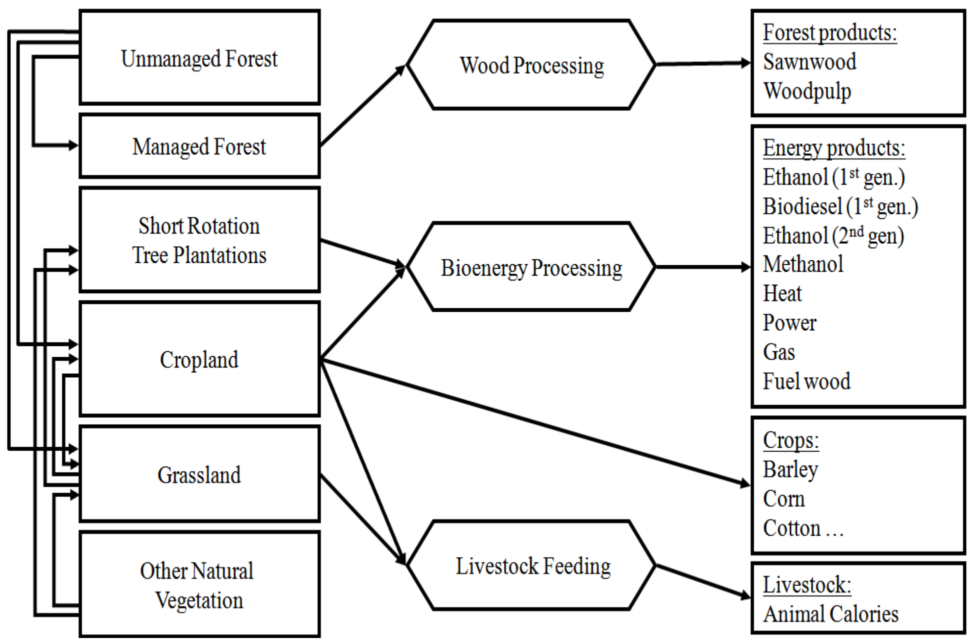



Figure 2. GLOBIOM land use and product structures (Havlík et al, in press). Note: The arrows on the left represent the direction where a given land use/cover type can expand given the current constraints in the model.

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 model[5] (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 (Havlík 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, Schleupner 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).

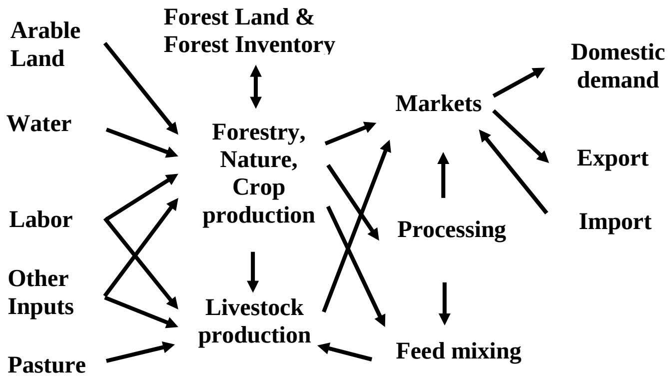



Figure 3: Resource and Commodity Flow in EUFASOM.

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; Ťupek et al. 2010). A detailed model description is given by Schelhaas et al. (2007a) and a schematic overview is shown in Figure 4.

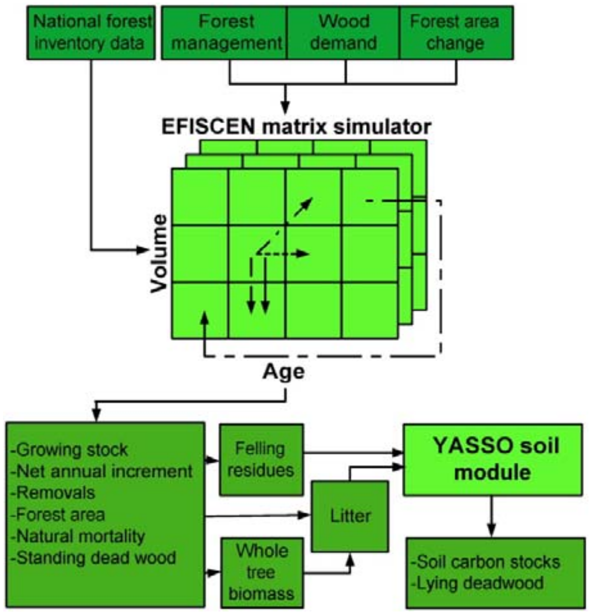



Figure 4: Schematic presentation of the EFISCEN model (Sallnäs 1990; Schelhaas et al. 2007a).

EFISCEN uses forest inventory data as an input, including:

- area (ha);
- average standing volume of growing stock ($m^3$/ha);
- net annual increment ($m^3$/ha/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. Ťupek 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.

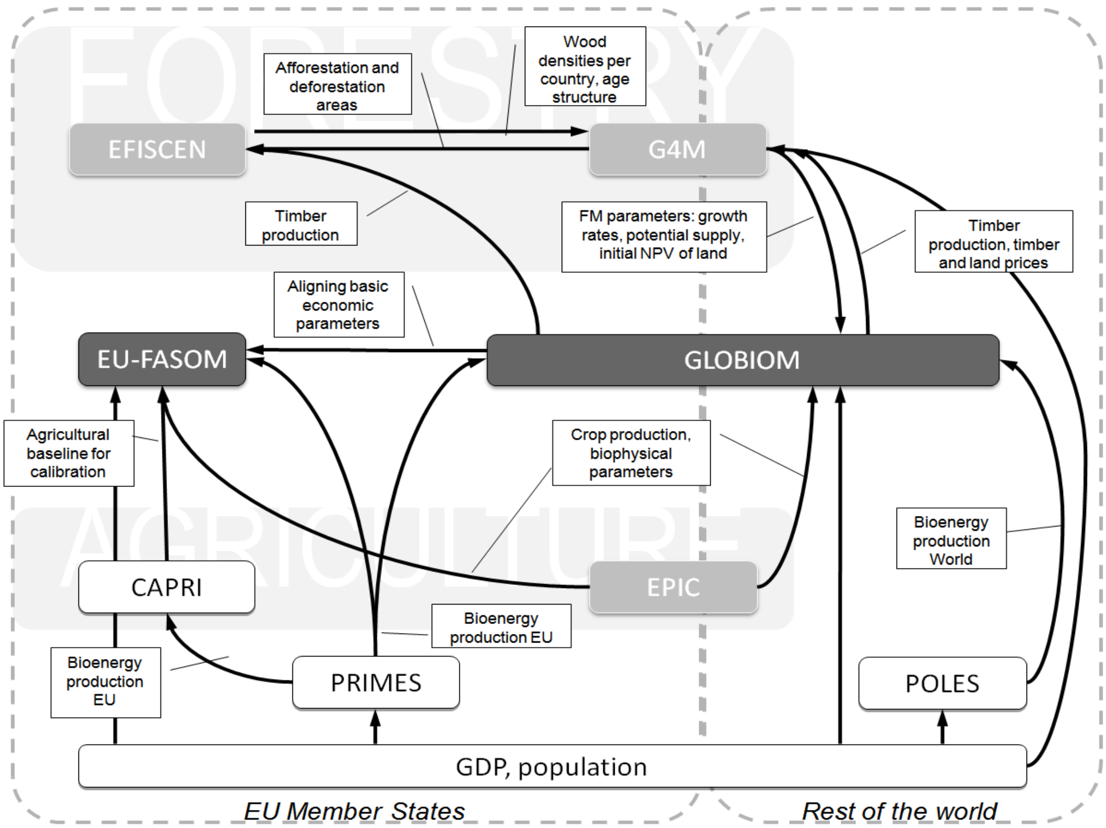



Figure 5: Schematic flowchart of the data exchange between models involved. Models of partners in the project consortium are in grey shaded boxes (economic models in dark grey, sector specific models in light grey). Arrows describe major data flows between models described in brief by call outs.

## 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 scenario[6] 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.

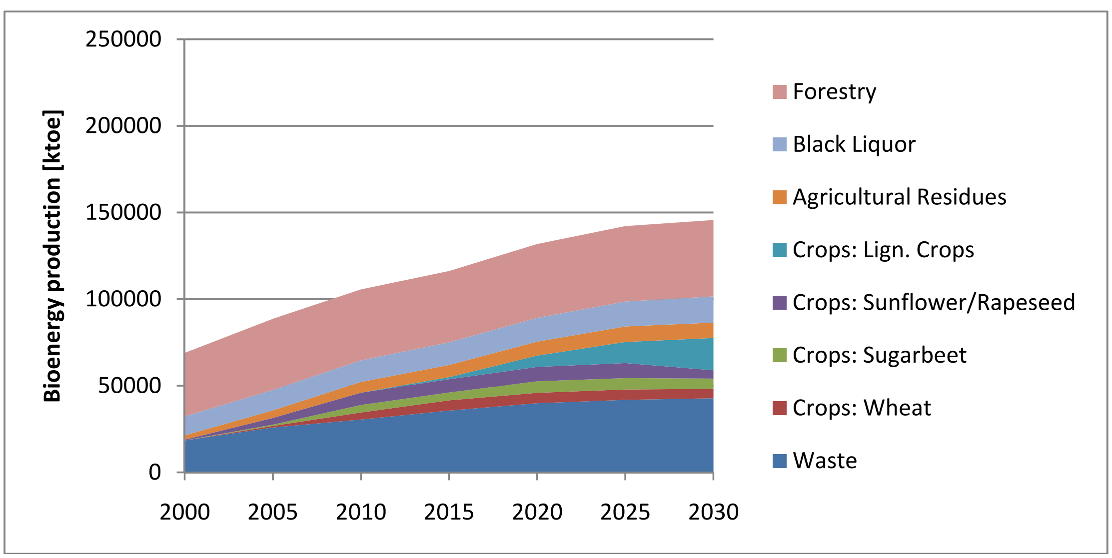
Table 2: Rate of growth of population and GDP per year in percent.

| | 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 mode[7]. 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 scenario[8] 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.

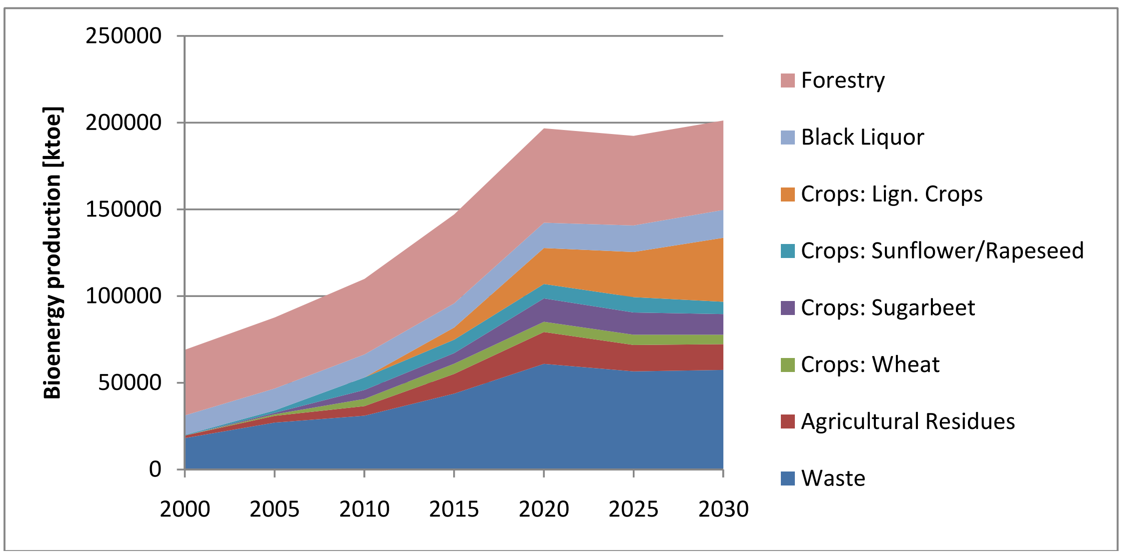



Figure 7: Reference scenario projection of total bioenergy production in the EU as suggested by the PRIMES biomass model (version July 2010).

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: Forest inventory data used 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 | 5408* |
| 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 |

| Country | Year of inventory | Forest area (1000 ha) |
|---|---|---|
| United Kingdom | 1995–2000 | 2094 |

*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 $CO_2$ 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 2.5.2) 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.

### 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 where 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 $CO_2$ 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. A full list of country comments and responses can be found in the Annex.

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 2010[9]).

| 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 | | | | |
| 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. 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
- Harmonization of NFI datasets
- Wood density
- Biomass Expansion Factors
- Wood removals

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

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

*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.

Table 6 lists the forest area used by the models. For EFISCEN the forest area for Austria, Finland, and Sweden refers 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. These cases can be assessed by making use of the detailed background data (among others forest area used by the model) delivered with the results.

These area deviations need to be considered when modeled emissions and removals from forest management are compared to reported data in the results section of this report.

Table 6: Forest area reported and used by the forestry models. Reported data were compiled by JRC from different sources. Values in 1000 ha. Forest management area data were taken either from the country Kyoto Protocol report (for those that selected KP Article 3.4) or other sources (e.g. UNFCCC reports or MCPFE 2007) in case the countries did not report or reported only a fraction of the managed forest (see Greece and UK, values in brackets).

| | Reported values in 1000 ha | | Values implemented in models in 1000 ha and % difference to reported value | | | |
|---|---|---|---|---|---|---|
| | Value for **2008** from KP tables (only MS which elected FM) | Other estimates (in case of no KP value) | EFISCEN | | G4M | |
| Austria | | 3793 | 3303* | -12.9% | 3753 | -1.1% |
| Belgium | | 681 | 683 | 0.3% | 648 | -4.8% |
| Bulgaria | | 3752 | 3753 | 0.0% | 3373 | -10.1% |
| Cyprus | | | | | 0 | |
| Czech Republic | 2563 | | 2563 | 0.0% | 2273 | -11.3% |
| Denmark | 533 | | 533 | 0.0% | 482 | -9.6% |
| Estonia | | 2081 | 2079 | -0.1% | 2145 | 3.1% |
| Finland | 21873 | | 18530* | -15.3% | 21082 | -3.6% |
| France | 14574 | | 14627 | 0.4% | 14517 | -0.4% |
| Germany | 10710 | | 10745 | 0.3% | 10958 | 2.3% |
| Greece | (1167) | 3752 | | | 4355 | 16.1% |
| Hungary | 1872 | | 1871 | -0.1% | 1644 | -12.2% |
| Ireland | | 465 | 465 | 0.0% | 608 | 30.8% |
| Italy | 7451 | | 7451 | 0.0% | 8878 | 19.2% |
| Latvia | 3221 | | 3221 | 0.0% | 3246 | 0.8% |

| | Reported values in 1000 ha | | Values implemented in models in 1000 ha and % difference to reported value | | | |
|---|---|---|---|---|---|---|
| | Value for **2008** from KP tables (only MS which elected FM) | Other estimates (in case of no KP value) | EFISCEN | | G4M | |
| Lithuania | | 2000 | 2000 | 0.0% | 2007 | 0.4% |
| Luxembourg | | 86 | 87 | 1.2% | 87 | 1.2% |
| Malta | | | | | 0 | |
| Netherlands | | 346 | 349 | 0.9% | 331 | -4.3% |
| Poland | | 8546 | 8522 | -0.3% | 9018 | 5.5% |
| Portugal | 2408 | | 2462 | 2.2% | 2664 | 10.6% |
| Romania | | 6685 | 6670 | -0.2% | 6294 | -5.8% |
| Slovakia | | 1916 | 1916 | 0.0% | 1571 | -18.0% |
| Slovenia | 1185 | | 1185 | 0.0% | 1237 | 4.4% |
| Spain | 12577 | | 12577 | 0.0% | 15675 | 24.6% |
| Sweden | 27644 | | 22621* | -18.2% | 25791 | -6.7% |
| United Kingdom | (1376) | 2591 | 2556 | -1.4% | 2784 | +7.4%% |

* The forest area for Austria, Finland, and Sweden refers to the forest available for wood supply, based on country consultations.

*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 7 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 7: 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.

| **Country** | **Age classes in years** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **1-20** | **21-40** | **41-60** | **61-80** | **81-100** | **101-120** | **121-140** | **>140** |
| Austria | 15.2 | 23.7 | 18.4 | 12.9 | 10.5 | 7.7 | 4.9 | 6.8 |
| Belgium | 13.6 | 17.2 | 26.8 | 15.3 | 9.8 | 6.3 | 4.0 | 6.9 |
| Bulgaria | 15.2 | 23.0 | 28.9 | 16.1 | 6.6 | 4.9 | 2.9 | 2.4 |
| Czech Republic | 10.4 | 18.9 | 17.0 | 19.3 | 16.5 | 11.3 | 4.4 | 2.2 |
| Denmark | 26.1 | 25.0 | 25.6 | 10.4 | 5.5 | 4.3 | 1.9 | 1.2 |
| Estonia | 16.3 | 19.4 | 29.9 | 21.9 | 9.3 | 2.4 | 0.5 | 0.2 |
| Finland | 17.8 | 21.6 | 20.4 | 16.6 | 11.0 | 5.4 | 2.6 | 4.5 |
| France | 16.2 | 20.0 | 20.7 | 17.6 | 10.7 | 6.9 | 4.2 | 3.7 |
| Germany | 12.5 | 15.7 | 20.8 | 17.1 | 13.9 | 9.5 | 5.6 | 5.0 |
| Greece | | | | | | | | |

| Country | Age classes in years | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1-20 | 21-40 | 41-60 | 61-80 | 81-100 | 101-120 | 121-140 | >140 |
| Hungary | 29.2 | 27.5 | 17.2 | 13.8 | 8.0 | 1.7 | 1.7 | 0.9 |
| Ireland | 52.0 | 34.1 | 13.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Italy | 5.8 | 23.0 | 24.7 | 5.4 | 7.1 | 15.0 | 10.5 | 8.4 |
| Latvia | 10.9 | 23.9 | 27.8 | 20.0 | 9.9 | 4.3 | 3.2 | 0.0 |
| Lithuania | 10.4 | 16.0 | 28.8 | 26.1 | 13.6 | 3.9 | 0.8 | 0.4 |
| Luxembourg | 12.1 | 10.4 | 19.4 | 10.8 | 7.7 | 9.9 | 13.8 | 16.1 |
| Netherlands | 8.5 | 23.5 | 28.5 | 20.1 | 10.3 | 3.6 | 3.6 | 1.8 |
| Poland | 9.1 | 24.2 | 20.6 | 21.4 | 15.3 | 5.9 | 1.7 | 1.7 |
| Portugal | 48.2 | 26.7 | 18.7 | 5.5 | 0.9 | 0.0 | 0.0 | 0.0 |
| Romania | 18.1 | 16.6 | 20.6 | 15.9 | 11.0 | 17.8 | 0.0 | 0.0 |
| Slovakia | 19.8 | 9.9 | 16.2 | 22.3 | 19.4 | 9.2 | 2.1 | 1.1 |
| Slovenia | 5.1 | 5.4 | 14.2 | 18.9 | 18.9 | 17.7 | 12.3 | 7.3 |
| Spain | 20.6 | 14.2 | 15.7 | 14.4 | 9.2 | 4.3 | 3.3 | 18.3 |
| Sweden | 20.4 | 21.8 | 16.3 | 11.1 | 9.3 | 7.9 | 6.6 | 6.6 |
| United Kingdom | 15.1 | 32.7 | 32.7 | 9.5 | 4.7 | 2.1 | 2.3 | 1.0 |
| EU average | 17.9 | 20.6 | 21.8 | 15.1 | 10.0 | 6.8 | 3.9 | 4.0 |

### *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 ensuring 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 8). 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 8: 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 9 displays the wood production for wood used energy and material use for individual countries.

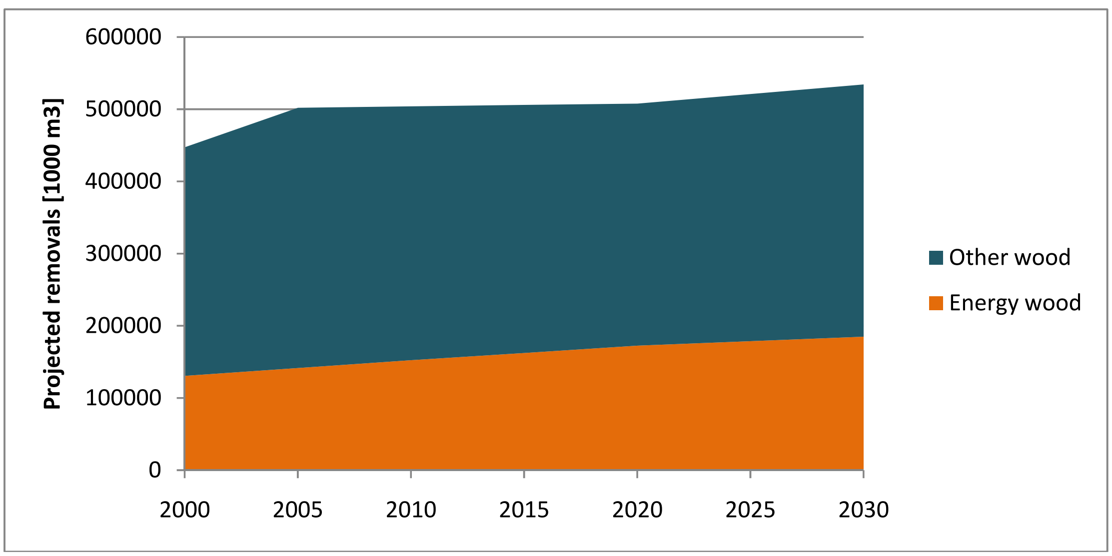


Figure 8: Baseline projection of domestic wood production for EU27 for energy wood (based on PRIMES bioenergy from fellings and traditional fuel wood) and other wood (i.e. material use including sawnwood, pulp wood and other industrial roundwood). The original GLOBIOM data were scaled by historic wood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

Table 9: Baseline projection of wood production in 1000 $m^3$ 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.

| | Material use | | | | | Energy wood | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Country | 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 | 2413 | 3766 | 3256 | 2557 | 2664 | 2384 | 2661 | 2938 | 3171 | 3130 |
| Cyprus | 29 | 13 | 20 | 31 | 32 | 0 | 0 | 0 | 4 | 6 |
| Czech Rep. | 15710 | 15818 | 14331 | 16643 | 17341 | 0 | 2329 | 4658 | 4030 | 5108 |
| Denmark | 991 | 1260 | 1284 | 1050 | 1094 | 1095 | 1264 | 1433 | 2053 | 2249 |
| Estonia | 7593 | 5324 | 6412 | 8044 | 8381 | 2071 | 2131 | 2190 | 2851 | 2955 |
| 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 | 472 | 162 | 554 | 500 | 520 | 1712 | 1693 | 1675 | 2477 | 2687 |
| Hungary | 4402 | 4411 | 4326 | 4663 | 4858 | 1670 | 2112 | 2554 | 2930 | 2428 |
| Ireland | 2562 | 2548 | 2461 | 2714 | 2827 | 216 | 372 | 528 | 413 | 1024 |
| Italy | 7989 | 6600 | 7468 | 8463 | 8818 | 6976 | 7896 | 8816 | 11395 | 15423 |
| Latvia | 8730 | 8576 | 9090 | 9248 | 9636 | 2310 | 2288 | 2266 | 3092 | 2944 |
| Lithuania | 4145 | 5073 | 4995 | 4392 | 4576 | 2019 | 1870 | 1720 | 1867 | 1956 |
| Luxembourg | 298 | 305 | 308 | 315 | 328 | 0 | 0 | 0 | 0 | 0 |
| Malta | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Netherlands | 1096 | 1209 | 1193 | 1162 | 1210 | 0 | 0 | 0 | 0 | 0 |
| Poland | 19706 | 27334 | 25288 | 20876 | 21751 | 8983 | 10098 | 11213 | 13764 | 16005 |
| Portugal | 7074 | 9323 | 8603 | 7494 | 7808 | 4501 | 4414 | 4327 | 3821 | 6279 |
| Romania | 6624 | 8164 | 7269 | 7017 | 7311 | 8135 | 8855 | 9575 | 9478 | 8718 |
| Slovakia | 6600 | 7265 | 5952 | 6992 | 7285 | 6 | 1597 | 3189 | 2706 | 2867 |
| Slovenia | 1230 | 1771 | 1527 | 1303 | 1358 | 1272 | 1404 | 1537 | 1537 | 1537 |
| Spain | 8986 | 9233 | 9257 | 9520 | 9919 | 8075 | 8548 | 9021 | 9753 | 8832 |
| Sweden | 56607 | 71899 | 69651 | 59969 | 62483 | 18273 | 19081 | 19889 | 26690 | 30046 |
| United Kingdom | 8434 | 9510 | 9555 | 8934 | 9309 | 294 | 427 | 561 | 1539 | 1632 |
| EU | 316677 | 360537 | 351680 | 335486 | 349548 | 130631 | 141465 | 152300 | 172452 | 184830 |

* 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 10 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).

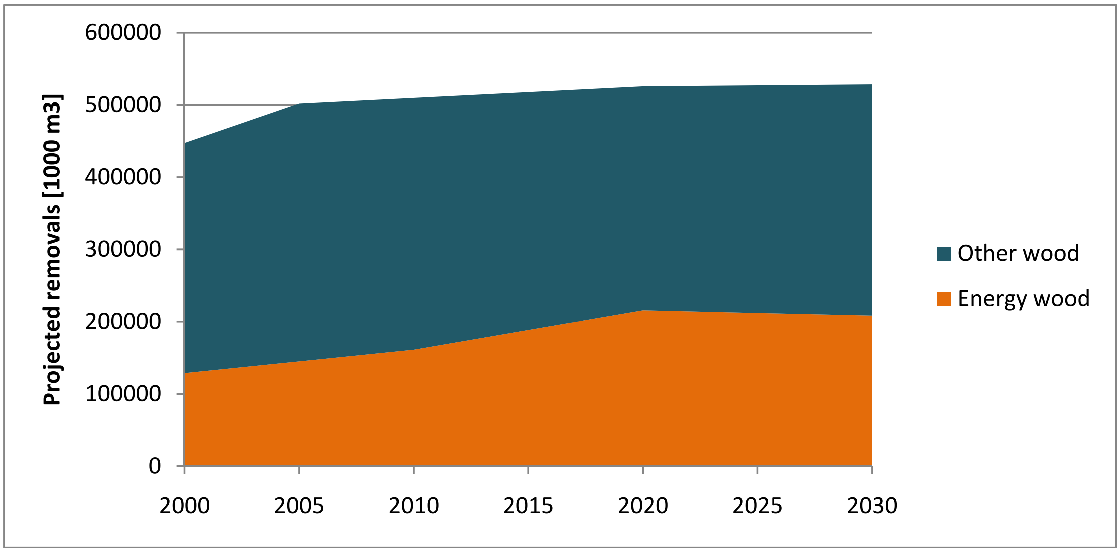


Figure 9: Reference scenario projection of domestic wood production for EU27 for energy wood (based on PRIMES bionergy from fellings and traditional fuel wood) and other wood (i.e. material use including sawnwood, pulp wood and other industrial roundwood). The original GLOBIOM data were scaled by historic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

Table 10: 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 11: 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 2010 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 | 61% | 84% | 59% | 37% |
| Latvia | 6% | 8% | 5% | 2% |
| Lithuania | -3% | -4% | 4% | 12% |
| Luxembourg | -5% | -8% | -9% | -9% |
| Malta | 0% | 0% | 0% | 0% |
| 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% | 4% | 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 project[10]. 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 20% 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 $CO_2$ 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 $CO_2$ prices. The calculations were done using G4M (forestry activities) and EU-FASOM (agricultural activities). Into both models a $CO_2$ 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 $CO_2$ price was introduced as a carbon tax to be paid by land owners when emissions occur on their land. The $CO_2$ price is introduced in the model year 2011 and kept constant at steps of 5 EUR per tonne of $CO_2$ 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 $CO_2$ price gives an additional value to the forest through the carbon stored and accumulated in it. The increased value of forests in a regime with a $CO_2$ price changes the balance of land use change through the net present value (NPV) generated by land use activities towards forestry. In general, it is therefore assumed that an introduction of $CO_2$ price leads to a decrease of deforestation and an increase of afforestation. This might not happen at the same intensity though. Less deforestation increases land scarcity and might therefore decrease afforestation relative to a baseline.

The existing forest under a $CO_2$ price is managed with longer rotations of productive forests, and shifting harvest to less productive forest. 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 ($NPV_{bau}$, $NPV_{bau}$>=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 $CO_2$ 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 12).

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 JRC[11] 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 12 and Table 13. Consistently over all model combinations, Belgium, Czech Republic, Estonia, Germany, Netherlands and Poland form $CO_2$ 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 13).

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[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

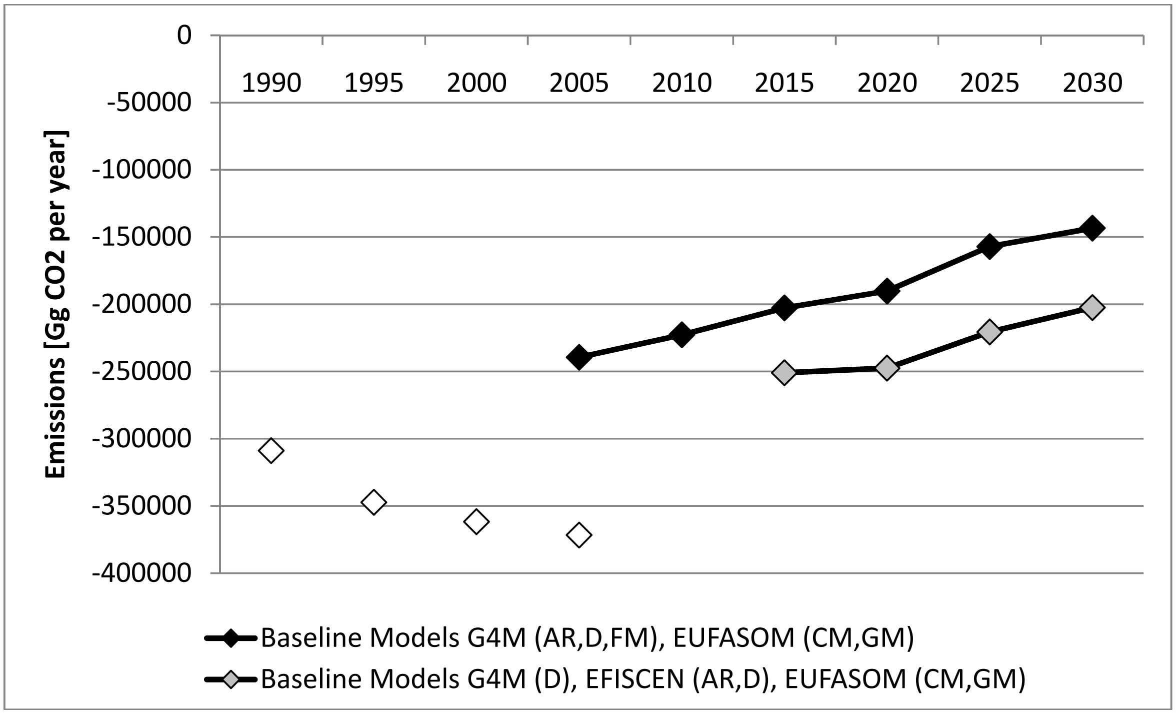


Figure 10: Baseline emission projection for different model combinations and reported data for LULUCF (sum of AR, D, FM, CM and GM). Reported data were compiled by JRC and include data reported by countries to UNFCCC and the Kyoto Protocol. Sums do not include values of Cyprus, Malta and Greece in order 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 12: Baseline total LULUCF projection at country level as projected by G4M (AR, D, FM) and EUFASOM (CM and GM) in Gg $CO_2$. G4M did not estimate numbers for Cyprus and Malta. Values in Gg $CO_2$ per year. Positive values show sources, negative values sinks of $CO_2$.

| G4M, EUFASOM | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|
| Austria | -17140 | -14984 | -14435 | -14445 | -14868 | -14627 |
| Belgium | 442 | 717 | 653 | 900 | 766 | 952 |
| Bulgaria | -15958 | -15059 | -14132 | -13298 | -13551 | -11836 |
| Cyprus | | | | | | |
| Czech Republic | 6866 | 8203 | 9951 | 10578 | 12543 | 13292 |
| Denmark | -216 | -253 | 107 | 411 | 732 | 1216 |
| Estonia | 865 | 2253 | 3536 | 4660 | 4556 | 4149 |
| Finland | -7089 | -6613 | -3828 | -269 | 1922 | 4854 |
| France | -51663 | -56343 | -54283 | -49274 | -44178 | -39526 |
| Germany | 17686 | 18070 | 17910 | 17729 | 20854 | 23114 |
| Greece | -7011 | -7166 | -6790 | -6556 | -6607 | -6305 |
| Hungary | -10039 | -9419 | -8213 | -8170 | -6325 | -6254 |
| Ireland | -745 | -872 | -1172 | -1820 | -2198 | -2521 |
| Italy | -44568 | -43198 | -41547 | -42312 | -41422 | -38687 |
| Latvia | -5187 | -2231 | -766 | 153 | 996 | 1408 |
| Lithuania | -2217 | -2209 | -1710 | -1786 | -1253 | -846 |
| Luxembourg | -562 | -376 | -432 | -384 | -338 | -294 |
| Malta | | | | | | |
| Netherlands | 2181 | 2411 | 2744 | 3063 | 3148 | 3121 |
| Poland | 16723 | 25041 | 31078 | 31438 | 35150 | 36366 |

| G4M, EUFASOM | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|
| Portugal | -1248 | -2706 | -4483 | -6071 | -5548 | -5997 |
| Romania | -60436 | -52391 | -45903 | -41966 | -29390 | -36645 |
| Slovakia | -1123 | 239 | 1079 | 2245 | 1774 | 1899 |
| Slovenia | -5317 | -5192 | -4804 | -4704 | -4339 | -3229 |
| Spain | -28827 | -31610 | -34156 | -35805 | -37427 | -38411 |
| Sweden | -17472 | -19681 | -22502 | -24063 | -23919 | -20219 |
| United Kingdom | -14414 | -16515 | -17451 | -16973 | -14791 | -14669 |
| SUM | -246467 | -229883 | -209547 | -196719 | -163714 | -149696 |

Table 13: Baseline total LULUCF projection at country level as projected by EFISCEN (AR, FM) G4M (D) and EUFASOM (CM and GM) in Gg $CO_2$. 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 $CO_2$ per year. Positive values show sources, negative values sinks of $CO_2$.

| EFISCEN, G4M, EUFASOM | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| Austria | -8741 | -11031 | -12852 | -12954 | -11673 |
| Belgium | 636 | 324 | -648 | 272 | 202 |
| Bulgaria | -14261 | -17028 | -15927 | -16979 | -14774 |
| Cyprus | | | | | |
| Czech Republic | 9871 | 10696 | 9079 | 10887 | 12010 |
| Denmark | -48 | -559 | -483 | -887 | -630 |
| Estonia | 138 | 2719 | 4370 | 4988 | 4736 |
| Finland | | -16244 | -11849 | -8924 | -6238 |
| France | -53942 | -53076 | -50543 | -49940 | -43983 |
| Germany | 14957 | -3459 | -10136 | -9386 | -9019 |
| Greece | | | | | |
| Hungary | | -8066 | -8274 | -7017 | -7679 |
| Ireland | | -566 | -826 | -750 | -54 |
| Italy | | -42321 | -32743 | -30606 | -25929 |
| Latvia | | -11472 | -10437 | -9789 | -8186 |
| Lithuania | -3712 | -3685 | -3834 | -3018 | -3030 |
| Luxembourg | -642 | -682 | -697 | -640 | -582 |
| Malta | | | | | |
| Netherlands | | 2186 | 2066 | 1927 | 1849 |
| Poland | 42031 | 48814 | 44313 | 48264 | 48830 |
| Portugal | 5435 | 942 | -940 | -278 | 1463 |
| Romania | -64574 | -66868 | -61370 | -50185 | -55360 |
| Slovakia | -2019 | -727 | 848 | 488 | 1583 |
| Slovenia | -5386 | -5154 | -5491 | -5442 | -5106 |
| Spain | -28342 | -29332 | -29765 | -30891 | -31404 |
| Sweden | | -30308 | -36148 | -34397 | -34278 |
| United Kingdom | -13835 | -16041 | -15183 | -15318 | -15207 |
| SUM | | -250936 | -247469 | -220575 | -202462 |

### 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 $CO_2$ removals from forest management is partly compensated by an increasing $CO_2$ sink of new forests. However, in 2030 forest management will still be the dominating term in Europe's LULUCF carbon budget.

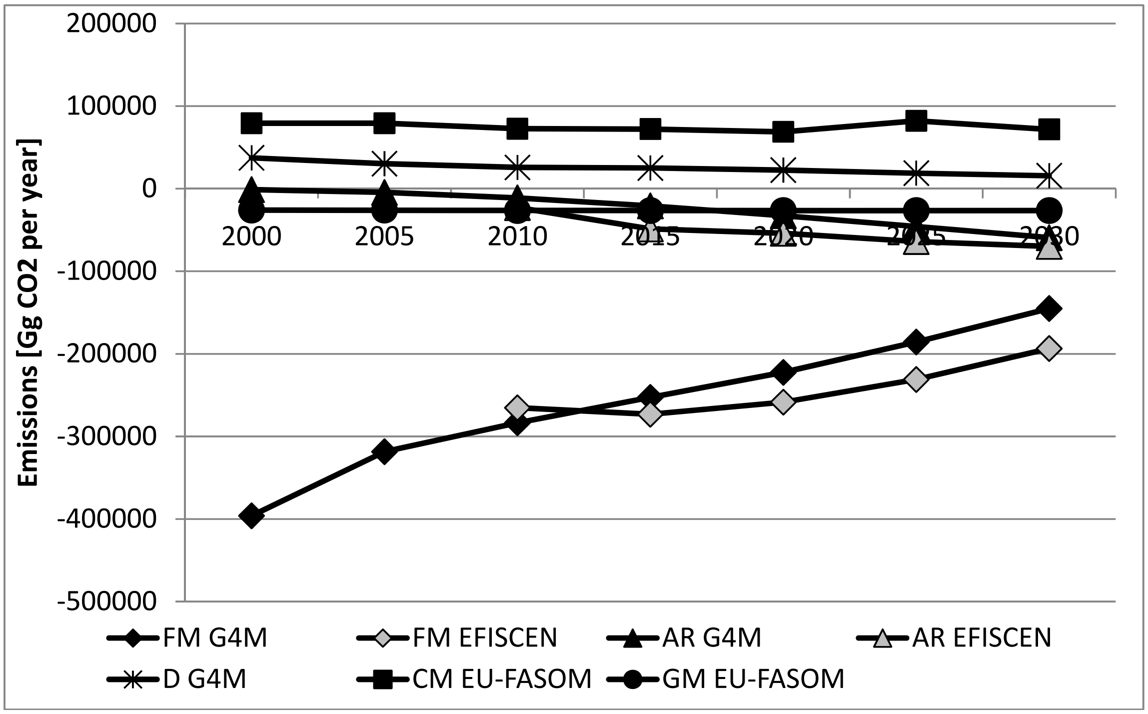

Figure 11: Projected development of emissions and removals by the different models in EU-27 for different LULUCF activities in the baseline scenario. Annual values are available in the database. For simplicity only five year steps are shown here. Sums do not include values of Cyprus, Malta and Greece 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 $CO_2$ per year. Positive values show sources, negative values sinks of $CO_2$.

Table 14 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 ($CO_2$ 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 14: 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 $CO_2$ per year. Positive values show sources, negative values sinks of $CO_2$.

| Activity, model | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|
| Forest management | | | | | | |
| G4M | -318549 | -283479 | -252736 | -222490 | -185674 | -145094 |
| EFISCEN | | -265314 | -273063 | -258498 | -231053 | -193604 |
| Reported | -403012 | | | | | |
| Afforestation | | | | | | |
| G4M | -4446 | -11148 | -20804 | -32702 | -45870 | -59345 |
| EFISCEN | | | -48657 | -53999 | -63959 | -69905 |
| Reported | -38052 | | | | | |
| Deforestation | | | | | | |
| G4M | 30256 | 25792 | 25050 | 22617 | 18799 | 15679 |
| Reported | 21790 | | | | | |
| Cropland management | | | | | | |
| EU-FASOM | 79226 | 72620 | 72236 | 68914 | 82140 | 71870 |
| Reported | 74480 | | | | | |
| Grassland management | | | | | | |
| EU-FASOM | -25943 | -26502 | -26502 | -26502 | -26502 | -26502 |
| Reported | -26849 | | | | | |
| Total LULUCF | | | | | | |
| G4M, EUFASOM | -239456 | -222717 | -248490 | -232576 | -212745 | -188759 |
| EFISCEN, G4M, EUFASOM | | | -250936 | -247469 | -220575 | -202462 |

## 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 $CO_2$ 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 pronounces for forest management activities.

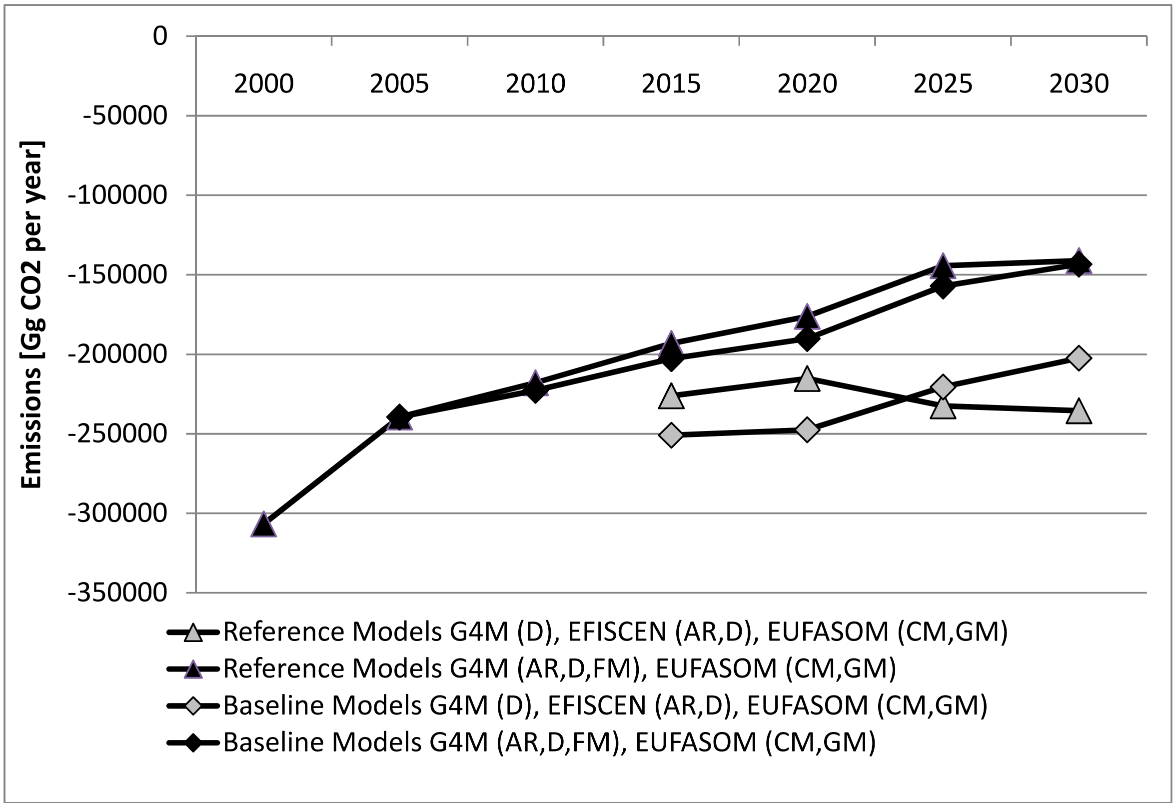


Figure 12: Projected development of emissions and removals in EU-27 for total LULUCF in the baseline and reference scenario by different model result combinations. Sums do not include values of Cyprus, Malta and Greece in order to make numbers comparable among models (EFISCEN does not include Cyprus,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

Table 15: 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 | -14597 | -13627 | -13621 | -14371 | -14058 | -8042 | -9745 | -11022 | -12734 | -12736 |
| Belgium | 531 | 373 | 350 | 465 | 762 | 373 | -147 | -741 | -89 | 168 |
| Bulgaria | -14547 | -13312 | -11774 | -12127 | -10504 | -13389 | -15382 | -13590 | -15456 | -13985 |
| Cyprus | 0 | 0 | 0 | 0 | 0 | | | | | |
| Czech Rep. | 8836 | 10355 | 11530 | 13835 | 14026 | 10659 | 12118 | 11075 | 11802 | 12092 |
| Denmark | -285 | 91 | 328 | 627 | 969 | -84 | -624 | -571 | -1106 | -945 |
| Estonia | 1184 | 1518 | 2027 | 2079 | 1843 | -1432 | -358 | -213 | 417 | 90 |
| Finland | -7486 | -5608 | -2585 | -1663 | 367 | | -18798 | -15628 | -13845 | -12369 |
| France | -56796 | -54864 | -50207 | -47011 | -47364 | -54684 | -54457 | -52503 | -57551 | -56507 |
| Germany | 18357 | 18584 | 18819 | 24693 | 30179 | 15413 | -2610 | -8924 | -4392 | -487 |
| Greece | -7256 | -6963 | -6788 | -7059 | -7127 | | | | | |
| Hungary | -9148 | -7936 | -7446 | -6273 | -7248 | | -7468 | -7425 | -7441 | -9176 |
| Ireland | -688 | -762 | -1251 | -1996 | -2887 | | 68 | 84 | -840 | -612 |
| Italy | -39347 | -32847 | -31686 | -34033 | -36028 | | -21686 | -2314 | -8788 | -12663 |
| Latvia | -1881 | 37 | 1368 | 1986 | 2043 | | -10303 | -8644 | -8656 | -7660 |
| Lithuania | -2297 | -1909 | -2136 | -955 | -65 | -3853 | -3953 | -4224 | -2515 | -1729 |

| | G4M, EUFASOM | | | | | EFISCEN, G4M, EUFASOM | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2015 | 2020 | 2025 | 2030 | 2010 | 2015 | 2020 | 2025 | 2030 |
| Luxembourg | -376 | -750 | -728 | -444 | -323 | -656 | -708 | -735 | -680 | -625 |
| Malta | 0 | 0 | 0 | 0 | 0 | | | | | |
| Netherlands | 2385 | 2704 | 3022 | 3029 | 3016 | | 2117 | 1972 | 1841 | 1770 |
| Poland | 22580 | 25832 | 24109 | 28660 | 30722 | 38545 | 42713 | 35646 | 39763 | 39519 |
| Portugal | -2699 | -4843 | -6567 | -6582 | -7496 | 4795 | -315 | -2865 | -3886 | 1674 |
| Romania | -52000 | -44938 | -40200 | -29269 | -38982 | -63553 | -65000 | -58832 | -51217 | -59166 |
| Slovakia | 131 | 884 | 1925 | 1353 | 1274 | -2159 | -991 | 462 | -403 | 282 |
| Slovenia | -4899 | -4327 | -3834 | -3538 | -2664 | -4977 | -4378 | -4350 | -4629 | -5224 |
| Spain | -28093 | -26336 | -23263 | -20119 | -16484 | -21306 | -16789 | -15093 | -33203 | -34543 |
| Sweden | -20676 | -24957 | -28759 | -28798 | -27988 | | -34633 | -42490 | -44293 | -47606 |
| UK | -16061 | -16516 | -15531 | -13846 | -14194 | -13139 | -14746 | -14282 | -14535 | -15046 |
| SUM | -225131 | -200116 | -182898 | -151354 | -148213 | | -226075 | -215207 | -232437 | -235484 |

## 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 $CO_2$ 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 $CO_2$ 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.

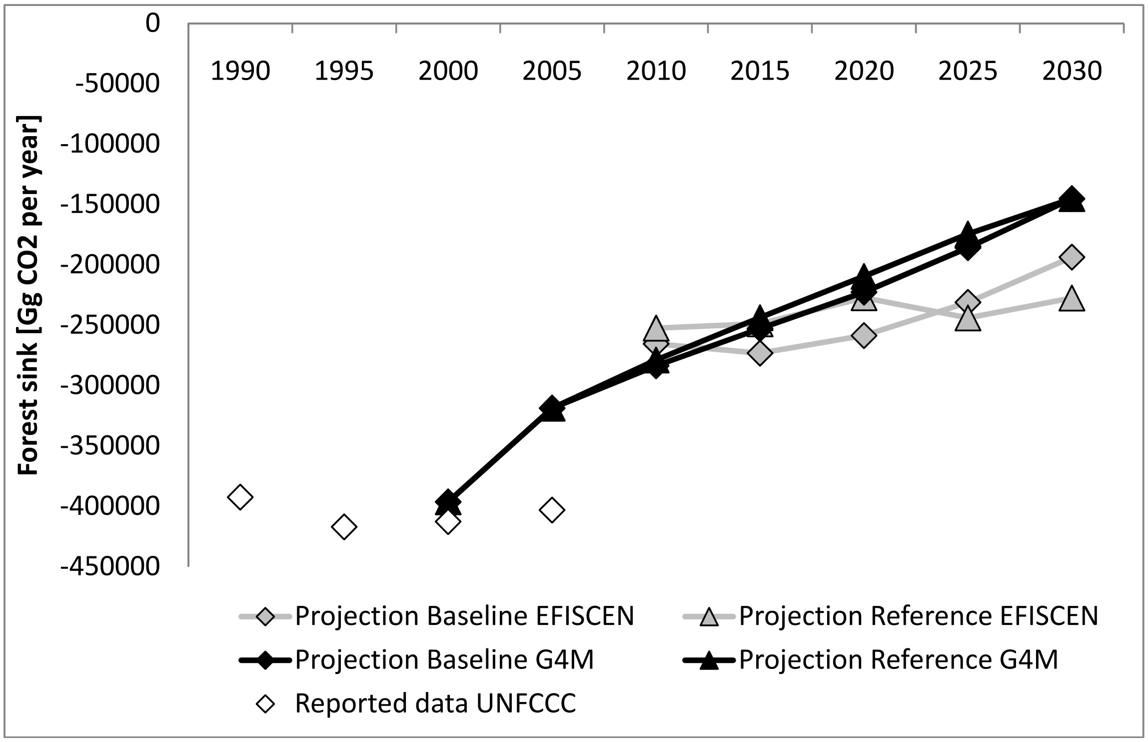


Figure 13: Comparison of model baseline results to UNFCCC reported data showing most recent (end of 2010) submissions by countries, collected by JRC for forest management activities. Explanations of differences and interpretation are given in the text. Sums do not include values of Cyprus, Malta and 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 lat 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 $CO_2$ 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 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 16).

But also harvest routine in the models differs and may lead to different interpretations of the prescribed wood production projection by GLOBIOM. Table 17 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 16: Increments as projected by EFISCEN and G4M ($m^3\ ha^{-1}\ yr^{-1}$).

| | EFISCEN | | | | | G4M | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Country** | **2000** | **2005** | **2010** | **2020** | **2030** | **2000** | **2005** | **2010** | **2020** | **2030** |
| Austria | | 7.7 | 8.1 | 8.4 | 8.2 | 10.2 | 10.3 | 9.6 | 8.7 | 8.5 |
| Belgium | 8.6 | 8.5 | 8.7 | 8.5 | 7.6 | 8.9 | 8.6 | 8.3 | 8.1 | 8.3 |
| Bulgaria | | 4.5 | 4.5 | 4.5 | 4.3 | 5.9 | 5.5 | 5.2 | 4.6 | 4.2 |
| Cyprus | | | | | | | | | | |
| Czech Republic | | | 6.9 | 7.5 | 7.7 | 10.4 | 10.3 | 10.2 | 10.1 | 9.9 |
| Denmark | | 8.9 | 9.8 | 11.0 | 11.7 | 14.1 | 14.4 | 14.4 | 13.2 | 11.5 |
| Estonia | | 5.6 | 5.3 | 5.1 | 5.0 | 5.2 | 4.8 | 4.8 | 5.0 | 5.1 |
| Finland | | | 4.9 | 5.1 | 5.2 | 4.4 | 4.6 | 4.6 | 4.7 | 4.6 |
| France | 6.5 | 7.1 | 7.3 | 7.2 | 6.8 | 7.6 | 7.8 | 7.8 | 7.2 | 6.4 |
| Germany | | 10.7 | 11.3 | 11.5 | 11.3 | 11.2 | 11.3 | 10.9 | 9.8 | 8.9 |
| Greece | | | | | | 1.2 | 1.2 | 1.2 | 1.1 | 1.1 |
| Hungary | | | 6.8 | 6.8 | 6.6 | 7.5 | 7.6 | 7.6 | 7.3 | 7.1 |
| Ireland | | | 9.2 | 10.8 | 9.6 | 9.5 | 9.7 | 9.6 | 9.4 | 9.2 |
| Italy | | | 3.6 | 2.7 | 2.4 | 4.7 | 4.4 | 4.2 | 4.0 | 3.6 |
| Latvia | | | 7.6 | 7.4 | 7.1 | 7.6 | 6.8 | 6.1 | 5.5 | 5.1 |
| Lithuania | | 5.7 | 5.6 | 5.3 | 4.9 | 6.7 | 6.5 | 6.3 | 5.6 | 5.0 |
| Luxembourg | 11.0 | 11.0 | 11.1 | 10.9 | 9.5 | 10.2 | 10.5 | 10.7 | 10.9 | 10.8 |
| Malta | | | | | | | | | | |
| Netherlands | | | 8.1 | 7.9 | 7.7 | 8.7 | 8.9 | 7.9 | 5.7 | 4.9 |
| Poland | 5.0 | 5.0 | 5.2 | 5.0 | 4.9 | 8.9 | 7.8 | 6.9 | 5.9 | 5.5 |
| Portugal | 4.2 | 4.5 | 4.1 | 4.4 | 4.2 | 4.6 | 5.2 | 5.6 | 6.2 | 6.8 |
| Romania | 7.5 | 7.4 | 7.4 | 7.4 | 6.7 | 8.3 | 8.0 | 7.1 | 5.7 | 5.0 |
| Slovakia | 6.7 | 6.5 | 6.5 | 6.1 | 6.4 | 7.9 | 7.8 | 7.4 | 7.1 | 7.3 |
| Slovenia | 6.1 | 6.1 | 6.1 | 6.0 | 5.9 | 7.0 | 7.0 | 6.8 | 6.2 | 5.0 |
| Spain | 2.3 | 2.6 | 2.7 | 2.7 | 2.7 | 2.9 | 3.2 | 3.4 | 3.7 | 3.7 |
| Sweden | | | 4.8 | 5.2 | 5.4 | 4.9 | 5.0 | 5.1 | 5.2 | 5.1 |
| United Kingdom | 7.7 | 8.1 | 8.6 | 8.7 | 8.1 | 9.5 | 9.5 | 9.6 | 9.4 | 8.2 |

Table 17: Total wood removals realised in EFISCEN and G4M compared to projected wood production by GLOBIOM in percent.

| | EFISCEN | | | | | G4M | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Country** | **2005** | **2010** | **2020** | **2030** | | **2005** | **2010** | **2020** | **2030** |
| Austria | 100% | 100% | 100% | 100% | | 82% | 82% | 110% | 97% |
| Belgium | 100% | 100% | 92% | 85% | | 113% | 121% | 138% | 131% |
| Bulgaria | 100% | 100% | 100% | 100% | | 63% | 77% | 109% | 101% |
| Cyprus | | | | | | | | | |
| Czech Republic | | 100% | 100% | 100% | | 78% | 82% | 90% | 90% |
| Denmark | 100% | 100% | 100% | 100% | | 84% | 81% | 87% | 92% |
| Estonia | 100% | 100% | 100% | 100% | | 87% | 110% | 78% | 95% |
| Finland | | 100% | 100% | 100% | | 88% | 95% | 90% | 94% |
| France | 100% | 100% | 100% | 100% | | 103% | 104% | 91% | 95% |
| Germany | 100% | 100% | 100% | 100% | | 63% | 80% | 114% | 102% |
| Greece | | | | | | 141% | 100% | 74% | 94% |
| Hungary | | 100% | 100% | 100% | | 93% | 89% | 90% | 104% |
| Ireland | | 100% | 100% | 94% | | 76% | 91% | 97% | 81% |
| Italy | | 100% | 100% | 100% | | 82% | 88% | 84% | 81% |
| Latvia | | 100% | 100% | 100% | | 72% | 96% | 93% | 97% |
| Lithuania | 100% | 100% | 100% | 100% | | 70% | 90% | 108% | 96% |
| Luxembourg | 100% | 100% | 100% | 100% | | 101% | 97% | 137% | 137% |
| Malta | | | | | | | | | |
| Netherlands | | 100% | 100% | 100% | | 111% | 91% | 101% | 96% |
| Poland | 100% | 100% | 100% | 100% | | 69% | 78% | 109% | 92% |
| Portugal | 83% | 92% | 95% | 67% | | 88% | 92% | 109% | 80% |
| Romania | 100% | 100% | 100% | 100% | | 97% | 92% | 104% | 105% |
| Slovakia | 100% | 100% | 100% | 100% | | 68% | 72% | 93% | 97% |
| Slovenia | 100% | 100% | 100% | 100% | | 88% | 81% | 108% | 100% |
| Spain | 100% | 100% | 100% | 100% | | 99% | 95% | 97% | 105% |
| Sweden | | 100% | 100% | 100% | | 72% | 83% | 104% | 95% |
| United Kingdom | 100% | 100% | 100% | 90% | | 81% | 88% | 97% | 95% |

### 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 Figure 14 and Table 18 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 18: Projected development of emissions and removals from forest soils by EFISCEN and it 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 $CO_2$ per year. Positive values show sources, negative values sinks of $CO_2$.

| Country | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|
| Austria | | -250 | -596 | -795 | -1985 | -2069 |
| Belgium | -651 | -154 | 38 | -97 | -310 | -124 |
| Bulgaria | | 1181 | -361 | -41 | -849 | -414 |
| Czech Republic | | | -349 | -1828 | -2107 | -1910 |
| Cyprus | | | | | | |
| Denmark | | -789 | -1177 | -1183 | -1141 | -1186 |
| Estonia | | -1320 | -1551 | -1405 | -610 | -376 |
| Finland* | | | -9641 | -12282 | -12207 | -12705 |
| France | -393 | -7381 | -8072 | -9649 | -12497 | -9484 |
| Germany | | 3882 | -349 | -2201 | -6087 | -9061 |
| Greece | | | | | | |
| Hungary | | | -575 | -891 | -755 | -1127 |
| Ireland | | | -482 | -356 | -662 | -500 |
| Italy | | | -2485 | -3175 | -3728 | -3259 |
| Latvia | | | -2617 | -3486 | -3687 | -3175 |
| Lithuania | | -1035 | -846 | -975 | -1109 | -1219 |
| Luxembourg | -90 | -80 | -105 | -124 | -127 | -128 |
| Malta | | | | | | |
| Netherlands | | | -290 | -464 | -597 | -801 |
| Poland | -3115 | -157 | 2915 | 1068 | -14 | 349 |
| Portugal | -114 | 918 | 1321 | 525 | -377 | -487 |
| Romania | -9973 | -8922 | -9977 | -8234 | -8052 | -7455 |
| Slovakia | -2150 | -1705 | -1384 | -1108 | -1413 | -768 |
| Slovenia | -668 | -592 | -565 | -801 | -1004 | -962 |
| Spain | -3484 | -4976 | -6074 | -5735 | -6963 | -6966 |
| Sweden | | | -7560 | -10335 | -12987 | -15216 |
| United Kingdom | -2923 | -798 | -2063 | -1827 | -2282 | -2155 |
| SUM | | | -52843 | -65398 | -81549 | -81195 |

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

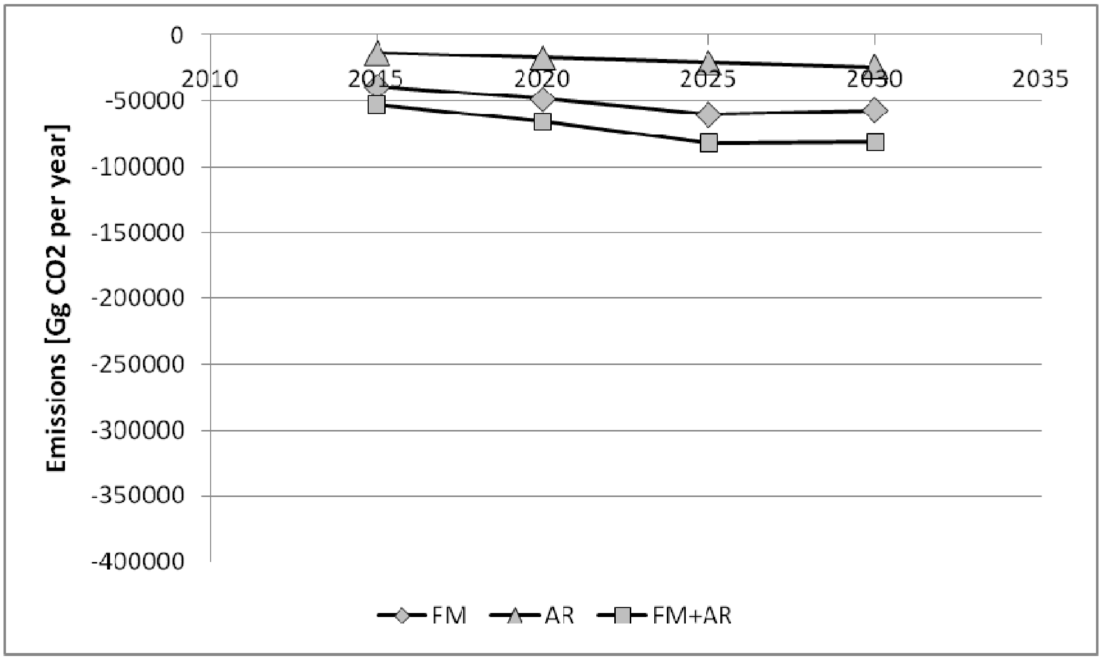

Figure 14: Projected development of emissions and removals from forest soils by EFISCEN and it soils module YASSO in EU-27 (excl. Cyprus, Greece and Malta) for Forest management (FM) and Afforestation/Reforestation (AR) activities in the baseline scenario. Values in Gg $CO_2$ per year. Positive values show sources, negative values sinks of $CO_2$.

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 sols 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 less distinct for the reference scenario compared to the baseline scenario (Table 19). This is because more wood is harvested and more residues are extracted for bio-energy energy production.

Table 19: Projected development of emissions and removals from forest soils by EFISCEN and it soils module YASSO in EU-27 (excl. Cyprus, Greece and Malta) for Forest Management (FM) activities only in the baseline scenario. Values in Gg $CO_2$ per year. Positive values show sources, negative values sinks of $CO_2$.

| Scenario | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| Baseline | -39205 | -48568 | -60407 | -56897 |
| Reference | -41661 | -49461 | -48769 | -52151 |

## 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) 20% higher and 2) 20%

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 20% reduction of harvest levels increases the sink by more than 50% 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.

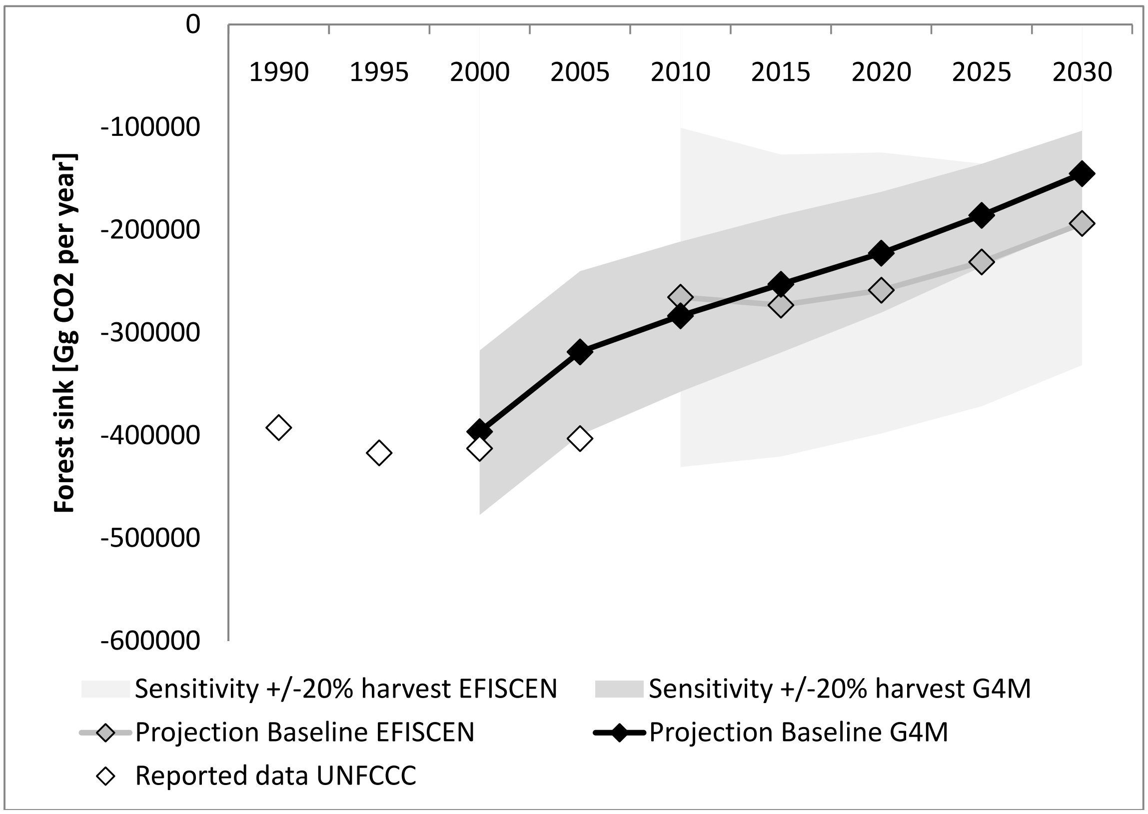


Figure 15: Projection of baseline emissions and removals of forest management activities for EU27 and estimates of 20% higher and lower total wood demand compared to the baseline. A third scenario prescribes constant harvest rates. Sums do not include values of Cyprus, Malta and Greece in order to make 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.

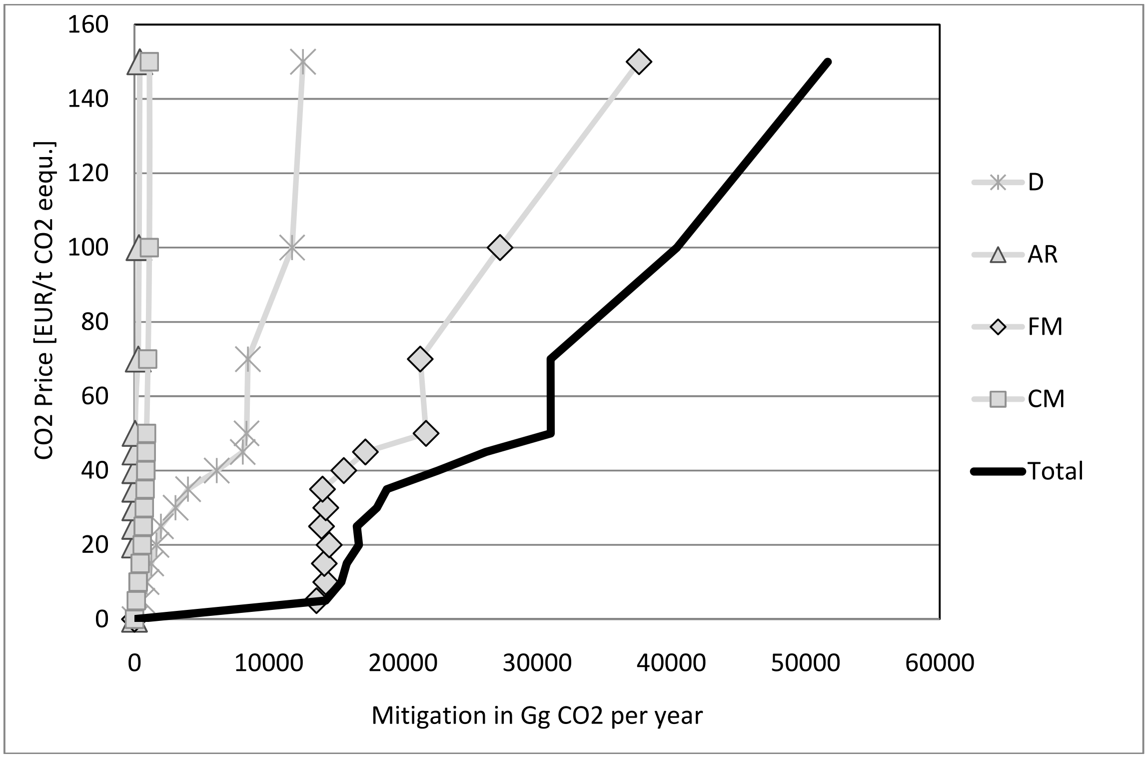


Figure 16: Abatement cost curves for different land use activities for the year 2020. AR, D and FM curves were produced by G4M, CM by EUFASOM. Sums include all 27 EU countries. Values of forestry activities for Cyprus and Malta were not estimated and set to zero.

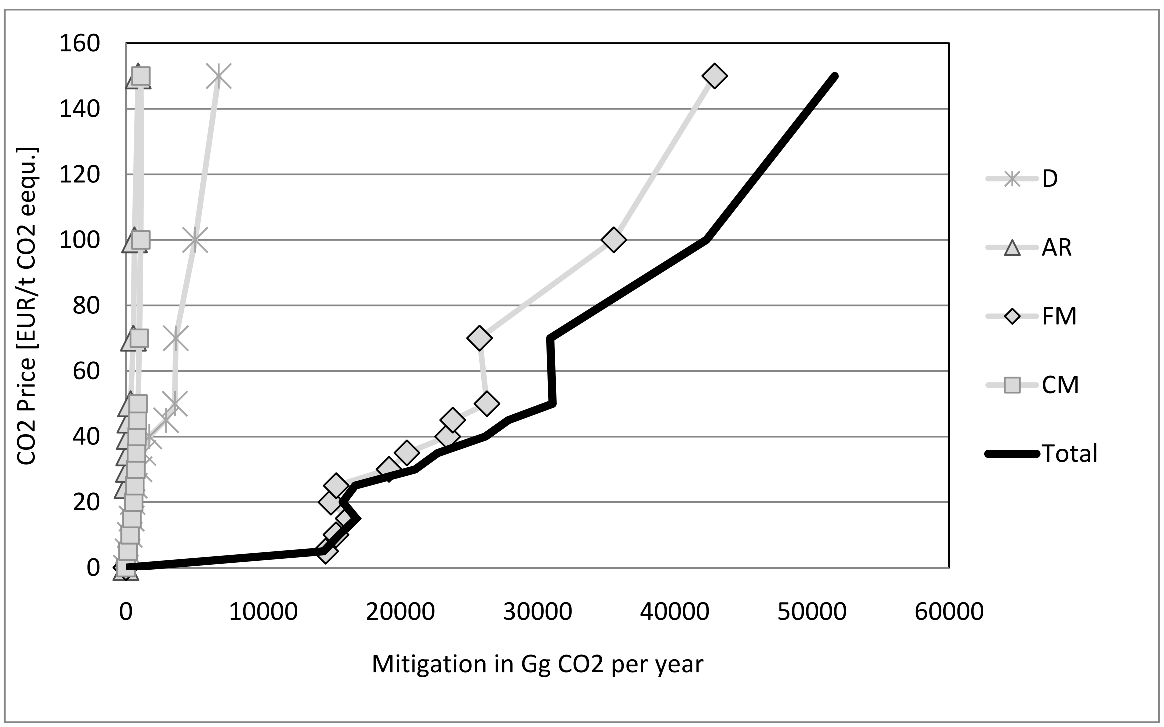


Figure 17: Abatement cost curves for different land use activities for the year 2030. AR, D and FM curves were produced by G4M, CM by EUFASOM. Sums include all 27 EU countries. Values of forestry activities for Cyprus and Malta were not estimated and set to zero.

Table 20: Abatement potential in Gg $CO_2$ 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.

| | Marginal costs in EUR per tonne of $CO_2$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Country** | **5** | **10** | **15** | **30** | **50** | **70** | **100** | **150** |
| Austria | 195.6 | 192.0 | 190.8 | 186.6 | 188.7 | 238.4 | 312.9 | 437.1 |
| Belgium | 67.9 | 69.7 | 64.7 | 58.3 | 34.2 | 31.0 | 41.4 | 58.9 |
| Bulgaria | 268.6 | 255.3 | 285.6 | 368.9 | 852.3 | 1020.6 | 1617.3 | 3848.4 |
| Cyprus | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Czech Rep. | -29.9 | -7.7 | -28.0 | 126.5 | 144.1 | 77.7 | 139.0 | 134.9 |
| Denmark | 10.7 | 11.0 | 11.0 | 8.0 | 14.4 | 15.2 | 16.5 | 18.7 |
| Estonia | 193.2 | 236.0 | 171.3 | 514.1 | 715.6 | 773.5 | 668.8 | 1387.3 |
| Finland | 2058.7 | 2141.1 | 2235.1 | 2550.0 | 3292.3 | 3342.3 | 3915.8 | 3802.5 |
| France | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Germany | 2347.7 | 2324.7 | 2314.9 | 2257.7 | 2334.5 | 2462.6 | 2642.3 | 3066.0 |
| Greece | 675.3 | 709.5 | 677.7 | 951.6 | 937.7 | 1073.5 | 1084.3 | 1219.8 |
| Hungary | 90.7 | 113.5 | 132.4 | 132.6 | 381.8 | 436.1 | 427.2 | 480.3 |
| Ireland | 54.7 | 56.6 | 64.5 | 59.9 | 72.5 | 78.5 | 75.8 | 113.6 |
| Italy | 2373.2 | 2360.6 | 2381.1 | 2861.0 | 3481.4 | 4413.4 | 4882.1 | 5271.9 |
| Latvia | 259.1 | 202.1 | 215.7 | 336.2 | 1037.8 | 1018.9 | 1016.7 | 1700.9 |
| Lithuania | 186.4 | 185.0 | 231.8 | 243.6 | 296.9 | 334.3 | 260.9 | 369.3 |
| Luxembourg | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 |
| Malta | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Netherlands | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Poland | 1211.5 | 1507.1 | 1799.7 | 1342.1 | 3837.3 | 4588.6 | 4908.1 | 5345.4 |
| Portugal | 308.2 | 295.4 | 381.1 | 532.0 | 557.9 | 1561.4 | 3416.1 | 4198.1 |
| Romania | 640.1 | 665.0 | 666.7 | 986.3 | 2161.7 | 2896.0 | 3096.4 | 3098.7 |
| Slovakia | 281.0 | 276.6 | 273.8 | 292.2 | 265.9 | 235.0 | 264.2 | 1006.9 |
| Slovenia | 108.5 | 112.9 | 143.8 | 198.6 | 242.5 | 290.5 | 329.6 | 327.3 |
| Spain | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Sweden | 2740.3 | 2738.9 | 2739.5 | 2693.7 | 4396.2 | 4716.3 | 10145.5 | 13782.0 |
| UK | 3.3 | 6.7 | 10.2 | -7.5 | 94.4 | 93.4 | 164.5 | 91.5 |
| SUM | 14044.7 | 14452.0 | 14963.5 | 16692.4 | 25340.1 | 29697.3 | 39425.5 | 49759.5 |

Table 21: Abatement potential in Gg $CO_2$ 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.

| | Marginal costs in EUR per tonne of $CO_2$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Country** | **5** | **10** | **15** | **30** | **50** | **70** | **100** | **150** |
| Austria | 15.9 | 31.9 | 47.8 | 95.7 | 159.5 | 175.4 | 227.0 | 373.6 |
| Belgium | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Bulgaria | 251.5 | 92.4 | 191.3 | 707.3 | 675.7 | 646.8 | 719.2 | 2757.5 |
| Cyprus | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Czech Rep. | 269.7 | 271.4 | 247.1 | 270.4 | 209.5 | 175.1 | 146.8 | 146.8 |
| Denmark | 64.2 | 67.2 | 67.7 | 69.3 | 66.0 | 107.1 | 117.3 | 117.3 |
| Estonia | 121.4 | 29.8 | 49.7 | 202.3 | 499.6 | 499.6 | 482.3 | 472.2 |
| Finland | 2568.8 | 2601.5 | 3083.7 | 3479.8 | 3977.2 | 4415.1 | 4273.9 | 4626.2 |
| France | 2415.2 | 2360.5 | 2437.0 | 3061.0 | 2965.7 | 3141.3 | 3317.0 | 3492.7 |
| Germany | 1177.8 | 1381.8 | 1234.8 | 1227.7 | 1435.4 | 1342.7 | 1411.5 | 2490.0 |
| Greece | 944.4 | 867.1 | 1019.6 | 962.9 | 822.3 | 1124.0 | 1195.5 | 1174.7 |
| Hungary | 30.9 | 63.8 | 87.8 | 303.8 | 523.1 | 522.2 | 469.3 | 668.2 |
| Ireland | 115.3 | 118.3 | 121.1 | 179.1 | 158.2 | 173.9 | 189.6 | 205.3 |
| Italy | 3476.8 | 3211.8 | 3266.2 | 3264.0 | 3663.4 | 5881.3 | 6900.1 | 7502.8 |
| Latvia | 229.2 | 302.6 | 220.6 | 170.2 | 1256.3 | 1031.4 | 1027.1 | 1451.4 |
| Lithuania | 389.0 | 406.7 | 357.9 | 427.2 | 374.2 | 318.7 | 250.3 | 442.3 |
| Luxembourg | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Malta | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Netherlands | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Poland | 454.0 | 1639.8 | 2104.9 | 2238.0 | 1772.7 | 5520.6 | 5802.7 | 5848.2 |
| Portugal | 176.5 | 129.8 | 85.1 | 532.0 | 557.9 | 1330.1 | 2766.7 | 3251.9 |
| Romania | 600.3 | 634.4 | 710.2 | 411.2 | 1021.7 | 1773.0 | 2196.0 | 2244.8 |
| Slovakia | 226.2 | 282.1 | 234.4 | 290.0 | 251.8 | 246.4 | 240.2 | 478.7 |
| Slovenia | 0.5 | 0.0 | 33.9 | 73.0 | 98.2 | 85.3 | 94.1 | 102.9 |
| Spain | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Sweden | 764.2 | 708.7 | 719.1 | 3249.1 | 9286.1 | 9438.6 | 9591.2 | 12933.6 |
| UK | 257.0 | 238.8 | 230.9 | 248.7 | 401.2 | 408.6 | 416.0 | 337.2 |
| SUM | 14548.6 | 15440.6 | 16550.8 | 21462.8 | 30175.8 | 38357.2 | 41834.0 | 51118.3 |

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 baseline afforestation this leads to a situation where even high carbon prices do not trigger additional afforestation (see Figure 16 and Figure 17). 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 $CO_2$ 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 favourable. 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 $CO_2$ price was only used to assess changes in forest management practices. An increasing $CO_2$ price could also lead to investment in new harvesting technology allowing more efficient harvesting (less harvest losses). However, these potential impacts of $CO_2$ 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 $m^3$ 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 $CO_2$ emissions or removals.

The future roundwood production is based on projections by GLOBIOM and PRIMES. The projection

[12] FAOSTAT data have been updated afterwards

by these two models depends on the same macro-economical developments. Furthermore, it was ensured 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 $CO_2$ 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 (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 influences 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 $CO_2$ 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 $CO_2$ 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 $CO_2$ 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 $CO_2$.

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