PROJECT N. 037033

EXIOPOL

A NEW ENVIRONMENTAL ACCOUNTING
FRAMEWORK USING EXTERNALITY
DATA AND INPUT-OUTPUT TOOLS
FOR POLICY ANALYSIS

Dose-response functions for the main forest externalities

Report of the EXIOPOL project

Title	Dose-response functions for the main forest externalities
Purpose	
Filename	EXIOPOL_PDII4b2_final.pdf
	EXIOPOL_PDII4b2_ResponseFunctions.xls
Authors	Hans Verkerk and Marcus Lindner
Document history	-
Current version	2
Changes to previous version	Revised structure, improved methods description, improved indicator for recreation, revised discussion.
Date	15 February 2011
Status	Final
Target readership	EXIOPOL project partners
General readership	EXIOPOL project partners
Dissemination level	Restricted to EXIOPOL project partners (including the Commission Services)

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15 February 2011

Prepared under contract from the European Commission

Contract no 037033-2
Integrated Project in
PRIORITY 6.3 Global Change and Ecosystems
in the 6th EU framework programme

Deliverable title:	Dose-response functions for the main forest externalities
Deliverable no. :	PDII.4.b-2
Due date of deliverable:	Month 40 (update)
Period covered:	from 1st March 2007 to 1st March 2011
Actual submission date:	15 February 2011
Start of the project:	01.03.2007
Duration:	4 years
Start date of project:	01.03.2007
Project coordinator:	Anil Markandya
Project coordinator organisation:	FEEM

Preamble

EXIOPOL ("A New Environmental Accounting Framework Using Externality Data and Input-Output Tools for Policy Analysis") is an Integrated Project funded by the EU's 7th Framework Program. It runs between March 2007 and 2011. The EXIOPOL project has 3 principal objectives:

1. To synthesize and develop comprehensive estimates of the external costs for Europe of a broad set of economic activities;
2. To set up a detailed environmentally extended (EE) Input-Output (IO) framework, with links to other socio-economic models, in which as many of these estimates as possible are included. Such an EE-IO table for the EU 25 does not exist. This will allow for the estimation of environmental impacts and external costs of different economic sector activities, final consumption activities and resource consumption for countries in the EU;
3. To apply the results of the external cost estimates and EE-IO analysis for the analysis of policy questions of importance, as well as to evaluate the impact of past research on external costs on policy-making in the EU.

The current report is a revision of the second deliverable from the forestry work package (WP) II.4.b on sources of forest externalities and estimation of dose response function. In this report, a literature review is presented on existing dose-response functions Furthermore, generic dose-response functions were estimated that could be used for scenario analyses in the EE-IO framework of cluster III. The approach presented for the generic response functions was discussed with partners of Cluster II and III at a project meeting during a meeting in Amsterdam on 23 January 2009. Finally, policy scenarios were defined and results of the scenario analysis are presented in this report. These scenarios were analysed during an internal workshop in Barcelona (24-28 August 2009). We would like to thank David Edwards for providing details on the recreation index included in the analysis.

All dose-response functions included in this report link changes in land use to changes in different forest goods and services and are expressed in physical units. The results will be combined with the economical valuation approach developed in deliverable PDII.4.b-3, which contains the results of the meta-data analysis linking the monetary values with the physical characteristics of forests. The combined results will be presented in milestone MII.4.b-2.

Marcus Lindner

Coordinator of WPII.4.b

EXIOPOL project

15 February 2011

Executive summary

Within the EXIOPOL project a number of forest goods and services have been identified, based on their importance at the European level. In this report we present (i) the results of a literature review on existing response functions concerning these goods and services, (ii) generic response functions estimated for the environmentally extended (EE) Input-Output (IO) framework developed within Cluster III of the EXIOPOL project, and (iii) the results of a policy scenario analysis on intensified biomass removal and increased forest protection.

There are few response functions available from literature concerning important forest goods and services. Several functions have been estimated in the SENSOR project related to possible reforms of the Common Agricultural Policy for the year 2025. The results indicate that such reforms have little effect on the provisioning of the most important forest goods and services at the European level for the time-span considered. Due to the limited availability of response functions from literature, we developed country-specific response functions for wood production and carbon sequestration that could be used in the EE-IO modelling framework.

Separately from the response function, we conducted a scenario analysis on intensified biomass removal and increased forest protection. The scenarios analysed were a baseline scenario (no policy changes, a moderate increase in wood extraction and no extraction of residues), a bio-energy scenario (wood and residue removal intensified to the potential maximum), a biodiversity protection scenario (set aside 10% of forest area, with strong restrictions on harvesting in the protected areas), and a combined scenario in which the area of protected forests was increased and the biomass removals in the unprotected forest area. The impacts of these scenarios was analysed on the following forest goods and services:

- Round- and fuelwood production
- Biodiversity
- Climate regulation (carbon sequestration)
- Recreation

We found that there is a substantial potential for intensifying the use of forest biomass and it can have strong impacts on carbon sequestration, biodiversity and recreation. On the other hand, setting aside 10% of the forest area for biodiversity protection appears to have minor impacts on these forest goods and services. These results serve as input to milestone MII.4b-2, in which they will be combined with an economical evaluation, which will allow us to compare the impacts on these goods and services together and may enable us to find an optimal strategy towards renewable energy and biodiversity objectives.

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1 Introduction

Forests provide a broad range of goods and services that are important to human society (MEA 2005). EXIOPOL deliverable report DII.4b-1 lists a number of forest goods and services for which the impacts of land use changes could be estimated, based on the availability of data at the European level (European Union member countries, Norway and Switzerland) and/or suitable modelling approaches. In the current report, we link changes in (policy induced) forest land use to changes in the provisioning of a range of forest goods and services. The approach applied within the forestry work package II.4.b has been defined in the EXIOPOL deliverable report DII.4b-1 and is schematically presented in Figure 1.

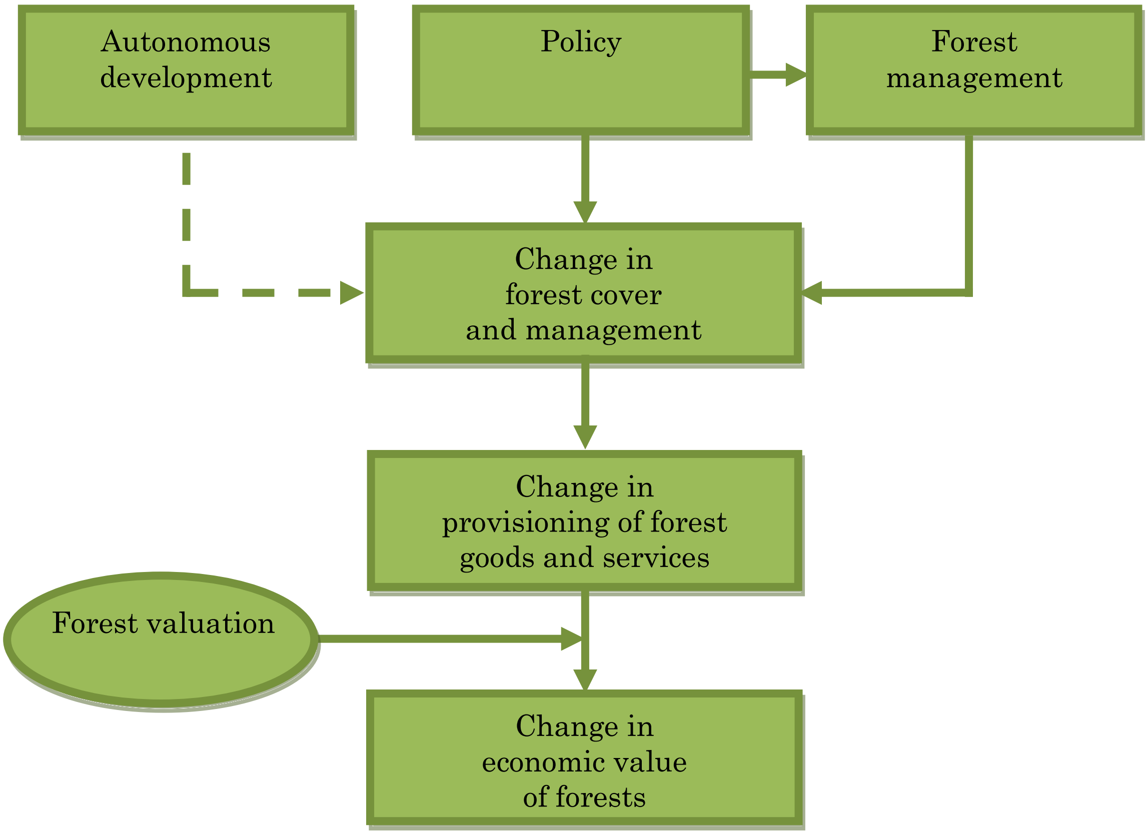

Figure 1: Conceptual framework of the forestry work package II.4.b in EXIOPOL

Approaches were defined how these goods and services could be estimated, focusing in particular on linking them to the European Forest Information SCENario model (EFISCEN) (Sallnäs 1990; Schelhaas *et al.* 2007). However, when taking into account the availability of data at the European level and/or suitable modelling approaches, not all these indicators can be quantified within EXIOPOL. Furthermore, when considering the available data on monetary values as collected in other EXIOPOL work tasks (Giergiczny *et al.* 2008a, b), it was concluded that only a limited amount of services/indicators could be considered for an economic valuation. The selected indicators are shown in Table 1 and are defined as:

- Wood removals: the volume of stemwood extracted from the forest during thinnings and final fellings;
- Harvest residue production: the mass of stem parts and branches extracted from the forest during thinnings and final fellings;
- Deadwood: the mass of standing and downed dead trees resulting from mortality and stem residues left in the forest after thinning and final fellings;
- Carbon sequestration: the mass of carbon stored in forest biomass, soil and dead organic matter during one year;
- Recreation index: the average public preference value of different forest stands for recreation.

Table 1: Overview of the major classes of forest services and goods and services (MEA 2005) included in this study with their indicators and items that can be considered in the economic valuation (Giergiczny *et al.* 2008b)

Class	**Forest good or service**	**Indicator**	**Item valued**
Resource	Industrial wood	Wood removals	Wood removals
	Fuelwood	Wood removals	Wood removals
		Harvest residues	Harvest residues
Biospherical service	Biodiversity protection	Deadwood	Recreational value protected forests
	Climate regulation	Carbon sequestration	Carbon sequestration
Social service	Recreation	Public preference for recreation	Recreational value unprotected forests

The indicators listed in Table 1 are all directly based on outputs from the EFISCEN model. It should be noted that the identified indicators are not explicitly included in the economical valuation. For example, we used deadwood as an indicator for biodiversity because it is positively correlated with species richness (Lonsdale *et al.* 2008). However, the economical value biodiversity protection will be based on the extent of the protected forest area. Furthermore, recreation will be economically values based on the area designated for recreational purposes, but as an indicator we use a recreation index indicating the average preference of forests in a region for recreation (Edwards *et al.* 2011).

In this report we present response functions, which capture the quantitative impacts of (policy induced) changes in forest land cover and management on the provisioning of the abovementioned forest goods and services. We first provide a brief overview on existing dose-response functions (chapter 2), but we also developed approaches to estimate new dose-response functions due to limited availability of suitable existing response functions in literature. The approach is presented in chapter 3, together with the description of a number of policy scenarios that were developed. The estimated response functions, as well as the results of the scenario analyses, are presented in chapter 4 and discussed in chapter 5. Chapter 6 ends with some conclusions.

All dose-response functions included in this report are expressed in physical units. The results will be combined with the economical valuation approach developed in deliverable PDII.4.b-3 (Giergiczny *et al.* 2008b), which contains the results of the meta-data analysis linking the monetary values with the physical characteristics of forests. The combined results will be presented in milestone MII.4.b-2.

2 Literature review

2.1 General approach

- We reviewed scientific literature for already estimated dose-response functions concerning forest land use, or results from which response functions could be estimated. We only considered the studies, which complied with the following criteria:Available data should not represent 'point' estimates. A large number of studies analysed alternative scenarios related to forest land use, but commonly only the most extreme scenario results are presented. This does not allow the estimation of response functions, because the functions are not necessarily linear.
- The studies should be preferably European-wide, because our study area comprises the European Union, Norway and Switzerland

To our knowledge, only results from the SENSOR project (Helming *et al.* 2008; Helming *et al.* accepted) fulfil these criteria. The SENSOR project covered several different land use sectors, but we shall focus only on response functions for the forest sector.

2.2 SENSOR response functions

In the SENSOR project a linked system of models was designed (Jansson *et al.* 2008a) (Figure 2). The linked system consists of five sector models: agriculture (CAPRI), forestry (EFISCEN; see also chapter 3), urbanization (SICK), tourism (B&B) and transport & infrastructure (TIM). All five sector models are connected to the macro-econometric model NEMESIS. Additionally, the land cover model Dyna-CLUE is used to disaggregate land use within the countries to a 1 km^2 grid, which is useful for evaluating impacts on a disaggregated scale but also for communicating results between models of different spatial resolution.

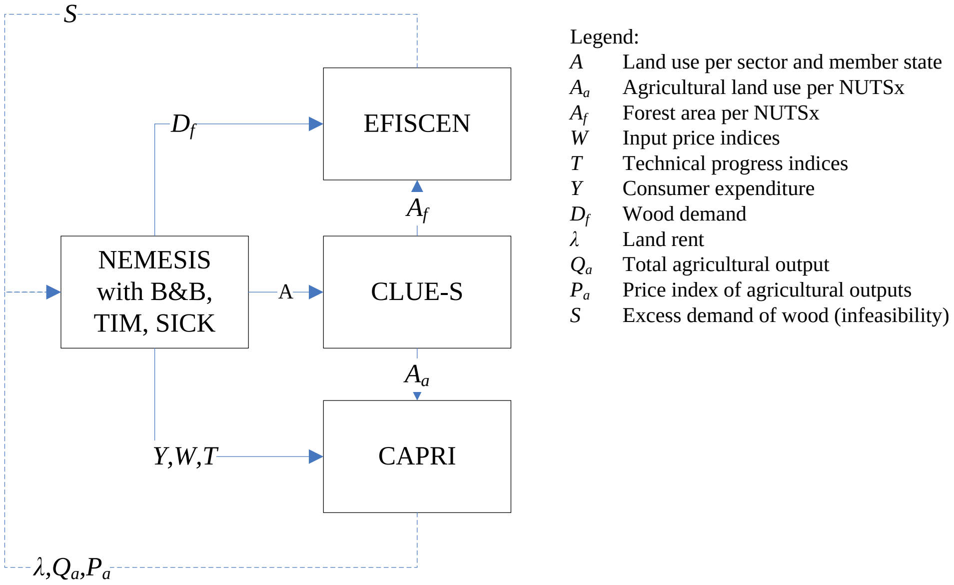

Figure 2: The SENSOR linked model system (Jansson *et al.* 2008a)

The model chain was applied to investigate sustainability impacts *inter alia* of reforms in the Common Agriculture Policy (CAP) (Jansson *et al.* 2008b; Kuhlman *et al.* 2008; Helming *et al.* accepted). In the SENSOR project a policy reform was investigated consisting of (*i*) removal of the direct income support in CAP Pillar I, (*ii*) removal of agricultural border protection for the EU versus all third countries, and (*iii*) transfer of the funds thus released in Pillar I either to general R&D or to general tax refunds. In total, 20 simulations were carried out in which the level of direct income support was stepwise reduced from current levels to no direct income support at all, agricultural market support (import tariffs and export subsidies) and quota (sugar and milk) was abolished and the amount of public expenditure saved by abolishing market support and/or reduction of farm income was either returned to the tax-payer or reinvested to research & development (Figure 3).

All scenarios are quantitatively analysed for the year 2025 for the European Union, excluding Bulgaria, Cyprus, Greece and Malta. Detailed results for all main land use sectors are presented by Jansson *et al.* (2008b), below the impacts of the CAP reform on the forest goods and services in EXIOPOL are shown.

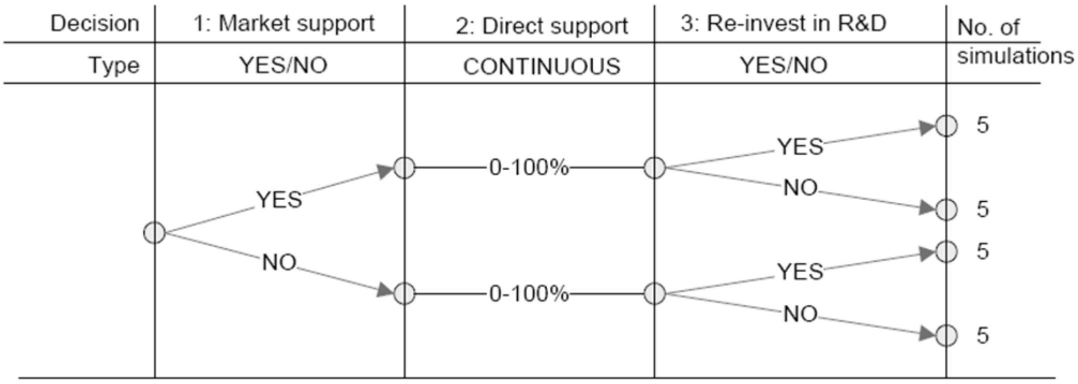

Figure 3: Schematical overview of the scenarios analysed related to the CAP financial reform in the SENSOR project (Kuhlman *et al.* 2008)

2.2.1 Wood and biomass production

Overall, reform of the CAP appears to have minor impacts on the amount of wood produced in 2025 (Figure 4). When all agricultural subsidies are abolished and all money is reinvested in research and development, wood production increases to 387 thousand m³ (+0.45%) compared to the baseline. Removing market support and reinvestment in research and development have the strongest effect on wood production. The estimated response functions are presented in Table 2.

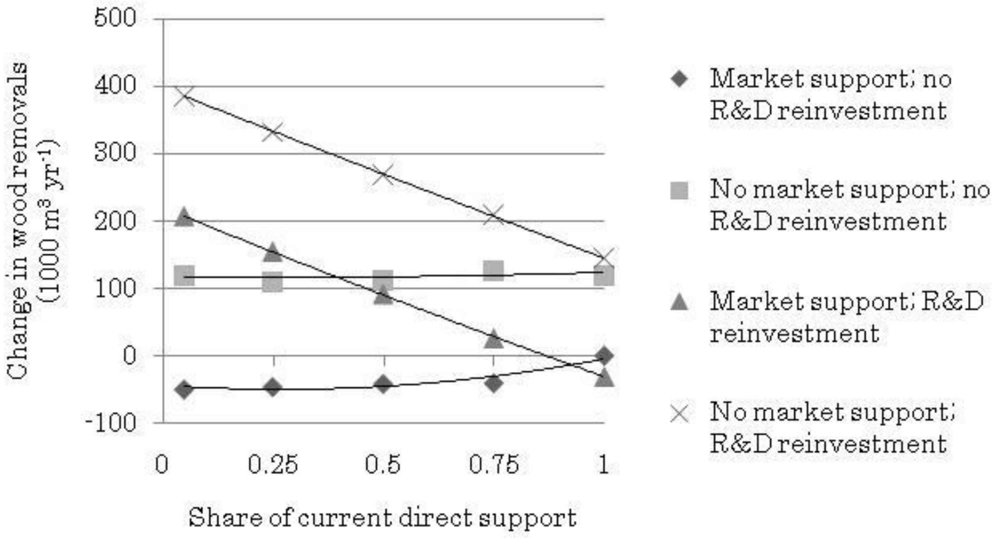

Figure 4: Deviation in volume of wood removals due to CAP reform compared to the baseline in 2025

Table 2: Response functions relating changes in direct income support (share (0-1) of current levels) to changes in the volume of wood removals (1000 m^3) compared to the baseline scenario in 2025.

Market support	R&D reinvestment	Response functions
Yes	No	$y = 87.306x^2 - 47.428x - 43.943$
No	No	$y = 16.154x^2 - 9.4835x + 117.18$
Yes	Yes	$y = 17.482x^2 - 268.82x + 220.39$
No	Yes	$y = 7.4813x^2 - 260.29x + 398.54$

2.2.2 Carbon sequestration

Reforming CAP leads in all cases to an increase of the amount of carbon stored in forest biomass, soil and organic matter (Figure 5). This is largely due to an increase of the forest area, following abandonment of agricultural land. The maximum gain compared to the baseline is 1.9 Tg of carbon (2.6% increase). Stronger impacts may be expected later in time, i.e. after 2025. The estimated response functions are presented in Table 3.

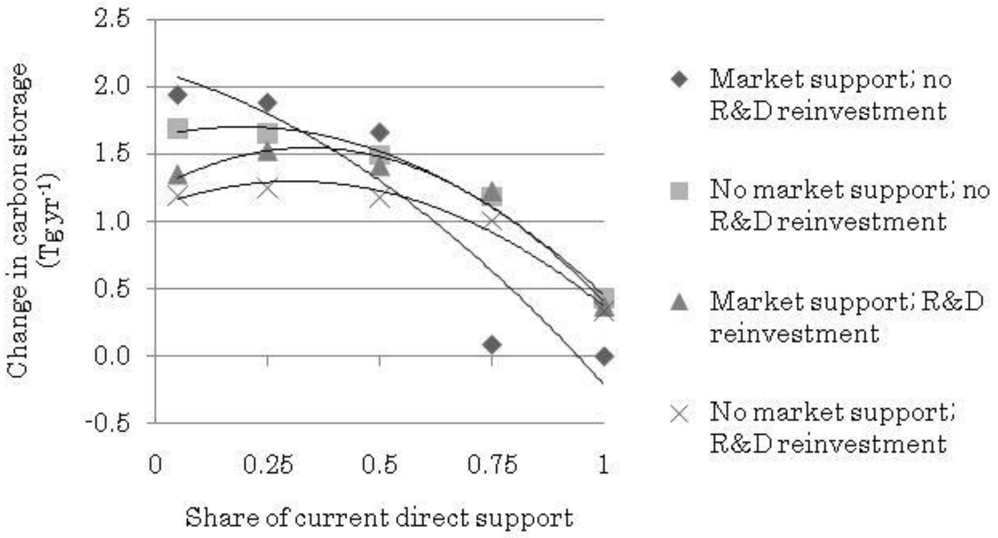

Figure 5: Deviation in carbon sequestration due to CAP reform compared to the baseline in 2025

Table 3: Response functions relating changes in direct income support (share (0-1) of current levels) to changes in carbon sequestered in forest biomass, litter and organic matter (Tg carbon) compared to the baseline scenario in 2025.

Market support	R&D reinvestment	Response functions
Yes	No	$y = -1.3988x^2 - 0.9253x + 2.1134$
No	No	$y = -1.9123x^2 + 0.737x + 1.6311$
Yes	Yes	$y = -2.6411x^2 + 1.8091x + 1.2412$
No	Yes	$y = -1.9504x^2 + 1.2106x + 1.1116$

2.2.3 Biodiversity

Reform of CAP does not have any significant impacts on the amount of deadwood in forests at the EU level. The maximum change in the amount of deadwood per hectare is -0.7% compared to the baseline scenario. Response functions have therefore not been estimated.

2.2.4 Recreation

Recreation has not been estimated in SENSOR.

3 Methods

3.1 The EFISCEN model

EFISCEN is a large-scale forest scenario model that projects forest resource development on regional to European scale (Nabuurs *et al.* 2007; Eggers *et al.* 2008). A detailed model description is given by Schelhaas et al. (2007) and a schematic overview is shown in Figure 6.

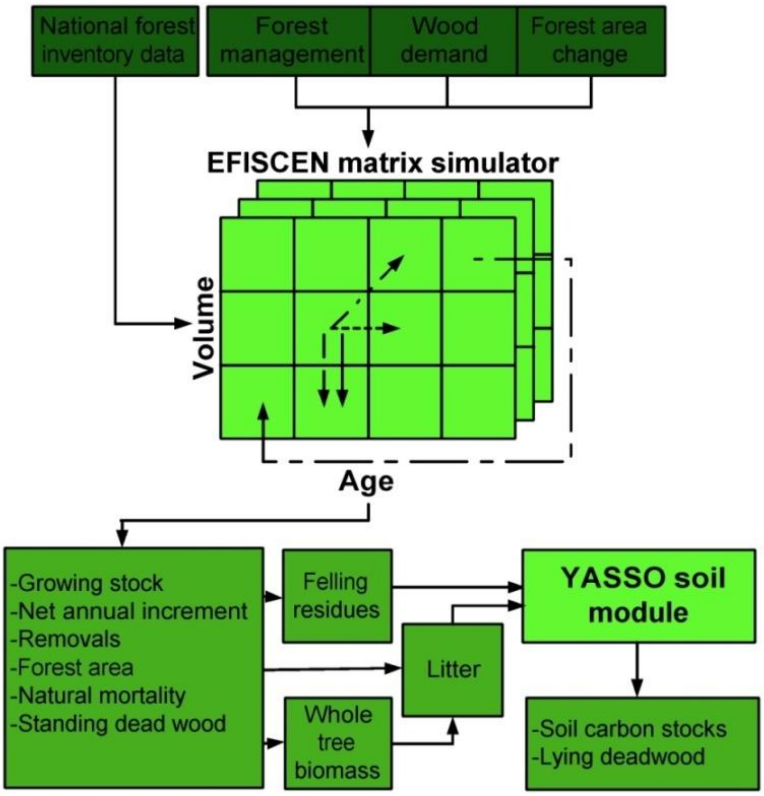

Figure 6: Schematical presentation of the EFISCEN model (Sallnäs 1990; Schelhaas et al. 2007)

In EFISCEN, the state of the forest is described as an area distribution over age- and volume-classes in matrices, based on forest inventory data. Transitions of area between matrix cells during simulation represent different natural processes and are influenced by management regimes and changes in forest area. 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 or yield tables.

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. The proportion of volume from thinning and final fellings that is removed from the forest is specified; stem parts that are left in the forest become stem residues (e.g. stem tops). Another parameter defines the fraction of stem residues that is removed from the forest. Model outputs consist of forest area and volumes of growing stock and increment for five year time-steps.

Based on the information mentioned above, EFISCEN projects stem wood volume, increment, age-class distribution, removals, forest area, natural mortality and dead wood for every five year time-step. With the help of biomass expansion factors, stem wood volume is converted into whole-tree biomass and subsequently to whole tree carbon stocks. Information on litterfall rates, felling residues and natural mortality is used as input into the soil module YASSO (Liski *et al.* 2005), which is dynamically linked to EFISCEN and delivers information on forest soil carbon stocks.

3.2 Data

Detailed forest inventory data on area, growing stock, annual increment and mortality was collected by Schelhaas *et al.* (2006) and Verkerk *et al.* (2011) for the 26 countries in our study. We used improved inventory data for Bulgaria and collected additional data on mortality for Norway and Switzerland. All forest inventory data that was used came from national forest inventories conducted between the 1980s and the year 2001. For several countries, there were small deviations between the forest area available for wood supply (FAWS) in our dataset and the areas reported in MCPFE (2007). We corrected for this by multiplying the area in each country by the ratio between FAWS area (MCPFE 2007) and the forest area in our dataset.

To convert stemwood volume into whole tree biomass, we used basic wood densities (IPCC 2003), a generic carbon content of 0.5, and age-dependent biomass distributions based on published biomass expansion factors (Vilén *et al.* 2005; Gasparini *et al.* 2006; Mokany *et al.* 2006). To assess carbon fluxes from forest soils, we specified litterfall rates (Vilén *et al.* 2005), which together with unused harvest residues form input to the soil module YASSO. Fractionation and decomposition of litter and residues were modelled by YASSO, based on cumulative degree days (0°C threshold) and the summer drought index (Liski *et al.* 2005). Average degree days and drought index values were calculated from Mitchell *et al.* (2004) for every EFISCEN region over the period 1961-1990.

We used the direct model outputs on roundwood production, harvest residue production, deadwood and carbon sequestration (Table 4).

The average recreation index for each country was calculated by multiplying (i) the area in different age-classes as projected by EFISCEN, with (ii) age-class and species-group specific recreational scores for different forest types across Europe obtained from Edwards *et al.* (2011). The recreational scores are based on separate Delphi surveys for four European regions, involving 46 experts (10 to 14 experts per region) for each region and represent the average public preference value of different forest stands for recreation. The data for each region were extrapolated to other similar European countries (Schelhaas et al. in prep.) and shown in Table 1.

Table 4: recreation scores for broadleaved (brl) and coniferous (con) species in protected and unprotected forests across Europe, based on Edwards *et al.* (2011).

Region	Countries	Age-limits	Recreational score			
			Unprotected		Protected	
			Brl	Con	Brl	Con
Nordic	Estonia, Finland, Latvia, Lithuania, Norway, Sweden	0-5	1.5	1	2	2
		5-15	3	2.5	3.5	3
		15-50	7	5.5	8	7
		>50	8	8	10	9
Great Britain	Ireland, United Kingdom	0-5	2.5	1	3.5	3
		5-15	3.5	2	6	3
		15-50	5	3	8	5
		>50	6	4.5	10	7
Central	Austria, Belgium, Bulgaria, Czech Republic, Denmark, France, Germany, Hungary, Luxembourg, the Netherlands, Poland, Slovak Republic, Slovenia, Romania, Switzerland	0-5	2	1	4	4
		5-15	3	2	5	4
		15-50	5	3	7	6
		>50	6	4	9	7.5
Iberia	Italy, Portugal, Spain	0-5	2	1	3	2

		5-15	3	1.5	5	3.5
		15-50	5	4	7	6.5
		>50	6	5	8.5	8

3.3 Scenarios

3.3.1 Generic response functions

We used the EFISCEN model to estimate generic dose-response functions, which could be used for scenario analyses in the EE-IO framework of cluster III. Due to the requirements of the EE-IO framework, response functions could only be estimated for roundwood production and climate regulation (carbon sequestration).

The response functions link a demanded amount of wood (in 1000 m^3 yr^{-1}) in the period 2001-2005 (due to the model's five-year time steps) to the volume of roundwood that can be harvested and to the amount of carbon sequestered in forest biomass, soil and organic matter. The maximum harvest potential was determined by estimating the long-term harvest level for thinning and final fellings that could be sustained until the year 2100. We conducted in total six model simulations (using the same set-up as described above) and varied wood demand between 10, 20, 40, 60, 80 and 100% of this maximum demand for the period 2001-2005. The demand for following years followed the wood demand in the baseline scenario.

The estimated response functions are based on a linear regression with resource use (wood demand) as independent variable and EFISCEN projections of wood production and sequestered carbon as dependent variables. We applied simple linear regressions, due to the requirements of the EE-IO modelling framework. The response functions are estimated here for the years 2005, 2025 and 2050.

3.3.2 Policy scenarios

In addition to developing these generic response functions, EFISCEN was applied to analyse the impacts of a number of policy scenarios for the goods and services included in our study for the European Union member countries (excluding Cyprus, Greece and Malta), Norway and Switzerland until the year 2050.

In Europe, intensified use of forest biomass for renewable energy production and forest biodiversity protection are two important topics related to forest land use. However, the combination of policies related to biodiversity and to bio-energy may result in a classical dilemma between wood production and forest biodiversity and also with other important goods and services including carbon storage and recreation. The aim of the policy scenario analysis is to analyse possible trade-offs between forest biomass production and biodiversity protection.

We analysed a baseline scenario and multiple scenarios in which we combined intensified biomass removals for bio-energy production with increasing shares of protected forests for biodiversity protection. Below the different scenario storylines are defined;

- In the *baseline scenario* we assumed no changes in policies or management strategies throughout the simulation. Wood demand was taken from demand projections for OECD Europe by the IMAGE model (Image Team 2001) based on the B2 storyline of the Intergovernmental Panel on Climate Change (IPCC) (Nakicenovic & Swart 2000). The B2 scenario represents increased concern for environmental and social sustainability, with a trend toward local self-reliance and stronger communities. The demand for the 26 countries included in this study increased from 447 million m^3 in 2005 to 508 million m^3 in 2025 and declined afterwards to 469 million m^3 in 2050. Final fellings were assumed to make up 67% of total fellings, with 33% of the wood coming from thinnings. Harvest residues were not removed from the forest.
- In the *bio-energy scenario* we extracted harvest residues (stem parts and branches) and increased the felling level to the maximum sustainable potential (where possible) from 2010 onwards. We applied environmentally compatible harvest residue extraction rates from EEA (2006), which relate to the suitability for stem residue extraction (% of residue ha^{-1}) and are based on environmental criteria including slope, elevation, soil water regime, base saturation in top- and subsoil and soil type. The maximum, long-term harvest potential was determined by estimating the long-term, average harvest level for thinning and final fellings that could be sustained until the year 2100.
- In the *biodiversity scenario* we applied a baseline wood demand, but we set aside forest area to increase the protected forest area and applied felling restrictions to these protected areas. Felling restrictions were calculated from data collected by the COST action E27 study on protected forests in Europe (Frank *et al.* 2007). Restrictions to conventional management practices in protected forest areas were estimated by the national experts from this data we calculated felling restrictions expressed as a percentage reduction in wood supply; 0% means that fellings are allowed without restrictions and 100% means that fellings are strictly prohibited (Verkerk *et al.* 2008). Average felling restrictions in protected forests are presented in Figure 7. For countries with no data on felling restrictions available we used the felling restrictions from neighbouring countries; for Hungary, Poland and Slovakia we used the

restriction level calculated for the Czech Republic, for Estonia and Latvia we used the value from Lithuania and for Luxembourg we used the value from France. We increased the protected forest area by setting aside 10% of the forest available for wood supply. Harvest residues were not removed from the forest.

- In the *combined scenario* we set aside 10% of the forest area available for wood supply as in the biodiversity scenario, but we increased the harvest level to the maximum, long-term harvest level in the remaining forest area, similarly as in the bio-energy scenario.

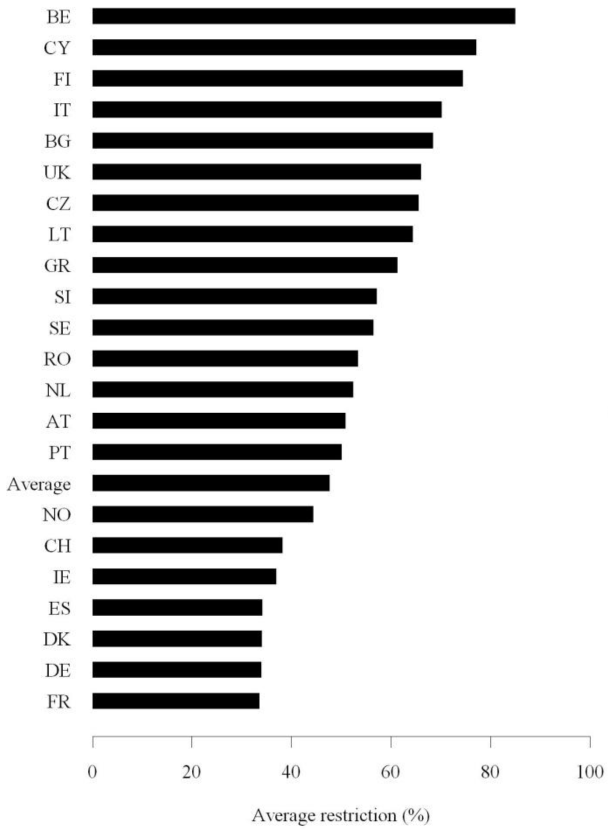

Figure 7: Average felling restrictions in protected forests with biodiversity protection as primary objective (Verkerk *et al.* 2008). 0% means that fellings are allowed without restrictions and 100% means that fellings are strictly prohibited.

In all scenarios we assumed constant climatic conditions throughout the simulations. We used historical roundwood production (FAOSTAT 2009) converted to overbark volumes (UNECE-FAO 2000) as wood demand until the year 2005. Age-limits for thinnings and final fellings were based on conventional forest management according to handbooks on a country-level (Nabuurs *et al.* 2007) and did not change during the simulations. The proportion of volume from thinning or final fellings being removed from the forest was calculated on a country level, distinguishing between coniferous and broadleaved species (UNECE-FAO 2000).

We analysed the impacts of all scenarios on roundwood and harvest residue production, carbon sequestration, deadwood, and recreation.

4 Results

4.1 Generic response functions

The response functions[1] provide the total amount of wood produced or carbon sequestered for any cubic meter of wood demanded. A change in the demanded amount of wood in 2005 has an immediate effect on wood production and carbon sequestration in 2005, but the effect in 2025 and 2050 is almost negligible (slope is almost 0) (Figure 8). This suggests that the demand for wood in 2001-2005 does not or hardly affect the amount of wood that can be harvested, as well as the amount of carbon sequestered in 2025 and 2050. Only the amount of carbon sequestered in 2050 seems to increase due to changes in resource use in 2001-2005. This is probably due to the fact that increased felling levels result in a larger share of young forests with high increment rates, thus sequestering carbon at a higher rate.

The response functions are based on a simple linear regression, due to the requirements of the EE-IO modelling framework. For the results in the year 2005 linear regressions are a suitable option. For 2025 and 2050, simple linear regressions are a suitable solution for most countries, but not for all. In the annex all response functions with an R^2 below 0.95 (indicated in red) should be considered as (far) less reliable. The tables in the annex also contain information on the range (minimum and maximum value) for which the response functions have been estimated. The range is different for all countries and depends on the extent of the forest area and the age-structure of the forest.

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[1] Response functions are presented in the file EXIOPOL_PDII4b2_ResponseFunctions.xls

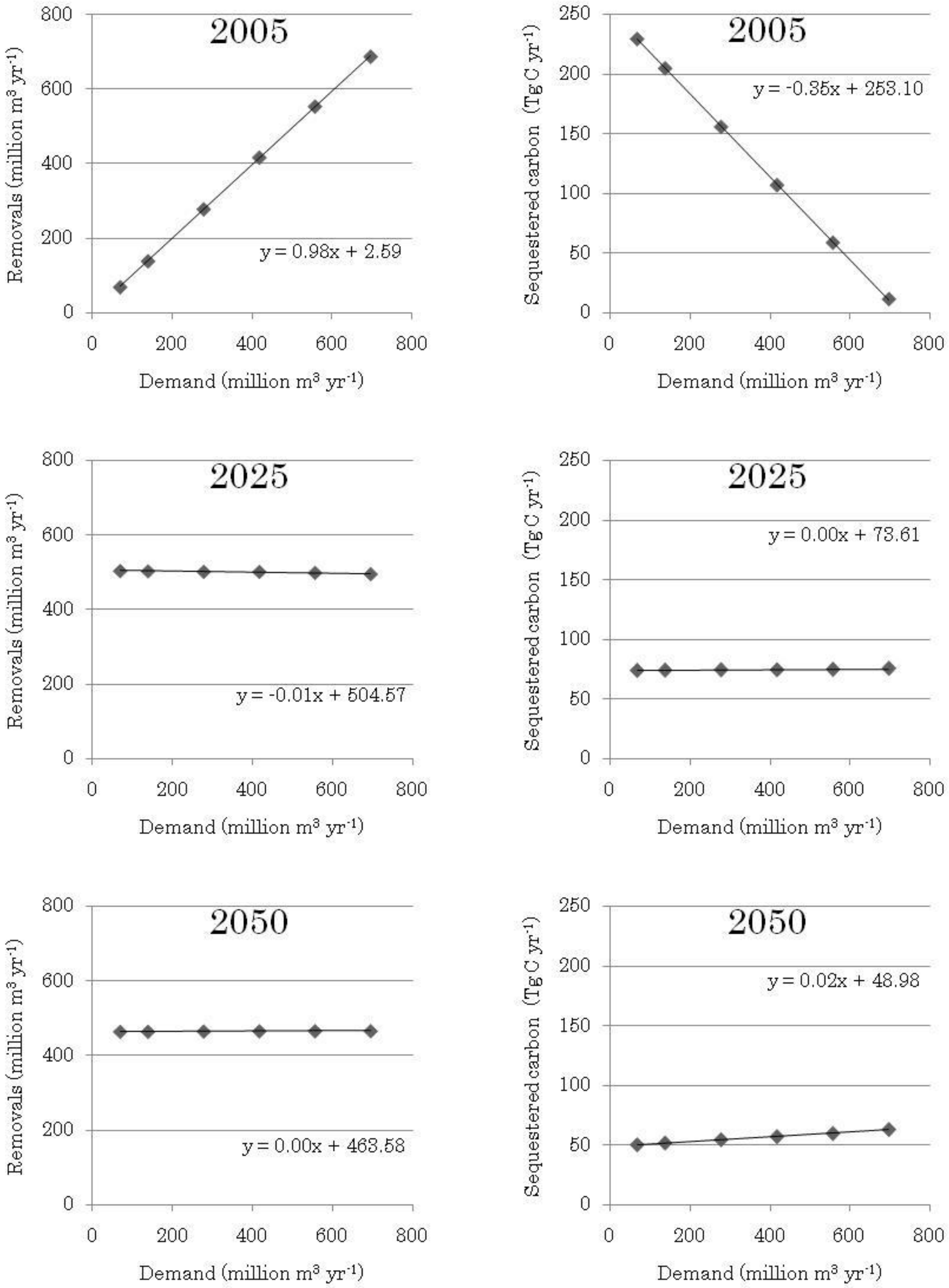


Figure 8: The volume of roundwood removal (left) and the amount of carbon sequestered in forest biomass, soil and organic matter (right) in European forest in 2005, 2025 and 2050 under alternative levels of demand for wood in the period 2001-2005.

4.2 Policy scenarios

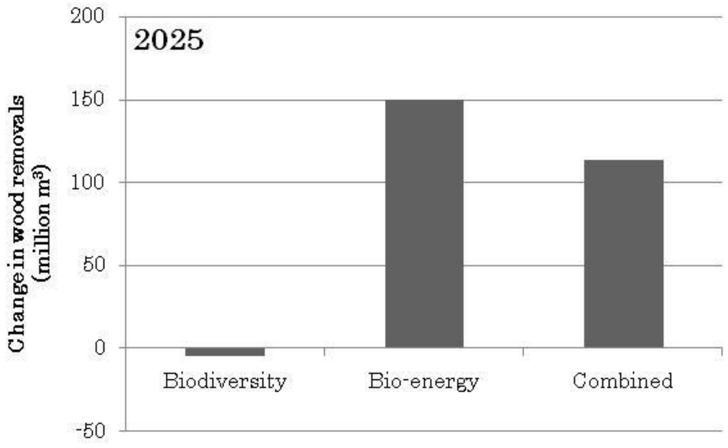
4.2.1 Wood and biomass production

According to our projections, the supply of wood from European wood reduces due to setting aside 10% of the forest area for biodiversity protection. In 2025 the European wood supply is reduced by 5.2 million m^3 and in 2050 it is 1.9 million m^3 (Figure 9 and Table 5). The supply of wood is constrained in countries that impose strong restriction on fellings in protected forests and/or intensively manage their forests, in such a way that the reduced supply from protected forests cannot be compensated by more intensive use of the unprotected forests.

We did not consider trade between countries and that is why according to the bio-energy and combined scenarios, wood supply can be increased. In other words, the demand in some countries cannot be satisfied when forests are increasingly protected, but the felling levels in other countries can be substantially increased to compensate for the reduced supply. According to our bio-energy scenario, wood removals can be increased by 149.5 million m^3 and in 2050 by 193.3 million m^3. The difference between the two years is largely explained by a declining demand for wood in the baseline scenario after 2025.

The supply of wood can mainly be increased in countries that do not intensively manage their forests in the baseline scenario. Countries that can increase their wood removals in 2025 and 2050 with more than 50% compared to the baseline scenario are France, Italy, Luxembourg, Norway, Romania, Slovenia, Switzerland and the United Kingdom.

The amount of residues that could be extracted in the bio-energy scenario is 56 Mt yr^{-1} in 2025 and in 2050 (Figure 10). The largest amounts of residues are available from France, Germany and Sweden.



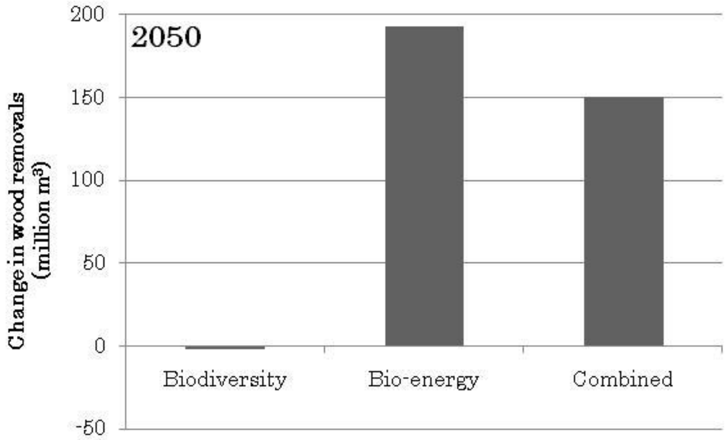


Figure 9: Deviation in volume of wood removals in the biodiversity, bio-energy and combined scenarios compared to the in 2025 (up) and 2050 (down)

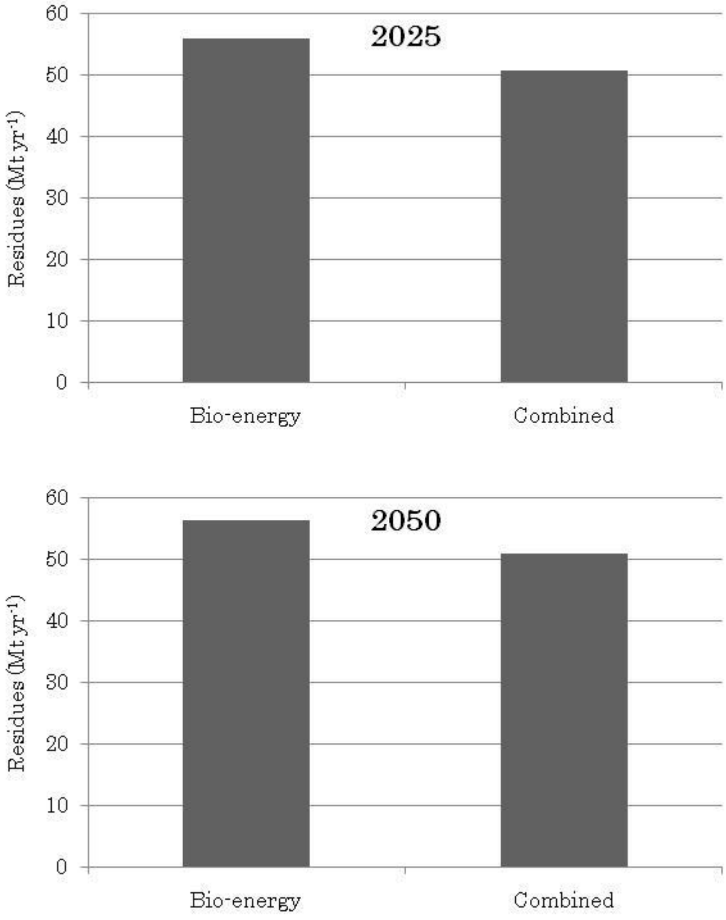


Figure 10: Deviation in harvest residue (stem parts and branches) removal in the bio-energy and combined scenarios compared to the baseline in 2025 and 2050 in 2025 (up) and 2050 (down)

Table 5: Deviation in volume of wood removals in the biodiversity, bio-energy and combined scenarios compared to the baseline in 2025 and 2050 (in million m^3)

Country	2025			2050		
	Biodiversity	Bio-energy	Combined	Biodiversity	Bio-energy	Combined
Austria	0.0	11.0	8.8	0.0	12.1	9.9
Belgium	-0.5	0.0	-0.5	-0.7	0.0	-0.7
Bulgaria	-0.2	1.0	0.4	-0.2	0.9	0.5
Czech	-0.1	-0.5	-1.3	0.0	3.6	2.1
Denmark	-0.1	0.0	-0.1	0.0	0.4	0.3
Estonia	0.0	0.8	0.1	0.0	1.8	1.0
Finland	-1.7	6.5	0.7	0.0	15.0	8.6
France	0.0	34.1	28.8	0.0	36.9	31.6
Germany	0.0	22.2	18.0	0.0	24.6	20.3
Hungary	-0.3	1.5	0.9	0.0	2.1	1.4
Ireland	0.0	1.1	0.9	0.0	1.0	0.8
Italy	0.0	26.0	22.7	0.0	30.2	26.5
Latvia	-0.5	1.5	0.6	-0.2	2.3	1.3
Lithuania	0.0	1.0	0.5	0.0	1.5	0.9
Luxembourg	0.0	0.5	0.4	0.0	0.4	0.3
Netherlands	0.0	0.5	0.4	0.0	0.8	0.6
Norway	0.0	11.0	9.4	0.0	10.4	8.9
Poland	0.0	1.5	0.5	-0.4	0.6	-0.4
Portugal	-0.1	0.0	-0.1	-0.2	0.0	-0.2
Romania	0.0	13.3	11.0	0.0	13.8	11.5
Slovenia	0.0	4.0	3.4	0.0	4.9	4.2
Slovakia	0.0	0.3	0.0	0.0	0.9	0.3
Spain	-1.0	0.8	0.3	0.0	4.9	3.8
Sweden	-0.7	1.7	-0.3	0.0	12.2	6.2
Switzerland	0.0	3.0	2.5	0.0	4.2	3.5
United Kingdom	0.0	6.8	5.4	-0.1	7.8	6.4
Total	-5.2	149.5	113.4	-1.9	193.3	150.1

4.2.2 Carbon sequestration

According to our projections, the amount of carbon stored in biomass, soil and organic matter in Europe's forests increases by setting aside 10% of the forest area for biodiversity protection. The gain in stored carbon is about 1.4 Tg yr^{-1} in 2025 and 2050 (Figure 11 and Table 6).

Intensified use of biomass in the bio-energy scenario leads to a loss of carbon stored in forests, because the carbon is removed in the form of roundwood and harvest residues. The loss of carbon compared to the baseline is about 59 Tg yr^{-1} in 2025 and 57 Tg yr^{-1} in 2050. The largest losses occur in countries with the largest biomass potentials. The losses in the combined scenario are smaller and amount to 46 Tg yr^{-1} in 2025 and 44 Tg yr^{-1} in 2050. European forests remain acting as a carbon sink in all scenarios in 2025 and 2050, according to our results.

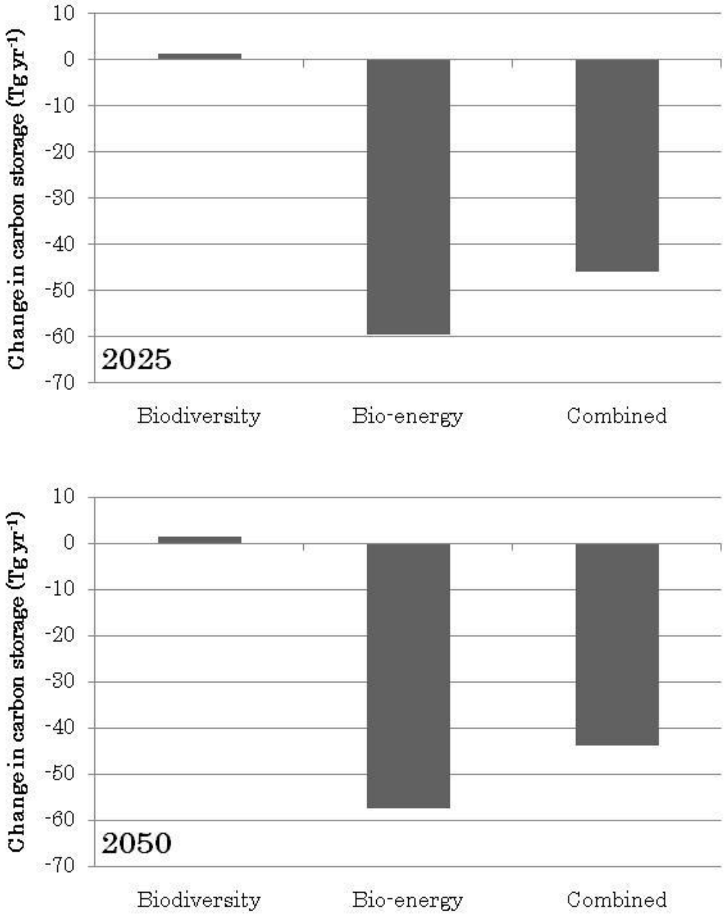


Figure 11: Deviation in carbon sequestration in the biodiversity, bio-energy and combined scenarios compared to the baseline in 2025 (up) and 2050 (down)

Table 6: Deviation in carbon sequestration in the biodiversity, bio-energy and combined scenarios compared to the baseline in 2025 and 2050 (in Gg yr^{-1})

Country	2025			2050		
	Biodiversity	Bio-energy	Combined	Biodiversity	Bio-energy	Combined
Austria	9	-3021	-2464	3	-1411	-1160
Belgium	213	-71	147	113	-20	104
Bulgaria	59	-560	-305	39	274	240
Czech	23	93	348	-79	-1382	-936
Denmark	40	-38	8	24	-186	-147
Estonia	-2	-426	-123	-42	-784	-501
Finland	502	-4195	-1483	-223	-6813	-4253
France	-6	-11608	-9743	-23	-8877	-7512
Germany	-5	-8898	-7376	-24	-7872	-6602
Hungary	94	-433	-263	-29	-447	-326

Ireland	-12	-565	-482	-3	-317	-279
Italy	-1	-13029	-11423	-12	-11907	-10525
Latvia	187	-821	-431	-9	-959	-639
Lithuania	-1	-463	-239	-5	-626	-424
Luxembourg	0	-197	-174	0	-177	-155
Netherlands	8	-105	-83	-3	-126	-106
Norway	0	-4696	-4018	-4	-4769	-4100
Poland	-11	-837	-594	-46	-349	-194
Portugal	32	-31	4	102	-32	73
Romania	0	-2530	-2036	-3	-1233	-1003
Slovenia	-2	-1468	-1253	2	-2029	-1770
Slovakia	-12	-310	-191	-20	-401	-186
Spain	387	591	704	25	-487	-265
Sweden	-133	-1366	-736	1633	-3053	-292
Switzerland	-1	-1095	-922	-1	-979	-843
United Kingdom	-5	-3257	-2675	6	-2593	-2204
Total	1362	-59337	-45803	1422	-57555	-44004

4.2.3 Biodiversity

According to our projections, the amount of deadwood hardly changes in Europe's forests after setting aside 10% of the forest area for biodiversity protection (Figure 12; Table 7). The amount of standing and downed deadwood increases, but the amount of harvest residues decreases, because less harvest takes place, which results in less harvest residues being formed. Residues form the major part of deadwood in forest and due to the reduction in this type of deadwood we found a small decline in the overall amount of deadwood in protected forests.

Intensified use of biomass in the bio-energy scenario leads to substantial losses of deadwood. The loss of deadwood compared to the baseline is about 1.3 ton ha^{-1} in 2025 and 2.7 ton ha^{-1} in 2050; this corresponds with a reduction of 10 and 19% resp. compared to the baseline. The losses in the combined scenario are smaller and amount to 1.3 ton ha^{-1} in 2025 and 2.4 ton ha^{-1} in 2050.

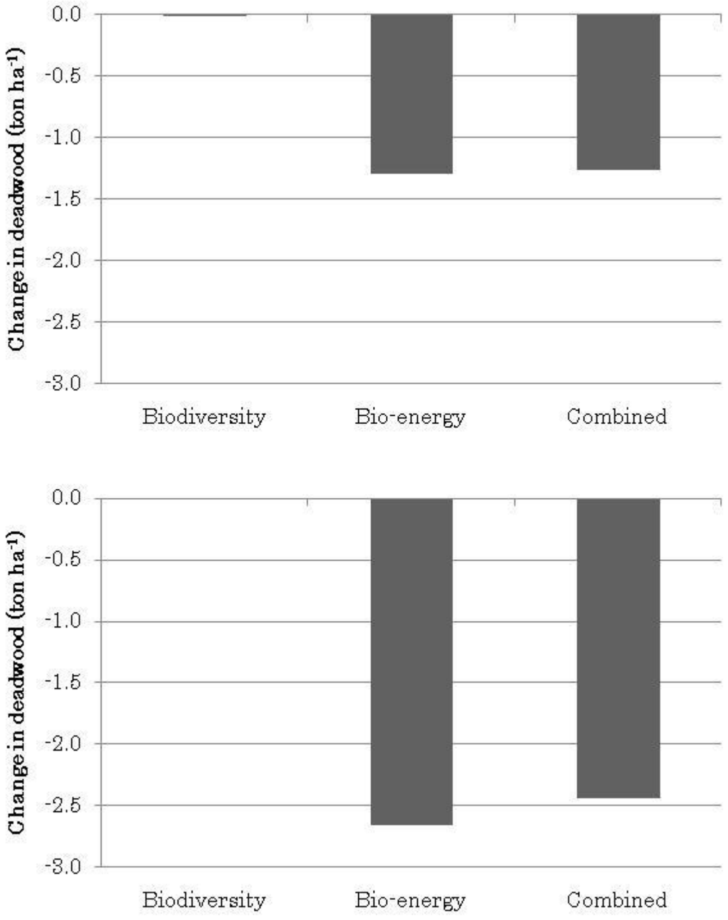


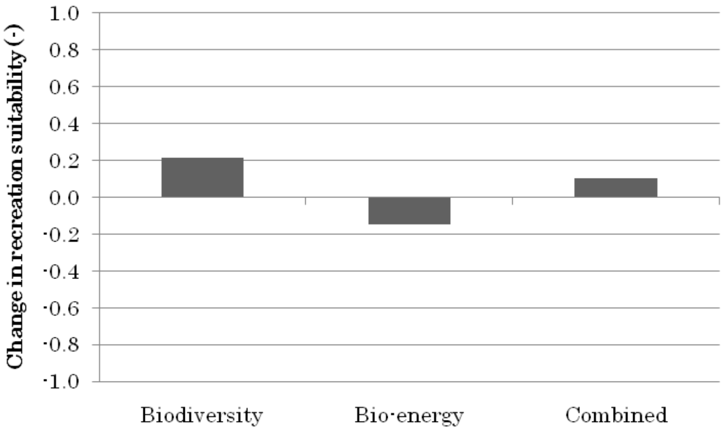
Figure 12: Deviation in deadwood compared in the biodiversity, bio-energy and combined scenarios compared to the baseline in 2025 (up) and 2050 (down)

Table 7: Deviation in deadwood in the biodiversity, bio-energy and combined scenarios compared to the baseline in 2025 and 2050 (in ton ha^{-1})

Country	2025			2050		
	Biodiversity	Bio-energy	Combined	Biodiversity	Bio-energy	Combined
Austria	0.0	-0.7	-1.0	0.0	-2.8	-3.0
Belgium	-0.5	-3.2	-3.4	-0.3	-4.3	-4.3
Bulgaria	-0.1	-4.3	-4.2	-0.4	-7.7	-7.1
Czech	0.0	-4.2	-4.1	0.1	-6.1	-5.7
Denmark	-0.1	-2.9	-2.7	0.0	-4.4	-4.1
Estonia	0.0	-0.6	-0.7	0.0	-1.2	-1.2
Finland	0.0	-0.4	-0.4	0.0	-0.8	-0.7
France	0.0	-1.8	-1.7	0.0	-4.1	-3.8
Germany	0.0	-2.8	-2.7	0.0	-4.6	-4.4
Hungary	-0.1	-1.7	-1.6	0.0	-3.6	-3.1
Ireland	0.0	-0.6	-0.6	0.0	-1.7	-1.6
Italy	0.0	-0.1	-0.1	0.0	-1.2	-1.1
Latvia	0.0	-1.4	-1.3	0.1	-2.4	-2.0
Lithuania	0.0	-1.9	-1.8	0.0	-3.2	-2.9
Luxembourg	0.0	0.5	0.3	0.0	-2.6	-2.4
Netherlands	0.0	-1.9	-1.8	0.0	-5.1	-4.6
Norway	0.0	-0.5	-0.4	0.0	-1.9	-1.7
Poland	0.0	-2.2	-2.1	0.0	-3.3	-3.1
Portugal	0.0	-0.9	-0.9	-0.1	-1.6	-1.5
Romania	0.0	-2.6	-2.4	0.0	-7.4	-6.6
Slovenia	0.0	-0.2	-0.2	0.0	-1.9	-1.7
Slovakia	0.0	-3.1	-3.1	0.0	-4.7	-4.4
Spain	0.0	-0.4	-0.4	0.0	-0.8	-0.7
Sweden	0.0	-0.9	-0.9	-0.1	-1.7	-1.5
Switzerland	0.0	-1.0	-1.0	0.0	-3.2	-2.8
United Kingdom	0.0	-0.2	-0.3	0.0	-2.3	-2.0
Total	0.0	-1.3	-1.3	0.0	-2.7	-2.4

4.2.4 Recreation

According to our projections, there is a small, but positive change in the average recreation appreciation value of forests after setting aside 10% of the forest area for biodiversity protection (Figure 12; Table 8). Intensified use of biomass in the bio-energy scenario is projected to lead to only a small reduction in the average appreciation in 2025. However, in 2050 a larger reduction in the average recreation appreciation is projected. This is because in 2025, intensified harvest does not lead to large changes in the age-structure of forests, which in our approach are important for assessing the average recreation appreciation. By 2050, there are larger differences in the forest structure, compared to the baseline, which explains the larger reduction in the average appreciation in 2050.



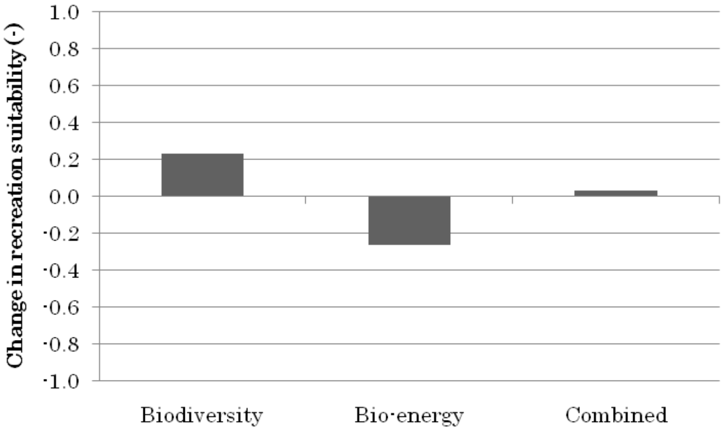


Figure 13: Deviation in recreation appreciation value in the biodiversity, bio-energy and combined scenarios compared to the baseline in 2025 (up) and 2050 (down)

5 Discussion

5.1 Generic response functions

We developed country-specific response functions for wood production and carbon sequestration that could be used in the EE-IO modelling framework. Response functions have been estimated for the years 2005, 2025 and 2050. The response function could also be estimated for other years between 2005 and 2050. A change in the demanded amount of wood in 2005 has an immediate impact on wood production and carbon sequestration in 2005, but the impact in 2025 and 2050 is almost negligible. We would probably find more long term impacts if change in resource use is prolonged (see the results of the policy scenarios), but this does not match the requirements of the EE-IO framework.

The estimated response functions are based on simple linear regressions, due to the requirements of the EE-IO modelling framework. In most cases, linear regressions appear to be appropriate, but not in all cases. For example, the response function for wood production in Denmark in 2005 appears to be non-linear and a quadratic function appears more suitable. In general, the response functions with an R^2 below 0.95 should be considered as (far) less reliable.

Finally, it is important to realise that not all carbon sequestered (or emitted) can be attributed to a demanded volume of wood; past resource use and forest management, climate etc. are other factors that determine the carbon balance (Böttcher *et al.* 2008). The carbon sequestered (or emitted) in forest biomass and soil that could be attributed to use of wood could be determined by conducting a scenario analysis in which result from a (policy) scenario are compared against a baseline or business as usual scenario (cf. Böttcher *et al.* 2008). The difference in carbon sequestered or emitted between the policy scenario and the baseline can then be attributed to the (changing) use of wood. Furthermore, it is also very important which time frame is considered. Use of wood may initially lead to a net emission of carbon and this carbon may be recaptured only after decades to centuries (Kujanpää *et al.* 2010; Repo *et al.* 2010; Zanchi *et al.* 2010).

5.2 Policy scenarios

In this report we present the impacts for scenarioson intensified biomass removal for bio-energy production and setting aside forest area for biodiversity protection on forest land use in Europe. We found that there is a substantial potential for intensifying the use of forest biomass and it can have strong impacts on carbon sequestration, biodiversity and recreation. On the other hand, setting aside 10% of the forest area for biodiversity protection appears to have minor impacts on these forest goods and services. This is due to the fact that less intensive use of protected areas can be compensated for by an intensified use of the unprotected forests.

According to our projections, the supply of wood will be reduced in some countries if they would set aside 10% of their forest area, in addition to already protected areas. However, the felling levels in other countries can be substantially increased to compensate for the reduced supply in these countries. According to our bio-energy scenario, the theoretical average annual supply of roundwood is around 650 million m^3 (excluding harvest residues from stems and branches)..Mantau et al. (2010) also applied the EFISCEN model, but developed a refined method and included various environmental, technical and social constraints that reduce the potential supply. They estimated within the European Union, the average realisable annual potential supply of stemwood was 622 million m^3 in 2010.

The amount of carbon stored in biomass, soil and organic matter increase slightly by setting aside 10% of the forest area for biodiversity protection. Intensified use of biomass in the bio-energy scenario leads to a loss of carbon stored in forests. This carbon is no longer in our system (i.e. forest land), but it is not lost. The carbon removed in the form of roundwood and harvest residues and these products can be used to offset carbon emissions from more energy intensive materials such as steel, concrete (Glover *et al.* 2002) or stone (Petersen & Birger 2003), and (in the long-term) also from fossil fuel use (Kujanpää *et al.* 2010; Repo *et al.* 2010; Zanchi *et al.* 2010; McKechnie *et al.* 2011).

Increasing the share of protected forests hardly changed the average amount of deadwood in European forests, according to our projections. Interestingly, we found a small reduction in the average amount of deadwood in protected forests. This was the result of less small-sized harvest residues being formed during harvest operations. Although the amount of residues decreased, the amount of standing and downed deadwood increased somewhat. These results suggest a change in the quality of deadwood (i.e. less small deadwood and more larger fractions) as a result of protecting forests. In the bio-energy scenario, we found a reduction in the amount of deadwood. Intensifying biomass removals may be quite detrimental for a large number of species dependent on deadwood, because the amount of all deadwood types (standing and downed deadwood and harvest residues) is projected to decrease significantly (Verkerk *et al.* 2011).

Combining our results by an economical evaluation will allow us to compare the impacts on these goods and services together and may enable us to find an optimal strategy towards renewable energy and biodiversity objectives. This step is being developed and will be presented in milestone MII.4.b-2.

6 Conclusions

Within the EXIOPOL project a number of forest goods and services have been identified, based on their importance at the European level. In this report we present (i) the results of a literature review on existing response functions concerning these goods and services, (ii) generic response functions estimated for the environmentally extended (EE) Input-Output (IO) framework developed within Cluster III of the EXIOPOL project, and (iii) the results of a policy scenario analysis on intensified biomass removal and increased forest protection.

Firstly, there are few response functions available from literature concerning important forest goods and services. Several functions have been estimated in the SENSOR project related to possible reforms of the Common Agricultural Policy for the year 2025. The results indicate that such reforms have little effect on the provisioning of the most important forest goods and services at the European level for the time-span considered in SENSOR. Due to the limited availability of response functions from literature, we developed country-specific response functions for wood production and carbon sequestration that could be used in the EE-IO modelling framework.

Separately from the response function, we conducted a scenario analysis on intensified biomass removal and increased forest protection. The impact of the scenarios was analysed on on roundwood and harvest residue production, carbon sequestration, deadwood, and recreation.

We found that there is a substantial potential for intensifying the use of forest biomass and that such intensification can have strong impacts on carbon sequestration, biodiversity and recreation. On the other hand, setting aside 10% of the forest area for biodiversity protection appears to have minor impacts on the investigated forest goods and services. These results serve as input to milestone MII.4b-2, in which they will be combined with an economical evaluation, which will allow us to compare the impacts on these goods and services together and may enable us to find an optimal strategy towards renewable energy and biodiversity objectives.

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