ALTERRA WAGENINGEN UR

Selection and quantification of forestry measures targeted at the Kyoto Protocol and the Convention on Biodiversity

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Alterra-report 1508, ISSN 1566-7197

EFI

Institute of Forest Ecosystem Research

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Commissioned by the MEACAP project, funded under the sixth Framework Programme, n°SSPE-CT-2004-503604.

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Alterra, Wageningen, 2007

ABSTRACT

M.J. Schelhaas, E. Cienciala, M. Lindner, G.J. Nabuurs, G. Zianchi, 2007. *Selection and quantification of forestry measures targeted at the Kyoto Protocol and the Convention on Biodiversity*. Wageningen, Alterra, Alterra-report 1508. 95 blz.; 16 figs.; 14 tables.; 97 refs.

Forests sequester large amounts of carbon and are important for nature conservation. These functions can be important in contributing to targets set by the Kyoto Protocol of the United Nation's Framework Convention on Climate Change (UNFCCC) and the Convention on Biodiversity (CBD). This report lists possible measures to increase the capacity of forest ecosystems to act as carbon sink. The most promising options are evaluated quantitatively in terms of carbon and qualitatively in terms of biodiversity.

Keywords: Kyoto Protocol, Convention on Biodiversity, Article 3.4, forest management, carbon sequestration, bioenergy

ISSN 1566-7197

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Preface

This report is a compilation of deliverables of the forestry workpackage of the MEACAP project (Impact of Environmental Agreements on the CAP). This project was funded by the European Commission under the sixth Framework Programme, contract n°SSPE-CT-2004-503604. The project was coordinated by David Baldock from the Institute for European Environmental Policy (IEEP). These and other deliverables can freely be downloaded from the project website (http://www.ieep.eu/projectminisites/meacap/index.php). The authors are grateful for the valuable comments received from Barbara Buchner (FEEM), Tamsin Cooper, Kathryn Arblaster (IEEP) and Susanne Wagner (FAL).

Executive summary

Forests fulfil many functions. Besides the production of wood and providing recreation space, they sequester large amounts of carbon and are important for nature conservation. The latter two functions can be important in contributing to targets set by the Kyoto Protocol of the United Nation's Framework Convention on Climate Change (UNFCCC) and the Convention on Biodiversity (CBD). Chapter 1 gives an overview of the legal framework of the Kyoto Protocol and UNFCCC and assesses the implications for the forestry sector. In Chapter 2 we evaluate in a qualitative way available measures to increase the capacity of forest ecosystems to act as carbon sink. For the most promising options we tried to quantify carbon effects in the near-term perspective for the EU25 (Chapter 3) and assessed the potential consequences for biodiversity for a range of qualitative indicators (Chapter 4).

The effect of the Kyoto Protocol on forestry in Europe during the first commitment period (2008-2012) is expected to be minor because of the rules established under the Marrakesh Accords and the current circumstances in the EU Member States. Forestry is allowed to contribute only a small proportion of its mitigation potential to national emission targets. While Forest Management may be adopted by some countries, more commonly, the cap imposed on potential credits from forestry does not provide a sufficiently strong incentive to choose Forest Management activity for accounting under the Kyoto Protocol. Additionally, in the absence of a market for carbon sinks, there is no direct way at present to put value on the potential contribution of sinks within the national emission budgets of the individual parties to the Kyoto Protocol. This makes the position of the forestry sector within the current framework of the Kyoto Protocol and Marrakesh Accords weak. However, an indirect effect of the Kyoto Protocol on the forestry sector can be seen in the growing awareness of forestry and its role in the carbon cycle and national/global emission balance.

Forests considerably contribute to the terrestrial carbon sink. Although the speed of uptake is generally low, the stocks in both biomass and soil are high. Therefore, most measures in forest management will have small effects, and effects will generally become visible at the long term only. Possible measures in forestry to enhance the carbon sink can be divided in three groups. Effective measures are firstly those that protect existing carbon stocks. Such measures are avoiding deforestation, not harvesting stands with high carbon contents, increased fire prevention and minimising site preparation. Estimated emissions due to deforestation in the EU25 range from 1.4 to 12.3 Tg C/year for the period 2000-2020 under different landuse scenarios, while we estimate current emissions due to forest fires at about 14.9 Tg C/year. We cannot estimate how much of these emissions could be avoided in future, but close attention is required. Although protection of stands with high carbon stocks at first sight seems to be an effective option, the effects on the national scale were only minor to negative. Harvesting activities are shifted to other stands, counteracting effects in protected stands. Minimising site preparation tries to

reduce decomposition of soil organic matter before planting or seeding a new crop. We were not able to quantify the carbon potential of this measure. However, intensity of site preparation has already decreased over the last decades as a consequence of a more close to nature kind of forestry in many countries. Protective measures generally have positive effects on biodiversity. With regard to fire prevention measures, some negative effects could occur. Creation of fire breaks could lead to fragmentation of the landscape. Furthermore, intensive management may be required to prevent fuel build up, which could negatively affect biodiversity.

The second group of measures aim to increase the current sink in the forest. Afforestation increases the sink by enlarging the forest area. However, new forest areas initially sequester carbon at slow pace and land is scarce. We estimate the potential sink capacity for this measure at 0.04-0.46 Tg C/year for the period 2000-2020, depending on the landuse scenario. Other options within this group of measures influence the sink strength by changes in the management. Without any changes in management, we estimate the current sink strength in the forest (biomass plus soil) at about 95.1 Tg C/year. Increasing the rotation length could increase this by an additional 23.6 Tg C/year. Increasing the thinning share would increase the baseline with 18 Tg C/year. These two measures combined could even increase the sink with 59.5 Tg C/year, as compared to the baseline. Another change in management is to shift to continuous cover forestry, but we were not able to quantify the impact of this measure. In general, extensification of management would be beneficial for biodiversity. Examples are increases in rotation length and a shift to continuous cover forestry. On the contrary, intensification of thinnings might have opposite effects on biodiversity, although some degree of disturbance in the forest can be very beneficial.

The third group of measures aims at using forest biomass to generate energy. One source of biomass is to collect residues after harvesting. Taking into account ecological constraints for residue extraction, a potential of avoided emissions equal to the equivalent of 13.5 Tg C/year was estimated. However, due to the lower input into the soil, the baseline sink would be reduced by 4 Tg C/year. Another possible biomass source is to increase the felling level. Increasing the felling level by 10% every 5 year where possible yielded an equivalent of 3.8 Tg C/year of avoided emissions. However, due to the rather early harvest of many stands, the total sink in the forest decreased with 10.2 Tg C/year as compared to the baseline. When we combined these measures, an equivalent of 18.4 Tg C/year emissions was avoided, but at the cost of a reduced sink by 15.2 Tg C/year in the forest. However, the effect of avoided emissions is ever-lasting, while carbon will be sequestered in the forest only temporary. Therefore, the effect of these measures must be seen in a cumulative way, which will be beneficial especially at the longer term. Pre-commercial thinnings could also serve as a biomass source, but we were not able to assess its potential contribution. All these measures have the potential to conflict with biodiversity issues, since they constitute an intense use of the forest ecosystem. Therefore, these measures should be implemented carefully, with close attention to biodiversity.

Table 1 summarises the carbon and biodiversity effects of all measures mentioned. The largest carbon effects can be achieved by changes in management. These changes can be beneficial for biodiversity, but more intensive thinnings could bring about some negative effects. The use of biomass for energy yields considerable potential to reduce fossil fuel emissions, but will cause reductions in the forest sink and might conflict with the biodiversity function. Use of logging residues seems most promising with regard to the net effect of avoided emissions and lower sink in the forest. Avoiding deforestation and reducing forest fire emissions have a potential of maybe half of that of extracting logging residues, but are certainly no-regret options. Another no-regret option is afforestation, although the effects at such a short term are very small. The sink effect of protection of stands with large carbon stocks proved to be minimal, probably due to a shift of harvesting activities to other stands.

Table 1. Comparison of the effect of different measures. Carbon effects compared to a baseline sink of 95 Tg C/year in existing forests; biodiversity effects: - potential negative effect, 0 no effect, + positive effect.

	NET EFECT ON SINK	AVOIDED EMISSIONS	NET TOTAL EFFECT	BIODIVERSITY
	(Tg C/year)	(Tg C/year)	(Tg C/year)	
Changing rotation lengths and thinning intensity simultaneously			59.5	-/+
Changing rotation lengths			23.6	+
Changing thinning intensity			18.0	-
Source due to fires			14.9	0/+
Source due to deforestation			10.9	0/+
Use of logging residues	-4.04	13.46	9.42	-
Application of complementary felling and use of logging residues	-15.23	18.39	3.16	-
Afforestation/reforestation			0.04 - 0.46	+
Complementary fellings for bioenergy	-10.15	3.83	-6.32	-
Protection of forests with high carbon stocks			~0	+
Continuous cover forestry			n/a	+
Pre-commercial thinnings for bioenergy			n/a	-
Minimising site preparation			n/a	+

1 Expected impact of the Kyoto Protocol on European forestry

1.1 Introduction

About 27% of Europe's land area is covered by forest. The contribution of the forest sector to the Gross National Product is not specifically high, although it reaches up to about 8 % in Finland. With growing industrialization and urbanization in Europe, forests become increasingly important as for their other functions besides wood production. These include recreation, biodiversity, nature conservation and various protective functions. With growing concern over the impacts of climate change, forestry also becomes recognized for its mitigation potential, specifically in terms of carbon sequestration. Therefore, international policies require the inclusion of forests and landscape for emission inventories and reporting in order to quantify their contribution to the total greenhouse gas balance of the individual countries. This should provide the basis for active management aimed at increasing carbon storing capacity in the current forest landscape.

The two current climate policy treaties that concern forestry are i) the United Nations Framework Convention on Climate Change (further abbreviated as UNFCCC or Climate Convention) and ii) its Kyoto Protocol. The Climate Convention, which entered into force in 1994, sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change. Under UNFCCC, the governments gather and share information on greenhouse gas emissions, national policies and best practices, launch national strategies for addressing greenhouse gas emissions and adapting to expected impacts, including the provision of financial and technological support to developing countries and cooperate in preparing for adaptation to the impacts of climate change (www.unfccc.org). The Convention does not contain any commitments to reduce greenhouse gas emissions, the governments started to work early on a treaty setting the specific obligations to reduce emissions. This effort brought up the text of the Kyoto Protocol that was adopted at the 3rd Conference of Parties (COP) in Kyoto, Japan in December 1997.

The aim of this chapter is to discuss the potential impact that the Kyoto Protocol may have on forestry in European countries[1].

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[1] Please note that this chapter is a further complement to a MEACAP report by Fondazione Eni Enrico Mattei (FEEM) on "The Kyoto Protocol: Current State and Implication for EU-25 Member States. A Focus on Agriculture and Forestry", document number MEACAP WP2 D3. FEEM's report and its addendums (downloadable at http://www.ieep.org.uk/publications/publications.php?search=39&Submit=Submit) provide an overview and assessment on developments in international and European climate policy that could have important implications on forestry and agriculture. The present chapter goes into more detail of possible interactions between the Kyoto Protocol and the sector of forestry.

1.2 Kyoto Protocol

1.2.1 Description of obligations

The Kyoto Protocol entered into force on February 16th, 2005, when the limit of at least 55 Parties to the Convention accounting in total for at least 55 % of the total carbon dioxide emissions for 1990 was reached. The Protocol commits the industrialized nations and those with economies in transition to reduce their greenhouse gas emissions in the first commitment period (2008-2012) by at least 5% with respect to the base year (1990, with some exceptions). The actual commitment varies among countries, and the actual commitment may be shared in a group of countries. This possibility has, for example, been applied in the case of EU15 that jointly committed to a reduction of 8 % (the so-called "EU bubble"), although the targets are different for its individual Member States.

1.2.2 Kyoto Protocol and forestry/LULUCF sector

An important aspect of the Kyoto Protocol is the possibility to offset part of the emission reduction by carbon sinks in the sector of land use, land use change and forestry (LULUCF). The negotiations over the role of biological carbon sequestration and inclusion of LULUCF within the frame of the Kyoto Protocol were particularly complicated for a number of reasons and uncertainties related to the topic (see e.g., Schulze et al. 2002). The final agreement was reached at COP 7 in Marrakesh, Morocco, and it is thereby termed the Marrakesh Accords (MA). In practice, MA mean that up to about 3 % of emissions may be offset by the LULUCF activities, thereby leading to a de-facto emission reduction of only 2.2 % under the Kyoto Protocol, i.e., less than the originally agreed 5.2 % reduction of emission (Ott 2002). This interpretation is vital to understand the two positions one may take when considering the effect of forestry activities to carbon cycle. On one hand, the LULUCF sector does represent a manageable resource that can offset some emissions of CO2 and at least temporarily) store it. On the other hand, it may lessen the pressure on cutting emissions in the sectors of energy and industry.

1.2.3 Description of 3.3. and 3.4 activities, cap principle

Article 3.3 of the Kyoto Protocol states that all Annex I countries must report emissions connected to afforestation, reforestation and deforestation (ARD) activities. These emissions will be taken into account in determining the emission reduction compliance of Annex I countries. Article 3.4 list additional activities in the LULUCF sector that may be optionally included in the Kyoto Protocol commitment of the individual party. These activities include Forest management (FM), Cropland management, Revegetation and Grazing land management. Election of FM allows accounting the net forest carbon stock increment ´generated over the selected area covered by managed forests. As decided by MA, FM activities may offset eventual emissions resulting from activities ARD (Article 3.3) up to a maximum of 9 Mt C, while other emission offset by FM is subjected to a prescribed maximum (cap[2]).

This chapter focuses only on the optional activity of FM, which may directly concern forestry in European countries. On the contrary, afforestation/reforestation (AR) activities are mainly taking place on non-forest land and concerns decision-making in agricultural sector. Similarly, deforestation (D) cannot be considered as a deliberate choice of forest manager, although it does concern forest land in this case.

1.3 Electing Forest Management

To aid consistent quantification of emissions and ensure transparent reporting, UNFCCC commissioned the Intergovernmental Panel on Climate Change (IPCC) to elaborate guidelines for the LULUCF sector. In 2003, COP 9 adopted the IPCC Good practice guidance (IPCC 2003), a comprehensive methodological material to guide the LULUCF emission inventory of the UNFCCC and Kyoto Protocol parties. With respect to the Kyoto Protocol and LULUCF related requirements, these were outlined in paragraph 1 of the Annex to the Draft decision -/CMP.1 (Land use, land-use change and forestry) contained in document FCCC/CP/2001/13/Add.1, p.58. Of these, it is vital to notice the IPCC definition of Forest management, which basically determines the management practices and hence also forest areas potentially concerned by the activity of forest management under Art. 3.4 of the Kyoto Protocol. This definition reads as follows:

"Forest management" is a system of practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest in a sustainable manner.

Obviously, this definition is very broad and may be applicable to basically all forest areas that fulfil the definition of forest in European countries. The actual area included for accounting FM may focus on some forested regions only. Similarly, the parties may exclude the regions not considered suitable for accounting the FM effects. Anyway, it becomes evident that most commonly, the parties electing FM in emissions accounting under Kyoto Protocol would adopt forest area identical to that reported under UNFCCC (COST E43 WG2 questionnaire – unpublished results).

However, the topic of potential areas to be included under FM is only one part of the considerations required for taking decision on FM election. The decision of the parties to the Kyoto Protocol regarding the voluntary activities under Art. 3.4. of the Kyoto Protocol should be reported to UNFCCC by the end of 2006. As for the European countries, this information should be delivered to the European Commission already by 15 June (Decision No 280/2004/EC of the European

[2] The cap for maximum offset generated from FM was estimated individually for each Annex 1 country. It was set so as to represent 15 % of the reported sink in FM, but no more than 3 % of the assigned amount units (AAU), whichever was lower. Hence, FM cap commonly represents just a small fraction of the carbon sequestration in managed forests in European countries.

Parliament). Since the decision on these activities is binding at least until the end of the first commitment period, the individual countries must carefully reconsider this issue from within their nationally specific situation. Obviously, the implications of the election of FM are manifold and the issue requires a thorough consideration.

To aid decision-making, experts from several countries met at the workshop „Land-use Related Choices under the Kyoto Protocol" that was initiated by the CARBOINVENT project[3]. One of the workshop sessions was devoted to the issue of FM election. It elaborated a list of advantages and disadvantages associated with electing FM, which is available at CARBOINVENT web page. The arguments for electing FM included positive side-effects the election might have on forest monitoring, recognition of forest services and role of forest in climate change mitigation. The listed counterarguments included a delay of mitigation action in the fossil-fuel sector, risk of forestry being a source instead of a sink, and some additional costs for inventory and reporting.

However, in our opinion the major motivation for considering electing FM is threefold:
1) The cap allocated to a party is large enough to significantly aid meeting the emission target of the party
2) The monetary value of the cap (Figure 1.1)[4]
3) The buffer for expected/potential emissions from activities under Art. 3.3 of the Kyoto Protocol
Obviously, these arguments will apply differently in the individual countries, depending on the countries' specific Kyoto Protocol commitment and the current state of its compliance. This is discussed bellow.

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3 CarboINVENT (Multi-Source Inventory Methods For Quantifying Carbon Stocks And Stock Changes In European Forests) was a EU (FP5) project (2002 to 2005). See www.joanneum.at/CarboInvent for more details.

4 Figure 1 is included to show the trend of CO2 credits valuation. Note, however, that sink (forestry) credits are not included in the European Trading System (ETS). Eventual valuation of CO2 credits generated in forestry depends on yet unpredictable circumstances and may be expected to be significantly lower as compared to ETS prices.

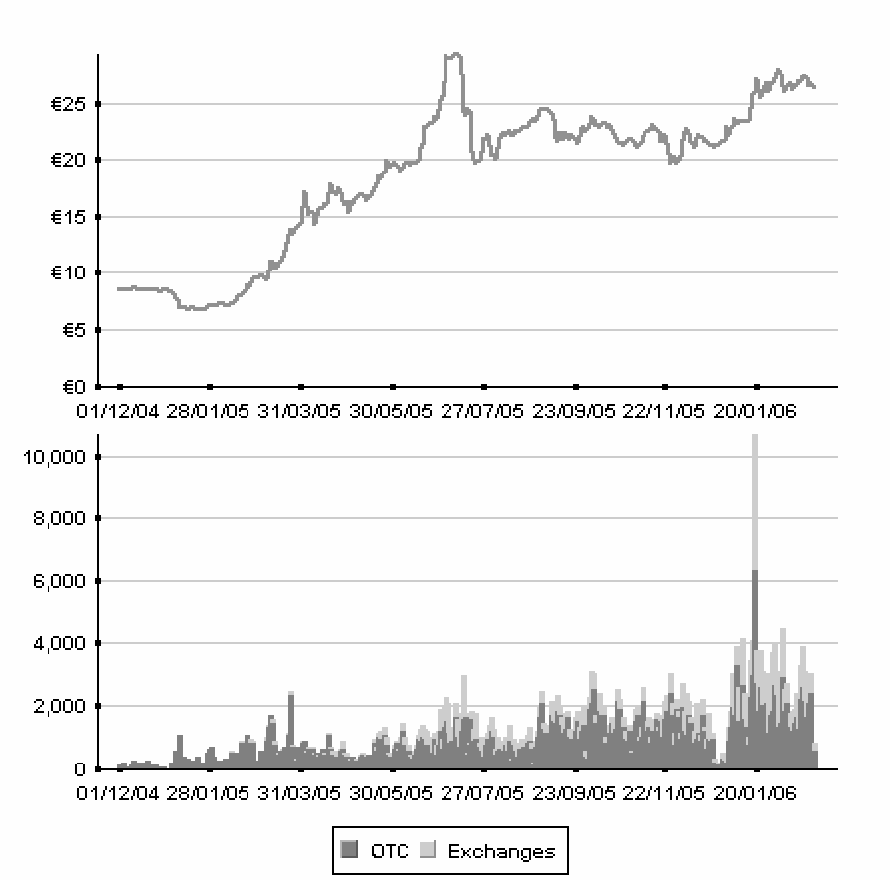

Figure 1.1: The development of Point Carbon's bid-offer closing price for EU allowances (Source: Point Carbon: www.pointcarbon.com). It may be observed that both the price and trading volume increased considerably since Kyoto Protocol entered into force.

1.4 Current position of FM in EU countries

As a result of political agreements, the contribution the forestry sector is authorized to make to meet the emission target under Kyoto Protocol is limited. It is expressed in the allocated FM cap for the individual countries, which is relatively small (Figure 1.2; Figure 1.3). Still, FM might help to offset a (small) proportion of emissions, which might be an attractive choice for those countries that face difficulties in meeting their Kyoto Protocol commitment. This case is generally expected for the members of the former EU15 countries, such as Austria, Denmark, Spain and others (Figure 1.3), whereas the new accession countries commonly benefit from a base year of 1990, which represents a period prior to a rapid industry revitalization and closing inefficient and outdated plants after the political changes following the collapse of communism. Therefore, most of the new accession countries safely meet their Kyoto Protocol target, most notably the Baltic countries (Figure 1.2; Figure 1.3).

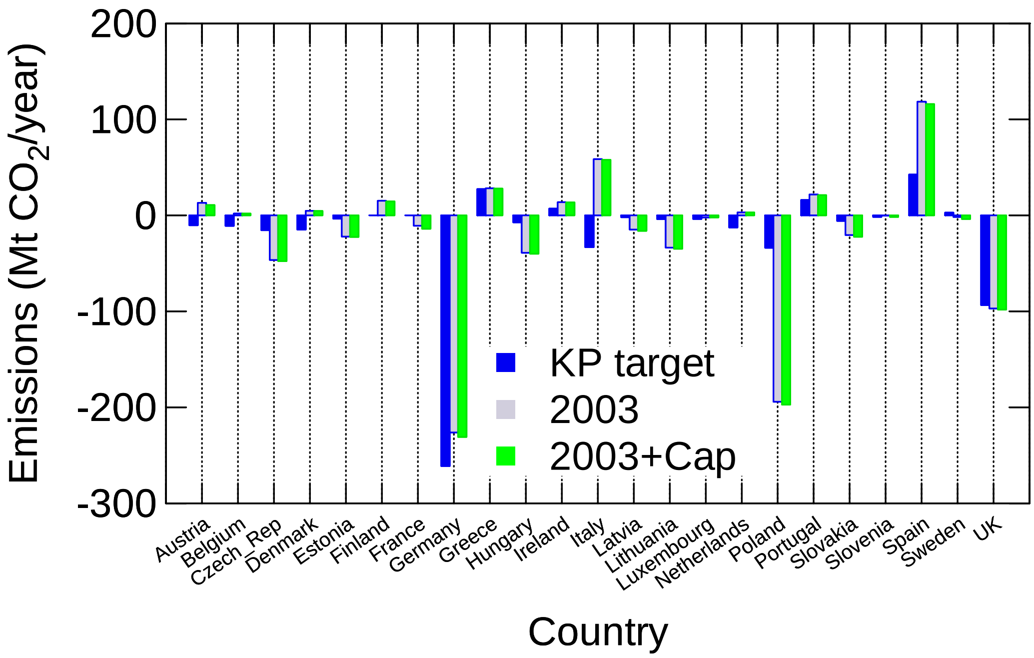

Figure 1.2: Overview of the European countries' commitment under the Kyoto Protocol (KP). KP target - the estimated emission reduction target based on the committed KP percentage and the most recently GHG emissions reported to UNFCCC for the year 1990[5]; In 2003 – emission compliance as of 2003 (2002 for Poland) excluding LULUCF; In 2003+Cap – emission compliance as of 2003 (2002 for Poland) including the potentially accountable cap from FM.

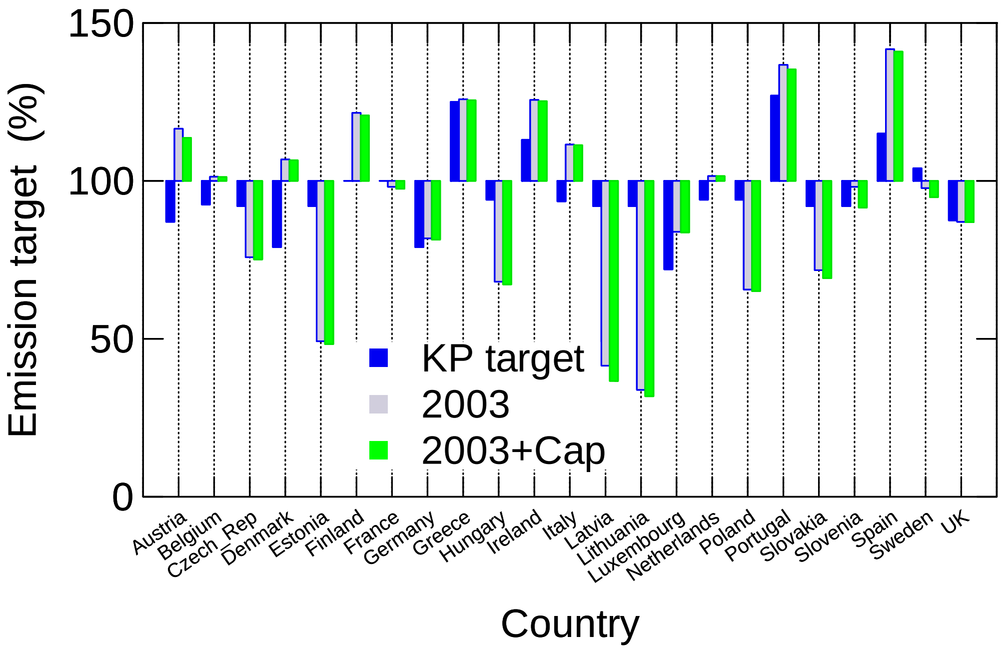

Figure 1.3: Kyoto Protocol emission target in individual countries expressed on relative scale. KP target gives the committed emission target under the Kyoto Protocol for the individual countries, 2003 denotes the emission reduction as in 2003 (2002 for Poland), while 2003+Cap moreover includes the FM cap expressed on relative scale for these countries.

[5] Note, however, that the base year differs for some countries.

With respect to the motivation of electing FM listed above, one may expect that Slovenia, for example, represents a country in which forestry can significantly contribute to the Kyoto Protocol compliance. Its cap for FM is large and currently would ensure meeting the Kyoto Protocol target (2). This country has already decided to elect FM for Kyoto Protocol accounting (Table 1.1).

As for the motivation of monetary value, this may be vital for other new accession countries to EU. These countries mostly safely meet their Kyoto Protocol targets and they are under no pressure to use the potentially available credits from forest management. However, the forestry sector may eventually claim some of the monetary value of CO2 credits that the country might offer to other parties of the Kyoto Protocol. The current price level of CO2 credits indicated by ETS (Figure 1.1) may represent a strong motivation for some countries to explore possibilities of crediting the forest sector via adopting FM to aid Kyoto Protocol compliance. However, it must be stressed that since ETC does not include sinks (CO2 credits generated in forestry), the eventual valuation of CO2 credits generated in forestry might be significantly lower as compared to the current ETS prices. With no market available for sinks, the valuation depends on yet unpredictable circumstances and individual agreements among the parties exchanging CO2 credits. Since the likely exchange might only concern AAUs (Assigned Amount Units), the eventual credit to forestry for its contribution to emission target may be realized only via internal agreements within the relevant sectors of a country. In practice, the cap of FM would count as a part of the country's commitment, hence making the adequate quantity of AAUs available for trade. Therefore, the motivation exists, e.g., at the Czech Ministry of Environment to pursue FM, because it may represent a viable option to eventually acquire funds to the forestry sector.

Finally, FM may be attractive to any country that expects emissions associated with the obligatory reported activities of afforestation, reforestation and deforestation (ARD) during the 1st commitment period. In such case, FM may act as a buffer to balance the potential emissions up to the 9 Mt C (totally for the commitment period) plus the prescribed cap. However, this option can be regarded theoretical as it is unlikely that ARD activities would result in significant emissions within the conditions of European countries.

Table 1.1 describes the current (as of February 2006) situation of the FM selection process in European countries based on the information from the individual UNFCCC focal points and on the basis of the COST E43 (www.metla.fi/eu/cost/e43) WG2 questionnaire responses. As it can be seen, only 10 countries have already made their decision about electing FM. Since about half of the countries addressed have not yet decided on the election, no general observation can be drawn at this stage.

Table 1.1: Election of FM for emission accounting (as of February 2006). No information was available from the countries in italics (Source: UNFCCC focal points and COST E43 (www.metla.fi/eu/cost/e43) WG2 questionnaire responses)

	YES	NO	Undecided
Austria		X	
Belgium			X
Czech Republic			X
Denmark			X
Estonia	X		
Finland		X	
France	X		
Germany			X
Greece			X
Hungary			X
Ireland		X	
Italy			X
Latvia			
Lithuania			
Luxembourg			
Netherlands		X	
Poland			X
Portugal	X		
Slovakia			X
Slovenia	X		
Spain			
Sweden	X		
UK	X		
Totally	6	4	9

1.5 Conclusions

Under the adopted agreements of the Kyoto Protocol and Marrakesh Accords, the effect of Kyoto Protocol to forestry in Europe is to be minor. Forestry is allowed to contribute to the emission target only by a minor part of its mitigation potential. This may be important for some countries, but more commonly, the cap imposed on potential credits from forestry does not provide a sufficiently strong incentive for electing forest management activity for accounting under the Kyoto Protocol. Additionally, in the absence of market for carbon sinks, there is no direct way to valuate the potential contribution of sinks within the national emission budgets of the individual parties to the Kyoto Protocol. This makes the position of the forestry sector within the current framework of the Kyoto Protocol and Marrakesh Accords weak. An indirect effect of the Kyoto Protocol to forestry sector can be seen in a growing awareness of forestry and its role in the carbon cycle and national/global emission balance.

2 Survey of technical and management-based mitigation measures in forestry

2.1 Background

2.1.1 The carbon cycle in forest ecosystems

Every day, forests exchange large quantities of CO2 with the atmosphere. During photosynthesis CO2 is absorbed, while respiration and decomposition release CO2. The net balance between these processes (Net Primary Production, NPP) determines if the forest is a sink or a source. Carbon can be stored in living biomass (trees and other vegetation) or soil (including litter and deadwood), usually referred to as Soil Organic Matter (SOM). An additional carbon stock is found in products that are made of harvested wood. Figure 2.1 gives an overview of these three compartments and the processes that influence the size of these stocks. By manipulating these processes, the size of the stocks can to a certain extent be manipulated as well. However, the stocks in different compartments are not independent. Management that focuses on enhancement of carbon in e.g. forest biomass therefore has an impact on soils and wood products as well.

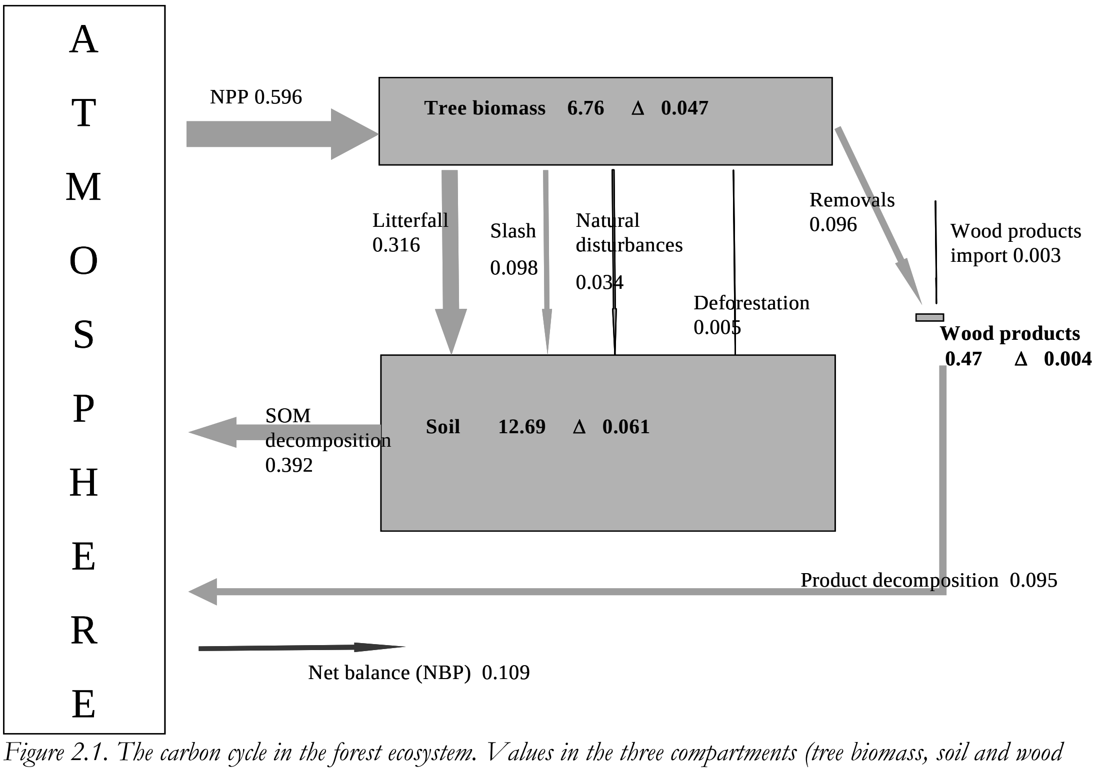

Figure 2.1. The carbon cycle in the forest ecosystem. Values in the three compartments (tree biomass, soil and wood products) are European stocks in 1990 (Pg C), flows between those stocks and net changes (Δ) in those stocks (Pg C y-1). The width of the arrows indicates the relative size of the flows, and the size of the three boxes indicates the relative size of the stocks. The width of the arrows is not in relation to the size of the boxes (Nabuurs et al. 2003).

2.1.2 Biomass

The biomass carbon stock is a balance between net primary production and removals of biomass, either due to natural processes (litterfall, natural disturbances) or human-induced measures (harvest, deforestation). Net primary production is determined by many factors, such as climate (temperature, precipitation), site conditions (soil type, fertility), tree species, age, genetic quality and stand density. Litterfall rates depend on productivity, tree species and tree age. The occurrence of natural disturbances depends on a complex of factors. First of all, climate determines where disturbances can occur (wind climate for storms; hot and dry weather for fires; suitable climate for insect species). Secondly, the state of the forest determines if a disturbance will occur and how large the impact is. Windthrow not only depends on wind speed, but also on a range of stand and site characteristics, such as tree species, height, stand density, rooting depth and management history. Forest fire risk is determined by the amount of fuel, the flammability of the fuel, stand structure and surrounding landscape. Occurrences of insect damage are linked to preferences and characteristics of the species in question: tree species, age, forest structure, availability of weakened trees, climate conditions, dispersal possibilities, etcetera.

2.1.3 Soil

The earth's soils contain approximately 1500 Pg C (comparison: total EU15 annual emissions are in the range of 1.1 Pg C y-1), making soils the largest surface terrestrial C pool, about 2–3 times greater than the amount of C stored in the earth's vegetation (Post et al. 1990). Later estimates for deeper soil profiles even concluded that the total stock may exceed 2300 Pg C (Jobbagy and Jackson 2000). Out of this total global stock, some 70% may be in forest soils.

This finding has been the reason for a large research interest in options to maintain soil C stocks, and management options to further increase the sink. All studies agree that the net balance of the soil C stock is the result of, on the one hand, the input rate of detritus (litter, dead wood) and on the other hand, the decomposition rate (as influenced by tillage, quality of the litter, temperature and moisture). Studies also agree that the influence that man has on the build-up of soil C stock is rather small. However they do not agree on the sign (increase or decrease of the stock) that certain measures will have on the soil C pool. Figure 2.2 depicts a theoretical soil C stock development over time in relation to the biomass dynamics.

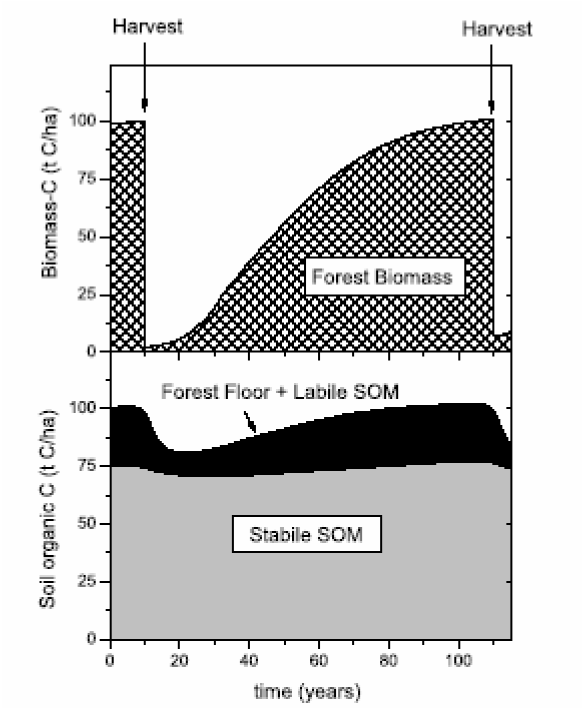

Figure 2.2. Dynamics of soil organic matter and litter layer (= forest floor) in relation to the biomass dynamics. Theoretically, if vegetation cover functions in the same way for a long time, the biomass carbon and soil carbon reach a steady state. However, in practice this is never reached, because of fluctuations in tree dynamics, differences in weather circumstances, disturbances, or land use changes. In the above case, the harvest causes a large input of organic matter (from harvesting slash) resulting in a short increase in forest floor stock. Afterwards, because of few trees producing litter, and because of enhanced soil disturbance and soil temperature, the litter layer looses carbon to the atmosphere through decomposition, but also through humification to the stable soil organic matter (Olsson et al. 1996). The soil C pool actually dampens the total system fluctuations in comparison to the strong fluctuations in the biomass pool. Later, the large dip in the forest floor as depicted here was disputed as well (Yanai et al. 2003).

2.1.4 The total system

Temporal carbon dynamics of forest ecosystems are characterised by long periods of gradual build-up of biomass (C sink), alternated with short periods of massive biomass loss (C source). Forests thus switch between being a source or a sink of carbon, depending on the succession stage, specific disturbance or management regime and activities (Figure 2.3). Large areas of undisturbed forest consist of a mosaic of patches in different successional stages. Averaged over the whole area, sources and sinks will be in balance. Although such areas do not capture new carbon, they represent large stocks. Harvesting or deforestation of such sites will therefore lead to large emissions in a short timeframe. In managed forests, trees are harvested at more or less regular intervals. Large parts of the European forest are managed in the traditional even-aged system. In this system, the main 'crop' consists of trees of equal age and species. During a rotation, several thinnings can be carried out, followed by a final harvest at the end of the rotation age. Harvests will decrease the amount of carbon in the living biomass, but increase the amount of carbon in the soil/deadwood compartment because of the slash (topwood, branches, foliage, roots) that is left after harvest (see also Figure 2.2). Rotation lengths can range from a few years for fast growing Eucalypt pulp plantations to well over 100 years for high quality sawlogs of slower growing species. Figure 2.3 illustrates the development of carbon stocks in a managed and an unmanaged stand.

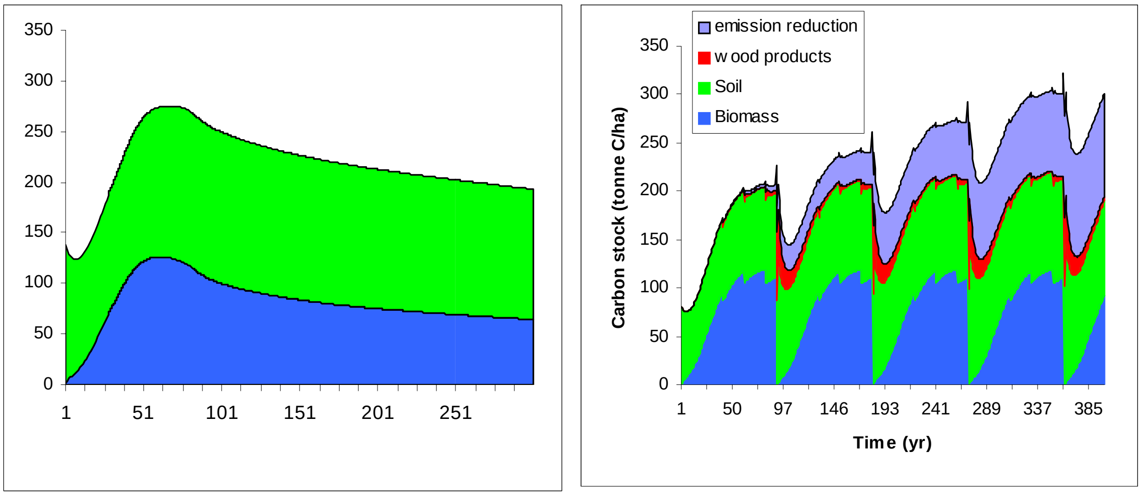

Figure 2.3. Comparison of carbon stocks in an unmanaged (left) and a managed (right) hypothetical forest stand.

2.1.5 Bioenergy

Bioenergy is energy derived from biomass. Biomass may be produced from energy crops (such as sugarcane or short rotation coppice) or forests, or as a by-product of forestry, sawmilling and agriculture. Biomass can be utilized directly for heat energy or can be converted into gas, electricity or liquid fuels.

With regard to CO2 emissions, energy production from fossil fuels has very different implications compared to energy production from biomass. Burning fossil fuels releases CO2 that has been locked up for millions of years. By contrast, burning biomass simply returns to the atmosphere the CO2 that was absorbed as the plants grew and there is no net release of CO2 if the cycle of growth and harvest is sustained (Figure 2.4). However, some input of (fossil) fuel is needed for harvesting and transportation. The bioenergy effect is thus only positive if energy inputs and associated emissions are (substantially) lower than the energy outputs and avoided emissions.

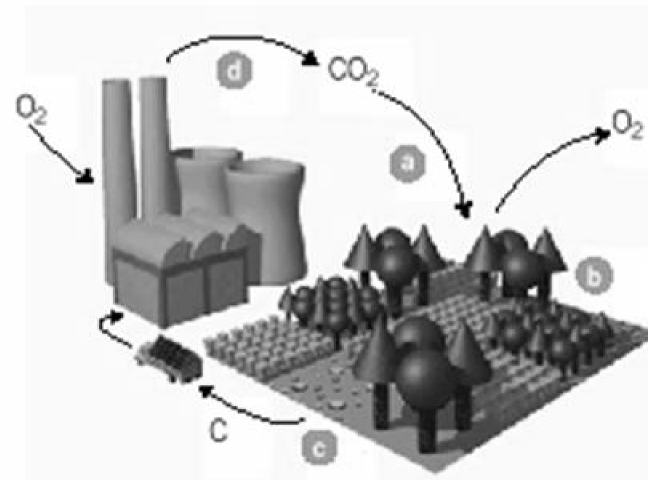

Figure 2.4. Carbon cycle of a bioenergy power plant (Source: IEA Bioenergy, 2001).

Substituting sustainably produced bioenergy for fossil fuels is a way of mitigating greenhouse gas emissions to the atmosphere. In contrast with carbon storage within the forest, the carbon benefits provided by bioenergy as a substitution for fossil fuels are irreversible, even if the bioenergy scheme only operates for a fixed period. This substitution effect is shown in Figure 2.3 as the emission reduction component.

2.1.6 The situation in Europe

In general, forest history in Europe can be characterised by a declining forest area since the Middle Ages, reaching a low in the 19th Century. Since then, the forest area has increased, either due to active afforestation or by natural means. Currently, the forest area in the EU25 is about 137 million hectares, and the net annual increase is 398 thousand ha (TBFRA 2000). Due to this recent expansion and quite intensive management, many countries show an age class distribution that is dominated by younger ages (Figure 2.5). The current harvest level is less than the increment, so growing stocks, and thus carbon stocks, are increasing (Figure 2.6). A large part of the forest is located on sites that do not have a long history of forest cover, so the soil carbon stock is also believed to increase. Without any changes in the current forest management, the forest is likely to act as a carbon sink for at least some decades. Another factor contributing to increasing soil carbon sinks is climate change (Karjalainen et al. 2003, Nabuurs et al. 2002). The production increase that is foreseen under climate change is projected to lead to increased litterfall. This would not be fully compensated by increased decomposition. Figure 2.6 shows the annual carbon sink strength from 1950 to 1999, and Figure 2.1 shows the carbon stocks and fluxes for the year 1990.

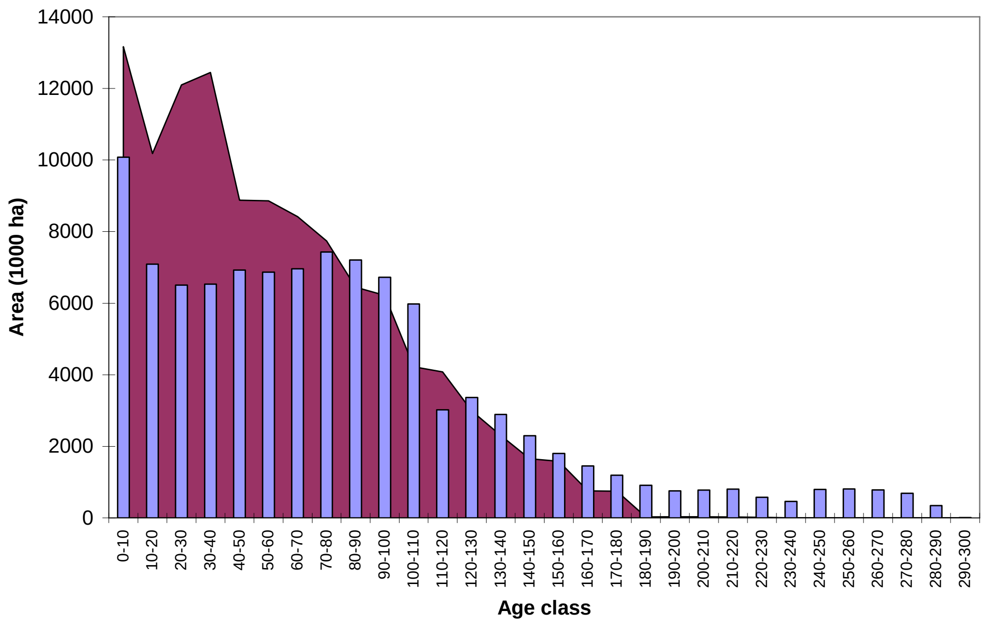

Figure 2.5. Current (about 1990, solid area) and projected (2090, bars) age class distribution of the European forest (Nabuurs et al. 2003).

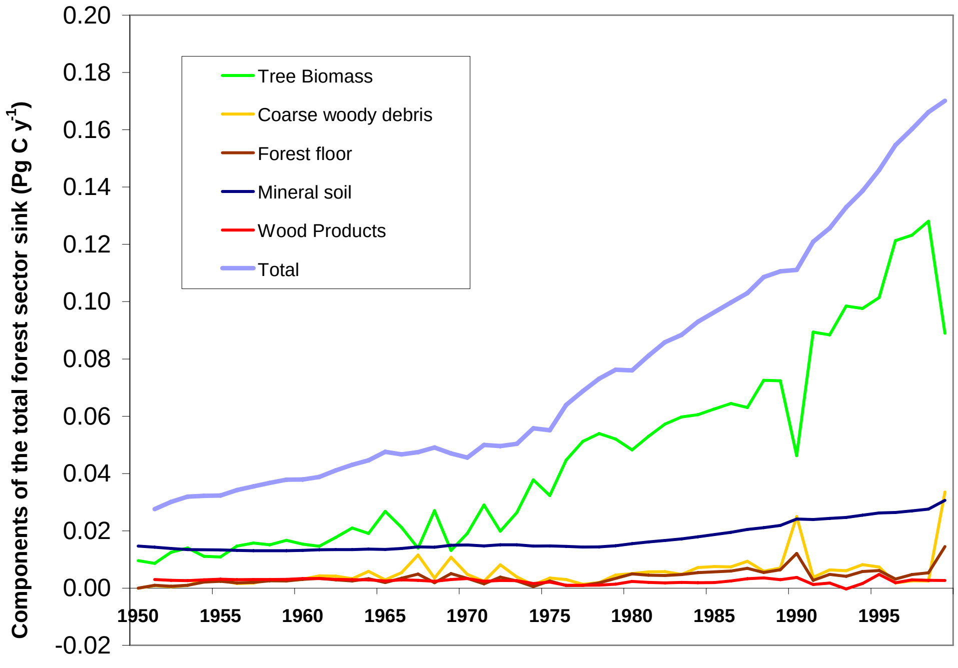

Figure 2.6. Sinks in the European forest sector, from 1950 to 1999, partitioned by compartments (Nabuurs et al. 2003).

2.2 Possible measures that can be taken in the forestry sector to contribute to the Kyoto Protocol

2.2.1 Introduction

In various ways, the forest sector could play a role in reaching the emission reduction targets as set in the Kyoto Protocol. Article 3.3 concerns Afforestation, Reforestation and Deforestation since 1990 (ARD). Reporting of these activities is obligatory for all Annex I countries (the industrialised countries). Article 3.4 concerns extra activities in agriculture and forestry. Countries are free to choose if they will include such activities or not. Most European countries are unlikely to choose the option of using the possibilities of Article 3.4. Apart from these specific Articles, forestry could play a significant role by providing biomass for the production of bioenergy. The use of bioenergy will not directly change the reporting in the Land Use, Land Use Change and Forestry (LULUCF) sector, but will show up as a reduction in the emissions due to fossil fuel use. In the following sections, we will discuss measures that can be taken in the forestry sector to contribute to the Kyoto Protocol and the implications they will have for both the greenhouse gas budget as well as for bioenergy. The measures are separated into measures under Article 3.3, Article 3.4, and other measures, such as bioenergy. The first (rough) screening of the measures followed the approach as described in the MECAP project guidelines. This approach consisted of ten different criteria that should be evaluated for each measure. However, the last three criteria (Monitoring and control parameters, Support and constraints in existing policies and Possible supporting political measures) would be covered in a later stage to those measures that were selected for further screening. Wherever information was readily available on these criteria, it was already included.

2.2.2 Article 3.3, Afforestation, Reforestation and Deforestation

2.2.2.1 Afforestation/Reforestation

Description: Afforestation is the direct human-induced conversion of other land uses to forested land through planting, seeding and/or human-induced promotion of natural seed sources. For specific purposes, the Kyoto Protocol recognizes the terms afforestation and reforestation (IPCC 2004). These terms differentiate land history; afforestation occurs on lands that did not contain forest for at least 50 years, while reforestation concerns forest land that did not contain forest by the end of 1989. Here, the term "afforestation" will represent the general term covering all cases of land conversion to forests. Since forests have higher carbon density than other ecosystems, afforestation represents a strong measure that increases carbon stock density on the land concerned, with likely attributable effects on large scale (e.g. Caspersen et al. 2000). Carbon sequestration is usually only one of the aims of afforestation.

Main potential: GHG mitigation through increase of forest area, increase of carbon stock density in biomass and soil pools.

Technical feasibility: Technically feasible throughout Europe, except for some regions where climate is restrictive, such as high elevation areas in Central Europe and tundras in northern Europe. However a land use change is a drastic change and a choice for a long term period. Therefore the changes are occurring at a slow pace. At present in the EU25 a net afforestation of some 0.4 million ha per year is occurring (TBFRA 2000).

Implication for GHG mitigation / biodiversity: The main implication of this measure for the GHG balance is an increased carbon stock in the longer term due to increased biomass and potentially increased soil carbon. The system changes from a low biomass system (where most of the NPP is harvested and removed) to a high biomass system with large amounts of litterfall. The usually intensive ploughing of agricultural soils ceases and a more moderate (moist) climate is created, which is beneficial for soil carbon. Furthermore, grassland emits N_2O, which will be stopped if it is afforested. It is clear that most profound effects are found in above-ground biomass and litter layers; the effects on the soil organic matter pool are much slower and smaller. Literature gives several overviews of impacts of land use change on the forest floor and soil organic matter (Post and Kwon 2000, Vesterdal et al. 2002, Paul et al. 2002). Results vary considerably; from reported losses during several decades after establishment to rather large increases in the long term. It is widely recognised that the net result of afforestation depends very much on the initial situation. If the initial stocks are low (for the soil type considered) then afforestation can yield considerable results in the soil C as well. Accumulation rates in the order of 0.3 to 0.4 Mg C ha^{-1} y^{-1} are frequently mentioned (see Figure 2.7).

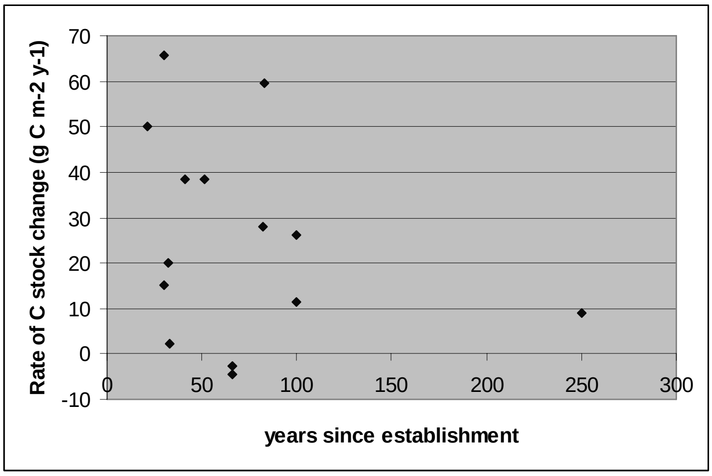

Figure 2.7. Average rates of soil carbon accumulation since forest establishment after agricultural use (Post and Kwon 2000).

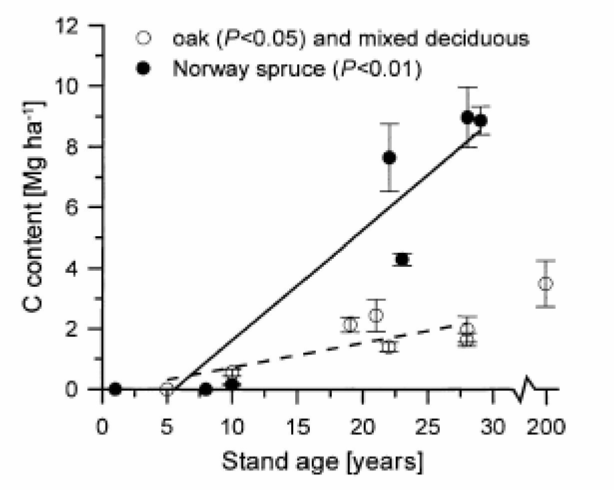

Figure 2.8. Forest floor C contents in afforestation chronosequences of oak and Norway spruce and of an adjacent ~200 years old mixed forest (Vesterdal et al. 2002).

Implications for biodiversity depend on the previous landuse, previous biodiversity values and on the surrounding landscape. Large scale afforestation of natural grasslands or culturally rich historical small scale landscapes could lead to the loss of specific species, while afforestation of intensively used agricultural areas could bring higher biodiversity. Similarly, afforestation of patches in an open landscape could increase biodiversity by creating additional habitats. Afforestation of open areas in a forested landscape could lead to a loss in biodiversity by destroying specific habitats. Open patches in the forest are known to be beneficial for many species. Effects of afforestation on biodiversity should therefore probably be judged by the diversity and structural heterogeneity of the newly created landscape. Effects on biodiversity also depend on the species that are used for afforestation. In Western Europe, earlier afforestations were aimed at production and often introduced coniferous tree species were used. Current afforestation is usually carried out with indigenous species, which is expected to be better for biodiversity (Larsson 2001). Furthermore, biodiversity could be enhanced through specific measures during afforestation. Such measures could include planting groups of species with different growth patterns to achieve a diverse structure or leaving parts of the area open, either permanently or to regenerate spontaneously. Furthermore, afforestation could be used to create corridors, e.g. in Natura 2000 frame.

Revenues and costs (real as well as opportunity): Cost effectiveness of this measure is low if measured in terms of carbon sequestration in biomass only. Inclusion of soil carbon and reduction of N_2O emissions from former grassland will increase the cost effectiveness slightly. However, afforestation can serve many goals and can have many positive side-effects. A review study by Richards and Stokes (2004) suggests that secondary benefits of afforestation might actually be as great as the costs. Costs, revenues and secondary benefits will vary much across Europe, depending on land price, labour costs, and for secondary benefits (recreation), for example, distance to population centres.

A known obstacle for afforestation in at least some countries is the loss in land value when agricultural land is afforested. Conversion to forest land is usually permanent, since it is prohibited by law to change forest to another landuse. Revenues from forestry are usually less than those from agriculture, so the farmer would experience a loss in income. Therefore, afforestation occurs mostly on lands that are no longer used for agriculture.

Constraints (Social, institutional, environmental etc.): Land use changes only take place slowly. These are drastic changes that are usually driven by other goals, or by developments in agriculture. Large-scale afforestation leads to losses in employment and abandonment of rural areas.

Some farmers oppose the idea of converting good agricultural land that often has been in family possession for centuries to forest. Further, afforestation can change the appearance of a landscape drastically. For example, the Northeast part of the Netherlands is known for its openness, caused by removal of the original peat layers and the cultivation of the area, where only agriculture was applied. Afforestation projects in these areas have led to protests because of the loss of the cultural identity of the landscape.

Furthermore, there are indications that specific types of afforestation could even enhance climate change. Claussen et al. (2001) concluded that afforestation with conifers in high altitudes leads to a net warming. Negative albedo effects were not compensated for by increased carbon storage.

Potential magnitude of technical measure: The potential of afforestation depends largely on the availability of abandoned agricultural land. Since these are usually marginal lands, the forest productivity would not be very high. On the other hand, the available area could be considerable and the increase in carbon stocks is for a large part permanent. The potential of new afforestation is recognized mostly in Eastern Europe, where both available land and low labour costs make afforestation feasible and attractive. On the contrary, a further major increase in forest land is unlikely in Western and Central Europe. Future availability of (marginal) agricultural lands is influenced by many factors, such as demand for agricultural products, (CAP) subsidies, openness of agricultural markets and possible competition with bioenergy crops. Different scenarios on land availability are provided by the ATEAM scenarios and the CLUE scenarios, for example, both based on the IPCC SRES scenarios. Depending on the scenario and the study, the forest area in Europe may either decrease by 4 million ha in total by 2030, or increase by 14 million ha over the same period.

Monitoring and control parameter (direct and indirect):

Forest area change can be detected with remote sensing techniques. Monitoring of C sinks would involve detailed repeated inventories. Direct and indirect effects are difficult to separate, unless the trees are planted.

Support and constraints in existing policies:

Land use changes are embedded in the Kyoto Protocol. Furthermore the CAP has provided subsidies for afforestation. Conflicts with local policies may arise in certain cases, for example with aims to keep certain areas open, or when maximum forest cover limits have been defined.

Possible political measure to support this technical measure: -

2.2.2.2 Avoiding deforestation

Description: Deforestation is the change of landuse from forest to some other landuse.
Deforestation leads to an immediate loss of carbon in living biomass, and to a rapid decrease of soil carbon due to decreased litter input and increased decomposition due to soil disturbance and increased temperature (less shading). Avoiding deforestation is the prevention of the transition of forest to another land use that would contain less carbon.
Main potential: The main potential of this measure is avoiding carbon emissions from current stocks in both biomass and soil carbon, and to a lesser extent the safe-guarding of future potential for carbon sequestration.
Technical feasibility: No specific technology required.
Implication for GHG mitigation / biodiversity: The implication of avoiding deforestation on the greenhouse gas budget is avoiding large carbon emissions. Implications for biodiversity can generally be judged as positive; it would mean a prevention of loss of current biodiversity. This depends of course on the previous biodiversity values and the type of landuse transition. Some nature conservation organisations create open patches in large homogeneous forests to increase the diversity in forest structure and biodiversity, or remove spontaneously regenerated trees from heathland to keep or restore biodiversity on these lands. However, most deforestation in Western Europe occurs in the context of urbanization and infrastructure development, which is not beneficial for biodiversity.
Revenues and costs (real as well as opportunity): Direct costs of avoiding deforestation are minimal, but indirect costs could be high. If for example a road must be build around a forest to avoid going through it, costs might be very high.
Constraints (Social, institutional, environmental etc.): In many Western and Central European countries, deforestation is only allowed under very high restrictions. Deforestation that occurs is usually for road construction or house building, and under the provision that the forest area is compensated elsewhere. In such cases, interests are often high, and it is unlikely that this kind of deforestation could be prevented. Bauer et al. (2004) conclude in an overview of forest laws of 23 European countries that in general: "Changes of forest land into other forms of land use (agriculture/ urbanisation/ industrialisation) need a separate and specific regulation procedure by the national forest law." Despite the importance of deforestation in terms of carbon and the obligation to report it under the UNFCCCC, few countries are currently able to estimate gross deforestation. Despite the above-mentioned restrictions on deforestation, The Netherlands reported an annual gross deforestation of about 1500 ha (0.4% of the forest area) to the UNFCCC (Nabuurs et al. 2004).
Potential magnitude of technical measure: The potential magnitude is hard to assess, since figures on gross deforestation are not widely available. Most European countries report an increase in forest area (TBFRA 2000), but this is often the net result of a small deforestation and a larger afforestation. Moreover, gross deforestation figures need to be split according to the type of transition to assess whether it could have been prevented or not. The potential area will probably be rather small, but the potential per hectare is large.

Monitoring and control parameter (direct and indirect): Remote sensing techniques are available.
Support and constraints in existing policies: -
Possible political measure to support this technical measure: Subsidies for not carrying out a planned deforestation will be hard to implement, because it is difficult to prove that you have serious plans to cut down forests. Restricting possibilities for deforestation would probably be the best option. However, in most cases such restrictions already exist.

2.2.3 Article 3.4: Additional measures in agriculture and forestry

2.2.3.1 Application of fertilizer to increase productivity

Description: In many parts of Europe, forests are located on the least fertile soils. Application of fertilizer can lead to a significant increase in productivity, and thus to an increased carbon sink in the biomass (e.g., Nilsson 1993, Mäkipää et al. 1999). The limiting factor is often nitrogen. Currently, an increase in forest production has been reported throughout Europe, which can at least partly be attributed to an increased nitrogen deposition (Karjalainen et al. in press). However, also other elements could be or become limiting, specifically magnesium. Fertilization has been extensively applied in Central and Northern Europe to offset acidification and nutrient degradation of forest soils.
Main potential: Increasing productivity of forests will lead to an increased carbon sink.
Technical feasibility: Feasible on sites with strong nutrient limitations, but not widely implemented. Implementation would not need any technological improvements. Many experiments have been carried out in the past. However, the potential benefit has been significantly reduced by widespread N depositions. (Not widely used because of the relative high costs and long periods before returns).
Implication for GHG mitigation / biodiversity: GHG mitigation: positive, increased productivity, increased carbon sink, at least in the biomass, but probably also in the soil. However, some studies point to a decreasing soil carbon stock in response to fertilization (Jandl 2002). Furthermore, the production of traditional fertilizer is unfavourable for the GHG balance and would partly offset increases in carbon sinks. Chen et al. (2000) found the carbon costs of applying low rates of N fertilizer to be only 0.5% of the carbon gains. However, the background N deposition was very low (2.5 kg N ha^{-1} yr^{-1}), so small additions of N had large effects. Other sources of fertilizer could perhaps be considered. Biodiversity: mostly negative, many forest plants live on poor sites, fertilization leads to change in species composition of ground vegetation and apparently also to soil fauna.
Revenues and costs (real as well as opportunity): Costs are relatively high and revenues in terms of timber are late and unsure. Revenues due to increased biomass sink depend on the price of carbon, type of fertilizer and increase in productivity.
Constraints (Social, institutional, environmental etc.): Conflicts with the ‘natural’ idea of forests, could lead to protests of local forest users, especially near urban areas and in Western Europe. Increased growth due to fertilization may affect stability of forest

stand and increase the risk of windthrow. There is a risk of unpredictable effects to soil chemistry with long-term impact on production and hence carbon sequestration potential. Due to unclear site-specific responses of soils, forest fertilization is unlikely to be recommended for larger areas. As a result of N deposition, there are large forest areas in Europe no longer limited by N nutrition and on these sites, N fertilization would increase the risk of nitrogen leaching (cf. nitrogen saturation…).
Potential magnitude of technical measure: Most likely limited to a small fraction of European forests, most likely to sites with severe nutrient degradation and acidification of forest soils. Possible areas would include the Northern European countries and new accession countries.
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies:
Possible political measure to support this technical measure:

2.2.3.2 Improving genetic quality

Description: The production of forest trees can be enhanced by improving the genetic quality of the trees. This could either be done through traditional breeding and provenance research or using modern genetic engineering techniques. Encouraging breeding strategies or genetic modification fall outside the scope of the CAP, but forest owners can be stimulated to pay attention to genetic quality, for example by purchasing high-quality plants for regeneration.
Main potential: Increased carbon sink through increased forest production.
Technical feasibility: Throughout Europe, provenance trials have been carried out for at least a century. Also breeding programmes are common, as well as certifying the seed quality of selected forest stands. Thus, in general, high quality propagation material is available. Knowledge on planting and seeding procedures is common.
Implication for GHG mitigation / biodiversity: This measure may be beneficial for GHG mitigation in the biomass due to the increased productivity of the forest. It might also be beneficial for soil carbon, through increased litterfall rates. Implications for biodiversity are most likely negative, since the genetic pool will be much smaller than in the natural situations. Another negative effect is that regeneration of the forest will be carried out by means of planting or seeding, leading to a more intensive management during the regeneration phase and less space for naturally appearing species. In general, the management will be more intensive, since higher investments are involved that need to be earned back. This will probably lead to monocultures of single species with severely limited age and spatial structure of such forest stands.
Revenues and costs (real as well as opportunity): Main costs for the forest owner are the costs for certified seed or planting material. These costs might be the full costs in case natural regeneration is otherwise used, or the additional costs relative to lower-quality propagation material that would have been used otherwise.
Constraints (Social, institutional, environmental etc.): A general trend in Europe is towards a more close-to-nature forestry, utilizing and mimicking natural processes. The traditional forest management, based on age classes and artificial planting, is slowly but steadily heading to a way of management that is closer to nature: stands with high age and spatial structure, rich and natural species composition and

promoting continuous natural regeneration. This trend runs parallel with promoting the policy of multifunctional forestry, stressing other important functions besides production, like recreation and nature protection. It is not very likely that this trend can be reversed.
Another important trend to note is the focus on, and protection of, indigenous genetic resources, which conflicts with this measure as well.
Potential magnitude of technical measure: At present difficult to provide any trustable estimation. The major areas of application are existing plantation forests with pine or Eucalypt species.
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies:
Possible political measure to support this technical measure: Subsidies on purchasing certified propagation material.

2.2.3.3 Drainage

Description: In very wet soils, forest production is limited by the high ground water table. Drainage can lower the water table, leading to a higher production. This measure could also include measures to restore or maintain current drainage systems.
Main potential: The potential would be to increase the productivity of the forest, leading to an increased carbon sink in the biomass.
Technical feasibility: Technically feasible, applied in various regions, in peatland in the boreal zone, but also on other wet soils in other regions.
Implication for GHG mitigation / biodiversity: Increased productivity would be beneficial for the carbon sink in the biomass. However, drainage of forest soils, and specifically of organic soils like peatlands, may lead to substantial carbon loss from the soil due to enhanced respiration (e.g., Harden et al. 2000, Ikkonen et al. 2001). It is still unclear if this effect will offset the increased biomass uptake. Also, peat stores carbon for much longer timeframes than aboveground biomass. Apart from that, drainage means a disturbance of the natural situation, with imposed change of species composition of ground vegetation and negative consequences for biodiversity. Due to the recognized importance of peat, it is recommended that GHG inventories treat mineral and organic soils separately (IPCC 2004).
Revenues and costs (real as well as opportunity): Drainage of peatlands has been common practice (at least in the Scandinavian region), and can be probably cost effective if only timber production is regarded. Extra revenues from carbon would increase the profitability, but only if carbon in the soil is not affected. Main costs are for construction and maintenance which must be done regularly, but is less cost intensive.
Constraints (Social, institutional, environmental etc.): Drainage in general might conflict with the water protection function of the forest. E.g., in the Netherlands, the recent trend has been to raise the ground water table of forests restoring it to the older status. Ground water table declined due to extensive water extraction for drinking water and for use in agriculture. Due to the concerns of carbon loss from peatlands, peatland drainage is not to be supported by local environmental policies, which concerns mostly the Northern European countries.

Potential magnitude of technical measure: Unlikely to be applied on substantial areas
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies:
Possible political measure to support this technical measure: Subsidy on construction and maintenance of drainage systems in forest.

2.2.3.4 Irrigation

Description: Part of the production in Europe's forest is limited by water availability. This is especially valid in the Mediterranean region, but at least partly also for the temperate zone of Europe. Irrigation is the artificial application of water during the growing season. This can be done either by pumping up groundwater or through the distribution of surface water. Surface water could be extracted from rivers or lakes, or from reservoirs that store rainwater. Another water source could be water from wastewater plants.
Main potential: The potential would be to increase the productivity of the forest, leading to an increased carbon sink.
Technical feasibility: Applied widely in agriculture and fast growing plantations (mainly Eucalypt in Spain and Portugal).
Implication for GHG mitigation / biodiversity: Increased productivity, leading to an increased carbon sink in the biomass. However, irrigation will probably be applied mostly to short rotation crops, so the effects on average biomass stocks will be low. Effects on soil are less obvious. Increased productivity could mean higher litterfall, which leads to higher soil and litter carbon stocks. On the other hand, increased water availability could lead to increased decomposition as well.
Effects on biodiversity are unclear, too. Irrigated plantations are likely to be managed intensively with negative impacts to biodiversity. On the other hand, the presence of trees in an otherwise probably open landscape could provide fauna shelter and nesting habitat.
Revenues and costs (real as well as opportunity): Investments costs are probably rather high. Intensive irrigation is currently only applied in crops with short rotations, with highly productive species. Discounted costs over longer rotations will probably be very high.
Constraints (Social, institutional, environmental etc.): The total amount of available water in the Mediterranean area is limited. Highly productive Eucalypt plantations are known to consume huge amounts of water, since they are not very water-efficient. Irrigation water needs to be extracted from deep soil layers or from the surrounding area. In case of water shortage, public opinion will likely favour using water for drinking and food crops over biomass production.
Potential magnitude of technical measure: This measure would probably primarily be beneficial for the establishment of new plantations, or the conversion of existing extensively used forest to short rotation plantations. The potential magnitude is likely more limited by water availability rather than by land availability. This measure would be applicable especially in the Mediterranean area.
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies:

Possible political measure to support this technical measure: Subsidies on establishment of irrigated plantations.

2.2.3.5 Changing rotation lengths

Description: Large parts of the European forest are still managed in the traditional way using clear-cut and establishing even-aged, often monospecies stands. The time between regeneration and final harvest is called the rotation length. Increasing this rotation length would on average lead to a higher amount of biomass at the site, and thus to a larger carbon stock. However, growth at higher ages is generally smaller, so the actual carbon sink strength will decrease.
Main potential: GHG mitigation through increased carbon stocks.
Technical feasibility: No technical measures needed.
Implication for GHG mitigation / biodiversity: This measure will lead to a longer retention of carbon in the living biomass. However, the size of the annual carbon sink in the biomass will decrease, and there will be some repercussions on soil carbon (Kaipainen et al. 2004, Liski et al. 2001). Liski et al (2001) (Figure 2.9) in a modelling study looked at the effect of rotation length on all C pools. Generally, a rotation shortening led to increased soil C, because of logging slash being added to the soil at faster intervals.

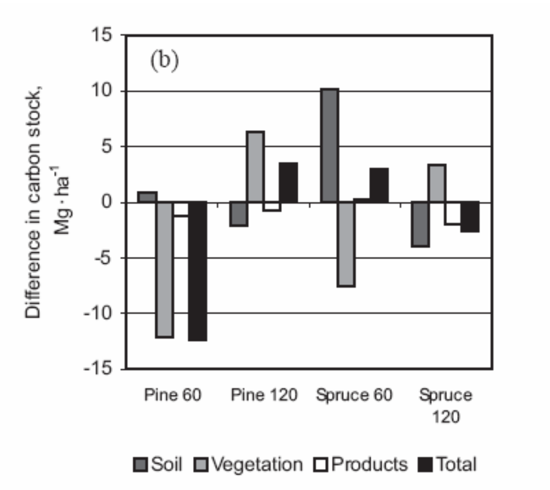

Figure 2.9: Difference in carbon stocks in soil, vegetation, and products compared to a 90 year rotation of the same species (Liski et al. 2001).

For biodiversity this measure will most likely be positive. Longer rotations will lead to trees with larger diameters, which is known to be positive for several bird and insect species. These trees are more likely to have holes for nesting and shelter and they provide stratum for mosses to grow on. Both the amount of deadwood in the forest as well as its size is likely to increase. This measure could also lead to a more diverse forest structure, which is beneficial for biodiversity as well (Larsson 2001). The general trend towards more close-to-nature forestry also propagates longer rotation lengths.

Revenues and costs (real as well as opportunity): Main costs associated with this measure are delayed revenues. Current rotation lengths are at least partly based on economic criteria and an increase will thus lead to less profitability. Harvesting costs will be somewhat different for larger trees. Longer rotations also mean a higher risk of quality loss and higher risks of unfavourable events, such as fire or windthrow.
Constraints (Social, institutional, environmental etc.): In some parts of Europe, rotation length is limited by natural factors, as for example windthrow in Sitka spruce plantations on peatlands in the UK and Ireland. Increasing rotation lengths in such situations is either impossible or involves very high risks. Furthermore, increased rotation lengths will lead to larger trees. The current woodworking industries are probably not capable of handling large amounts of much larger diameters.
In many tree species, longer rotations will lead to (for forest owners) unacceptable risks of quality losses. Although the physical rotation of beech could be much higher, risks of red heartwood formation limits it to about 120 years (Knoke 2003). Presence of this phenomenon will decrease the quality of the wood from excellent veneer quality to simple construction wood or less. Further, there is a risk that extending rotation lengths in one part of the forest (or region or Europe) leads to an increased harvest in other parts, since the same amount of wood is needed.
Potential magnitude of technical measure: The potential magnitude differs within Europe, depending on the tree species, current harvesting practices and intensity and current age class distribution.
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies:
Possible political measure to support this technical measure:

2.2.3.6 Changes in timing and intensity of thinnings

Description: During the rotation of a forest stand, usually several thinnings are carried out. A thinning is a reduction in the amount of trees per hectare. The aim of these thinnings is to increase the quality of the stand by removing the low quality trees, to concentrate the increment on fewer, carefully selected trees and to get early revenues. Thinnings reduce the amount of biomass in the stand, but could also stimulate the increment and thus carbon sink strength. Moreover, it provides extra litter input to the soil. Modern thinning schedules are strongly driven by economic considerations. First thinnings are often delayed to obtain larger revenues from the operation (cf. 4.2 pre-commercial thinnings). This leads to very dense overstocked forests which are not optimal for the C sink strength. Commercial thinnings are nowadays often done intensely with longer thinning intervals to obtain larger thinning volumes and to make the thinning more cost efficient. This leads to understocked stands which are not able to fully utilize the C sequestration potential. Optimum thinning strategies for C sequestration would aim to maintain a certain basal area in the forest which maximizes volume production. This requires more frequent, but less intensive thinning interventions.
Main potential: GHG mitigation
Technical feasibility: No extra technical measures needed.

Implication for GHG mitigation / biodiversity: Changing timing and intensity of thinning provides the opportunity to influence stocks and fluxes in the forest system. Less thinnings will lead to higher carbon stocks in the biomass, but probably to lower net sinks due to decreased productivity or increased mortality in the dense stands. Associated changes in soil carbon are very subtle. Overall we can state that soil C impacts of changes in management are very small, hard to detect, rather uncertain, and depend very much on the initial state.
The implications for biodiversity are not easy to estimate, since it will depend on the situation before and the actual changes. Less thinnings or less intense thinnings would mean less human disturbance, which is more natural. However, some degree of disturbance is beneficial for biodiversity, since it will lead to the mobilisation of resources and create niches and habitats. Many plants that are associated with old forests are dependent on forest management. The dispersal mechanisms of some species have been linked to human activities (Bijlsma et al. 2001). Others decreased in abundance after management activities stopped because the tree canopies became too dense (Bijlsma et al. 2001).
Revenues and costs (real as well as opportunity): In most cases, C optimum management would cost more than the current practices, because of an earlier start of the thinning schedule and more frequent thinnings with low extracted volumes.
Constraints (Social, institutional, environmental etc.): Forest management aims at multiple goals. Carbon-optimal thinning regimes may conflict with other aims of the forest.
Potential magnitude of technical measure: Effects per hectare may be quite small, but the area under active management in Europe is fairly large.
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies:
Possible political measure to support this technical measure:

2.2.3.7 Continuous cover forestry/ selective logging

Description: Traditionally, large parts of the European forest have been managed using clear-cuts and planting. This created even-aged stands, often consisting of single tree species. Several alternatives exist, whereby trees can be mixed both in species and in age. Regeneration can be done gradually, either in a fixed period of several (tens of) years (shelterwood systems), or continuously in different parts of the forest (selective felling systems). A continuous presence of forest cover leads to less fluctuation of the carbon stocks and fluxes at the site, and probably to a higher average stock present at the site.
Main potential: Both GHG mitigation and biodiversity.
Technical feasibility: Similar systems are practiced and investigated in different parts of Europe. However, such systems are usually more complicated and demand more insight and knowledge of the foresters.
Implication for GHG mitigation / biodiversity: A continuous presence of forest cover leads to less fluctuation of the carbon stocks and fluxes at the site, and probably to a higher average stock present at the site. The micro-climate at the soil will fluctuate less, due to more constant shading. These systems lead to more

diversity in forest structure and are believed to better resemble the natural situation. Therefore, effects on biodiversity are believed to be positive (Larsson 2001).
Revenues and costs (real as well as opportunity): Costs and revenues are unclear. Even-aged systems can be managed more efficiently, but uneven-aged systems can take advantage of natural processes. Moreover, continuous cover systems might be less susceptible to natural disturbances, or can at least react more quickly to disturbances. More research is needed
Constraints (Social, institutional, environmental etc.): These systems are less easy to manage by foresters. Interactions between tree species are much more complex and reactions of (combinations of) species might differ per site type. In most parts of Europe, the area under such a kind of management is very small, and practical experience is therefore limited.
Potential magnitude of technical measure: The effect on a per hectare basis is largely unknown, and will probably vary with local site conditions and species combinations. The area where it could be applied is large, since most European forests are managed in an evenaged way (Nabuurs et al. 2003).
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies: A current trend in forestry is a more close-to-nature way of management. This trend coincides with this measure and will thus not be difficult to implement.
Possible political measure to support this technical measure:

2.2.3.8 Changes in tree species

Description: The choice of tree species influences the carbon cycle of a forest stand in various ways. Species differ in productivity, maximum attainable biomass stocks, associated management regimes, litterfall rates and litter quality. Changing the tree species composition could thus lead to changes in stocks and sinks, both in the biomass as well as in the soil compartment.
Main potential: GHG mitigation
Technical feasibility: Changing tree species is technically feasible.
Implication for GHG mitigation / biodiversity: Increased productivity could lead to higher sinks. A change to species with longer rotations could lead to higher average stocks, at least in biomass terms but probably also in the soil. Figure 2.10 shows carbon stocks of different forest types in Europe. Although these types grow on different soil types under different climatic conditions, it gives an indication as to what changes in species could do.

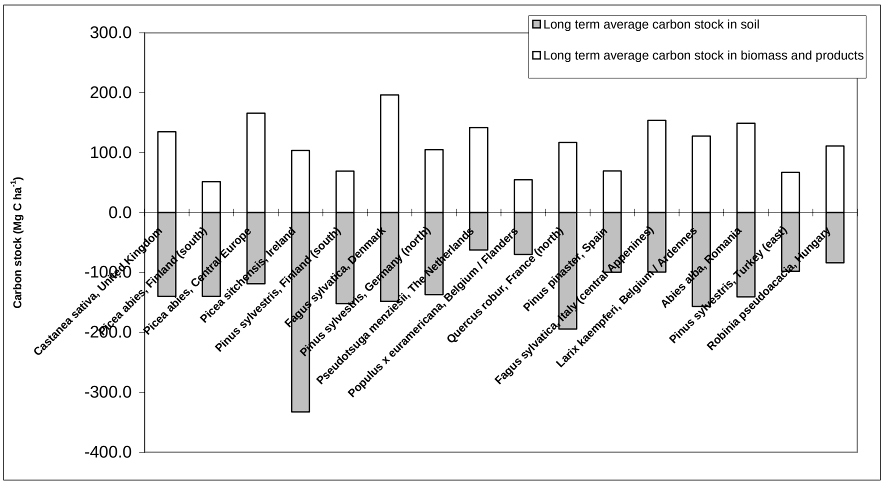

Figure 2.10. The long term average carbon stock in soil (below x-axis) and biomass and products (above x-axis) of 16 forest types throughout Europe. The negative sign for the stocks in soil was only used to display the soil stock below the x axis (Nabuurs and Schelhaas 2002).

In general, a change from introduced to indigenous species will be favourable for biodiversity, since indigenous species usually host specific organisms. Each tree species will have its own associated biodiversity, so changing from one species to another might lead to changes in biodiversity as well. If the same species has been growing at the site for a very long time, biodiversity might have adapted to this situation, so a species change will lead to a loss of biodiversity. In this case, a high sink strength would often conflict with biodiversity goals, especially when indigenous species are replaced with exotic species.

Revenues and costs (real as well as opportunity): To a large extent, revenues and costs will depend on the situation.

Constraints (Social, institutional, environmental etc.): A general trend in Europe is a shift from introduced to indigenous species. Introduces species are usually more productive, but have disadvantages regarding stability and biodiversity. It is not very likely that this trend could be reversed, if wanted. The most appropriate point within a rotation to change tree species is when the stand is mature and will be harvested and regenerated. Earlier conversion leads to large economical losses because the harvested wood will have too small diameters to be sold on the market, or will yield much less than when the original dimensions would have been reached. This will limit the annual potential area, and at the same time make the process span over a long timeframe. Another option is planting the new species under the canopy of the existing forest. However, not all species can be handled in this way, and some kind of management needs to be applied to the existing forest.

Potential magnitude of technical measure: The potential area of application is the whole European forest area. However, tree species change will be feasible only on a certain fraction, depending on which tree species can be grown, protection status of the forest, productivity of different species, risks involved, etcetera. Quantification will be very difficult.

Monitoring and control parameter (direct and indirect): Coverage of different tree species.

Support and constraints in existing policies:

Possible political measure to support this technical measure:

2.2.3.9 Protection of forests with high biomass carbon stocks

Description: Harvest of forest stands with a high amount of biomass will lead to a decrease in carbon stock in living biomass. Part of this biomass will be harvested and used for products; the rest will stay at the site and decompose. Not harvesting these stands would avoid a decrease in carbon stock in living biomass in these stands.
Main potential: GHG mitigation.
Technical feasibility: No technical measures needed.
Implication for GHG mitigation / biodiversity: Avoidance of decrease in biomass stocks, at least temporarily. In the longer term, stocks will probably decrease anyhow due to natural reasons (age-related mortality, natural disturbances). This measure might have implications for the soil carbon at the site, since less harvest residues are added to the litter layer. Moreover, leakage occurs as other stands will be harvested instead. If the products that would have been made from the harvested wood are made of other materials instead, the balance might even be negative. This might happen because other materials are generally more energy-intensive in production. Effects for biodiversity are probably positive, since the stands will not be harvested, and thus they can develop in a natural way (Larsson 2001). However, some degree of disturbance is thought to be positive for biodiversity, since it will create more diversity in forest structure, creating different habitats and niches.
Revenues and costs (real as well as opportunity): No direct costs are involved, only indirect costs in the form of lost revenues. These could be very large; the amount will depend on the species, quantity and quality of the wood available at the site.
Constraints (Social, institutional, environmental etc.): Some forest owners are probably not willing to leave high-quality wood in the forest until the trees die naturally. On the other hand, this measure is consistent with the current trend towards an increased awareness of the nature function of the forest.
In the longer term, the biomass will decrease again due to natural causes, such as age related mortality or disturbances. Per forest type and tree species the maximum attainable biomass and the period this amount can be sustained will differ significantly. Therefore, this measure will only work for a limited period of time, after which the stand will turn into a source. This uncertain behaviour will complicate the assessment and planning of this option.
Potential magnitude of technical measure: Currently the European forest is relatively young, and the increment rate is higher than the harvest. This has led to increasing growing stocks over the last decades. This trend is thought to continue for at least several decades (Schelhaas et al. in press, Nabuurs et al. 2003). The currently existing difference in many countries between increment and drain could be used to protect high biomass stands and to shift the harvest to younger age classes. However, it is not clear if this shift will increase the overall carbon stock.
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies:
Possible political measure to support this technical measure:

2.2.3.10 Minimising site preparation

Description: During the regeneration process forest soils are often disturbed in one way or the other to prepare the site for seeding or planting. This can be done with many different techniques such as patch or row scarification, ploughing, disking or shearing. Minimising such preparation minimises the disturbance of the soil, and thus results in less soil carbon losses. A review of the effects of site preparation showed a net loss of soil C (Johnson, 1992). Several studies that compared different site preparation methods found that the loss of soil C increased with the intensity of the soil disturbance (Schmidt *et al.*, 1996, Mallik & Hu, 1997). At scarified sites, organic matter in logging residues and humus, mixed with- or buried beneath the mineral soil, decomposes more rapidly than on undisturbed soil surfaces of clear-cut areas. The soil moisture status of a site has great importance for the response to soil scarification. The increase in decomposition was more pronounced at poor, coarsely textured dry sites than on richer, fresh to wet sites (Johansson, 1994). Sandy soils are particularly sensitive to management practices, which result in significant losses of C and N (Carlyle, 1993). Intensive site preparation methods might result in increased nutrient losses and decreased long-term productivity (Lundmark, 1988). However, site preparation may also increase productivity and this effect may balance or even outweigh the loss of soil C in the total ecosystem response. The chosen technique of site preparation is important and will determine if the net C effect of the activity is positive or negative.

Main potential: GHG mitigation

Technical feasibility: Techniques which expose the mineral soil to less intensive soil disturbance exist. Moreover, nature-oriented silvicultural systems with natural regeneration require no, or only minimal, site preparation.

Implication for GHG mitigation / biodiversity: Reduction of carbon emissions from decomposing soil organic matter. Less disturbance of the soil favours existing plant species. However, soil disturbance also provides opportunities for new (pioneer) species.

Revenues and costs (real as well as opportunity): Choosing site preparation techniques with less soil disturbance creates no additional costs. If the silvicultural management system is changed, the whole cost structure of management operations changes. The economic consequences are difficult to assess.

Constraints (Social, institutional, environmental etc.):

Reduced soil disturbance has positive side effects on nutrient balances and water quality because nutrient leaching will be reduced.

Potential magnitude of technical measure: The application of site preparation has already been improved as a consequence of more environmental concerns in forest management, and the increase of nature-oriented forest management systems have reduced the need for site preparation. Because of the different impacts of alternative techniques and the site dependent impacts it is very difficult to assess on a larger scale the extent to which current practices can still be improved.

Monitoring and control parameter (direct and indirect): soil carbon monitoring is very difficult to implement because of large spatial variability and because there is not a well established methodology to assess stock changes in various soil types.

Support and constraints in existing policies:

Possible political measure to support this technical measure:

2.2.3.11 Decrease of (impact of) fires

Forest fires do not only release stored carbon to the atmosphere in the form of CO2, they also produce other important greenhouse gasses, like CO and NOx (Hoelzemann et al. 2004). Hoelzemann et al. estimate the emissions of NOx for the year 2000 from Western Europe at 0.017 Tg (expressed as NO) and CO emissions at 0.49 Tg. Western Europe here includes those Mediterranean countries that dominate Europe's fire statistics: Spain, Portugal, Italy, Greece and France (see also Table 2.1). Barbosa et al. (submitted manuscript, cited in Hoelzemann et al. 2004) estimate emissions from these countries at 0.024 Tg and 0.46 Tg respectively. Schelhaas et al. (2003) estimate the annual damaged wood volume by forest fire at 4.9 million m3 over the period 1950-2000. However, only a fraction of this volume will be totally burned, in most cases this wood volume will only be killed. However, the associated (smaller) branches, foliage and forest floor litter will be burned as well. Table 2.1 gives an overview of the annual burned areas in forest and forest and other wooded land throughout Europe (Schelhaas et al. 2001).

Fire suppression has different influences on the carbon cycle. First of all, prevention of fires means prevention of loss of carbon that is stored in the vegetation and the soil. Secondly, fire suppression could lead to increased carbon stocks, since the forest is allowed to reach older ages and thus to accumulate more carbon (Tilman et al. 2000). Moreover, fires lead to a net loss of nutrients in the system, which could slow down carbon accumulation afterwards (Rovira et al. 2004). Further, changes in the fire regime will also affect the species composition of the forest, which in turn might influence carbon accumulation rates and maximum attainable stocks. For example, shrublands in the Mediterranean region are thought to be maintained by wildfires at 20-50 year intervals (Trabaud, 1991). If fires do not occur, these shrublands will convert to forest land in time.

Tilman et al. (2000) studied the effect of fire suppression on an oak savannah in Minnesota. They found an average carbon sink of 1.8 Mg ha-1 yr-1 over a 35-year period in unburned plots compared to periodically (annual or biannual) burned plots. This increase was mainly attributed to increased carbon stocks in woody vegetation and litter; effects on soil were not significant.

A possible negative effect of fire suppression is that fuel accumulates, and that the fire risk might increase. This accumulation might lead to very large, destructive fires that are difficult to manage. An effective fire strategy should therefore be not only to detect and fight fires at an early stage, but also to manage the forest in such a way that it is less susceptible to fires. Possible management measures aimed at reducing fire susceptibility are to reduce fuel loads (mainly litter and ground vegetation) by regular controlled burning or harvesting, keeping a forest structure that hinders fire spread, and by encouraging tree species that burn less easily. At the landscape level, the creation and maintenance of fire breaks might be an effective option, perhaps combined with a more effective fire detection and fighting system. Another important measure, but outside the scope of this project, might be to reduce the amount of ignitions; most fires are caused by humans, both intentional as well as by accident.

Table 2.1. Average annual fire area on the categories forest land and forest and other wooded land over the period 1991-2000 (source: DFDE database, Schelhaas et al. 2001). Data on total forest area and other wooded land from TBFRA 2000.

	Average annual forest fire area	Forest land area	% of forest land	Average annual fire area on forest and other wooded land	Forest and other wooded land area	% of forest and other wooded land
	(ha)	(1000 ha)	(%)	(ha)	(1000 ha)	(%)
Spain	62348	13509	0.46	155695	25984	0.60
Portugal	43932	3383	1.30	104062	3467	3.00
Italy	43293	9857	0.44	93331	10842	0.86
Greece	26692	3359	0.79	59387	6513	0.91
Poland	11185	8942	0.13	10635	8942	0.12
France	3925	15156	0.03	17405	16989	0.10
Sweden	1926	27264	0.01	2482	30259	0.01
Germany	1240	10740	0.01	1240	10740	0.01
Finland	744	21883	0.00	833	22768	0.00
Czech Republic	713	2630	0.03	1108	2630	0.04
Latvia	620	2884	0.02	1605	2995	0.05
Cyprus	376	117	0.32	629	280	0.22
United Kingdom	343	2469	0.01	344	2489	0.01
Slovenia	335	1099	0.03	610	1166	0.05
Lithuania	254	1978	0.01	241	2050	0.01
Estonia	241	2016	0.01	503	2162	0.02
Ireland	189	591	0.03	513	591	0.09
Belgium	98	646	0.02	203	672	0.03
Slovakia	94	2016	0.00	210	2031	0.01
Austria	64	3840	0.00	65	3924	0.00
Netherlands	34	339	0.01	224	339	0.07
Denmark	15	445	0.00	59	538	0.01
Luxembourg	3	86	0.00	3	89	0.00
Hungary		1811	0.00		1811	0.00
Malta		0.347	0.00		0.347	0.00
Total	198664	137060	0.14	451386	160271	0.28

Decreasing fuel loads by prescribed burning

Description: One of the determining factors for forest fire risk is the fuel load. The more fuel present at the site, the higher the risk for (uncontrollable) fires. One way of decreasing the amount of fuel on the ground is by prescribed burning. In prescribed burning, the ground vegetation and litter on the ground is burned regularly in low-intensity fires under controlled circumstances. These fires will remove large parts of the fuel load, without killing the canopy trees. The application of prescribed burning will not lead to fire exclusion, but will reduce the intensity of a wildfire, and thus greatly enhance the fire fighting possibilities. A permanent reduction of the fine fuel load to levels below 5 t/ha will guarantee control by ground forces at very high fire danger levels, while a fuel load of 9 t/ha will still allow wildfire control by aerial fire-fighting (Botelho et al. 2000).

Main potential: GHG mitigation through reduced fire risk

Technical feasibility: Prescribed burning has been used in many places in Europe in the past, and is commonly used in the US. However, prescribed burning is not widely applied in Europe at the moment and practical guidelines are lacking (Fernandes and Botelho, 2003).

Implication for GHG mitigation / biodiversity: A direct effect of prescribed burning is the emission of carbon sequestered in litter and ground vegetation, which is contradictory to the aim of GHG mitigation. Also the litter input to the soil might decrease by these burns. However, the risk for very intense fires is reduced, and thus the carbon stored in the remaining canopy trees is better protected. Effects on biodiversity are difficult to determine. Some fire-dependent species might benefit, others might be killed by the fires or may not be able to colonise the site. Large areas treated with prescribed burning might lead to unification and less biodiversity, but burning only certain patches might increase biodiversity by creating more habitats and a diverse landscape. Fire may also negatively affect individual animals. For example, slow moving animals may not be able to escape even low intensity fire fronts. Although ground nests may be lost in certain seasons, adult birds usually re-nest and benefit from the abundance of insects that follow a fire. Small animals that find cover in burrows or under logs, plants, or stumps may be much easier prey for predators, who truly benefit from fires (http://edis.ifas.ufl.edu/FR061).

Revenues and costs (real as well as opportunity): Revenues are difficult to assess, since there are no direct revenues. There are indirect revenues in the form of a larger chance that the trees will reach commercial proportions. Direct costs are planning costs and the costs of the crew to control the fire. Probably a rather large crew is needed to control a fire. Indirect costs might be the loss of a few trees and a loss of nutrients on the site.

According to Fernandes and Botelho (2004), prescribed burning is done in Northern Portugal by crews of 4-10 persons equipped with hand tools and led by a technical supervisor. The average burn is accomplished at a rate of 0.52 ha h^{-1}, which is two to five times faster than mechanical and chemical fuel management methods. Mean values vary from 0.12 – 1.03 ha h^{-1}.

Minimizing escapes is an important constraint which contributes to increase overall cost of the prescribed burning programme (González-Cabán 1997, cited in Baeza et al., 2002).

Constraints (Social, institutional, environmental etc.): (http://edis.ifas.ufl.edu/FR061)

Although the benefits of prescribed burning are clear, there are also notable concerns. Two of the most important are the possibilities of fire spreading to adjacent properties and smoke intrusions in populated areas. Good management can reduce these concerns, like limiting application to certain weather and fuel situations.

These restrictions may limit the opportunities to burn to just a few days each year. Given these limitations, many forest landowners do not have the staff or capability to burn all their land. Another concern with prescribed burning, especially in

plantations grown for timber production, is the potential for mortality or growth loss in trees. Even with older longleaf pines, long-term studies have demonstrated that repeated fires will reduce stand volume. The reductions are the result of individual trees killed by fires as well as productivity and growth losses due to needle scorch. The spatial pattern of fire application is critical to reduce fire risk at the landscape level significantly (Fernandes and Botelho, 2003). This would involve a planning strategy at a higher level than the individual owner.
Potential magnitude of technical measure: Fire-prone areas, like Mediterranean area and Poland. According to Fernandes and Botelho (2003), best results are likely to be attained in climates where the likelihood of extreme weather conditions is low. This might not be the case in large areas in the Mediterranean basin.
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies: Prescribed burning is not allowed in Greece and most of Italy (Botelho et al. 2000)
Possible political measure to support this technical measure:

Decreasing fuel loads by management activities
Description: Management can reduce fuel load or fuel structure in different ways, like cutting understory vegetation and leaving it on the site or removing it, chipping the understory vegetation, or the application of herbicides. In the short term, those options where the fuel is removed from the site are especially effective (Fernandes et al. 2000).
Main potential: GHG mitigation
Technical feasibility: This measure could be carried out manually or by machine. Manually would be very elaborate, but technically feasible. No special machines are designed for this task, but normal forest tractors and hand equipment will be sufficient. However, the chance to damage remaining trees is high, as well as the chances for soil damage (compaction).
Implication for GHG mitigation / biodiversity: Carbon stocks in litter and probably soils will be lowered, but the risk for intense fires is reduced, and thus the risk for loss of biomass carbon. This measure could be optimised by using the removed material for bioenergy production. Implications for biodiversity will depend on the species. It will be beneficial for pioneer species and others that need mineral ground for germination. If the removal cycle is shorter than the regeneration cycle of plant species, those species will disappear. This measure could also lead to smaller amounts of deadwood in the forest. However, of most importance in preventing fires is the removal of easily flammable material; logs will not burn too easily.
Revenues and costs (real as well as opportunity): Costs will be very high if the work is done manually. Even if carried out by machine, costs will probably be relatively high and recurring regularly. Indirect costs might be a loss of productivity due to removal of nutrients. Revenues are mainly indirect from reduced risks. Additional revenues could be created by using the removed material for bioenergy. Another indirect revenue (not at the owner level) would be an increase in labour opportunities in rural areas.
Constraints (Social, institutional, environmental etc.): This measure is very labour-intensive and thus costly. Application over large areas therefore seems to be unfeasible. However, this measure could be applied to certain carefully selected areas

to create barriers, so forest fires will spread less easily. However, to make such an approach work, an integral planning for the whole area needs to be made, and all concerned landowners need to co-operate. Another opportunity could be to apply this measure close to settlements as additional fire protection. Another constraint for large-scale application might be concerns about the removal of nutrients out of the ecosystem.
Effects of treatment are short, so they need to be repeated on a very regular basis (2-4 years) (Fernandes and Botelho, 2003).
Potential magnitude of technical measure: Fire-prone areas, like Mediterranean area and Poland.
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies:
Possible political measure to support this technical measure:

Decreasing fire risk by adapting forest structure through management
Description: Not only the fuel load (quantity) is important in fire risk, but also the horizontal and vertical distribution of the fuel. The presence of a shrub layer might cause ground fires to evolve in crown fires. Fire might spread more easily in dense stands than in very open stands. Thinning the tree layer will influence the occurrence of ground and shrub vegetation, and influences the fuel structure of the canopy. Increased thinning might lead to more ground and shrub vegetation, which might increase fire risk again. Therefore this measure should include both thinning and shrub removal.
Main potential: GHG mitigation through reduced emissions
Technical feasibility: Thinning is a regular forest operation.
Implication for GHG mitigation / biodiversity: Thinning will lower the carbon stocks in the trees, but soil carbon might be enhanced through increased slash input. However, the influence of thinning on the carbon budget is in general limited. The main advantage of this measure is a reduced risk for loss of carbon stocks. This measure could be optimised by using the thinned trees and shrub material for bioenergy production, which would reduce the fire risk further. This measure will involve a rather intensive management which might not be beneficial for biodiversity. However, pioneer species will be favoured, leading to a different species composition compared to less intensively managed stands. Biodiversity effects will also depend on the scale of the measure. Perhaps this measure could already be effective if applied only in certain areas, effectively creating a kind of fire breaks, thereby creating a patchier biodiversity structure.
Revenues and costs (real as well as opportunity): Thinning is a regular forest operation and will not be too costly, and there might be some revenues. Thinning intensities could be higher than usual to create sparse stands, leading to some more revenues. Some extra revenues might be created by removing biomass for bioenergy. Indirect costs might be a loss of productivity due to removal of nutrients. Revenues are mainly indirect from reduced risks.
Constraints (Social, institutional, environmental etc.): The effectiveness of this measure is not entirely clear. Although it is commonly assumed that thinning will influence fuel characteristics, Silva et al. (2000) could not show differences in fuel

characteristics and expected fire behaviour several years after the application of different thinning intensities, including a no-thin treatment.
Potential magnitude of technical measure: Fire-prone areas, like Mediterranean area and Poland.
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies:
Possible political measure to support this technical measure:

Decreasing flammability by changing tree species
Description: Large parts of the Mediterranean area are covered by vegetation that is very prone to fires, mainly pine species. Conversion of such species to less fire-prone species would reduce the chance of forest fires. Using strips of less susceptible species along streets and surrounding urban areas may reduce unintentional human induced fires. Strips can also be planted along fire breaks to reduce the fire spread (cf. fire break section).
Main potential: GHG mitigation
Technical feasibility: No special technical measures are needed.
Implication for GHG mitigation / biodiversity: The advantage for GHG mitigation is a reduced risk of carbon loss in biomass and litter due to fire. The productivity of such species might be less than that of pine species, which could lead to a somewhat smaller sink strength.
For biodiversity this measure might be beneficial, provided that species are used that would have occurred naturally. The current widespread occurrence of pine is unnatural. This measure could be used to restore the original vegetation types, and probably also the connected biodiversity.
Revenues and costs (real as well as opportunity): Main direct costs are the costs for preparation and planting a site. If conversion is done before the optimal or usual rotation age, indirect costs occur as lost revenues. If productive, commercial pine plantations are converted to less productive stands, the owner will have decreased revenues in future. Besides productivity, also the quality and commercial value of the new tree species could be lower. However, not all pine forest is commercially used. On the other hand, the risk for loss of timber is reduced as well.
Constraints (Social, institutional, environmental etc.): Species conversion of large areas will take a long time. It would be most logical to do the conversion at the end of the rotation length. The minimum time frame would be the longest rotation length in use, provided that all area is converted. However, not enough planting material or seed might be available, especially if the new species were until now not commercially interesting. Moreover, not all owners are probably willing to convert their land. Large parts of these forests might be managed as unevenaged stands, in which case the conversion could probably be done gradually. However, it is not sure if the knowledge to do so is widely available. Another constraint might be the willingness of owners to manage their land. Part of the land is not managed at all because of the low productivity.
Potential magnitude of technical measure: All flammable species in the Mediterranean basin.
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies:

Possible political measure to support this technical measure:

Improved fire detection and fighting
Description: The earlier a fire is detected, the larger the chance that it can be put out before it grows too large. Various measures could be taken to increase the chance that a fire will be detected in time. Such measures could include more intensive patrolling (land and/or air), automatic remote sensing fire detection systems, watchtowers, etcetera. However, such measures will probably fall outside the CAP, since it is not focussed on land and land management. We will therefore not evaluate this measure further.

Increased fire prevention (creation and maintenance of fire breaks)
Description: By maintaining fire breaks in strategic places, fires can be prevented from spreading over large areas. Fire breaks consist of a strip of land without vegetation (ploughed regularly to prevent establishment of flammable vegetation) or with vegetation that does not burn easily and that is wide enough to prevent the fire from reaching the other side. Fire breaks often consist of low vegetation that is kept short by grazing or mowing. This could be combined with measures to reduce the flammability on both sides of the fire break, like reducing the amount of understory vegetation and litter. Another possibility is the use of tree species that do not burn easily, like most broadleaved tree species. It is also possible to apply agriculture on such open strips, provided that the crops are not easily flammable. Fire breaks must be carefully planned on a regional level, taking into account the local circumstances and topography. Fire breaks could be planned in such a way so that optimal use is made of already open areas, like fields, roads and power lines.
Main potential: GHG mitigation
Technical feasibility: No specific new technology needed.
Implication for GHG mitigation / biodiversity: The main implication for GHG mitigation is a reduction of fire risk and size in the whole region. The carbon stocks in litter and biomass will be better protected, so the risk for carbon emissions will be lower, and probably also the average stock of carbon per hectare could increase. For the specific area where the fire breaks are made, the carbon stocks will be lower, but on a large area the carbon stocks will be higher. The effect on biodiversity will depend on the species. For species that have a limited dispersal capacity, fire breaks could be strong barriers. A well-maintained network of fire breaks would then effectively create isolated patches in the landscape. For other species this measure might be favourable, like large grazers. The fire breaks with short vegetation will provide grazing areas, while the adjoining forest provides shelter.
Revenues and costs (real as well as opportunity): The exact planning where to make fire breaks will involve input of many people, like the local government and fire experts, and thus might be costly. The actual creation of the fire breaks is an event that takes place only once, and consists of the removal of the tree and shrub vegetation, and probably seeding or planting the new vegetation. Further costs will be the regular maintenance of the fire breaks, like ploughing, removing the vegetation, pruning adjoining trees, removing shrub vegetation, etcetera. Some revenues could be created by selling the first removal of biomass, either as timber or for bioenergy (chips or fuelwood). Other revenues depend on the type of vegetation

in the fire breaks. Agriculture could provide some revenues, as well as selling hay or selling grazing rights on the fire breaks.
Constraints (Social, institutional, environmental etc.): An integrated plan for the whole area needs to be made, and all concerned landowners need to co-operate.
Potential magnitude of technical measure: All areas with a regular high fire risk
Monitoring and control parameter (direct and indirect): Length of fire breaks, spatial structure of fuel/fuel maps derived from remote sensing; indirect: burned area per fire, total fire area
Support and constraints in existing policies:
Possible political measure to support this technical measure:

Besides the possible effects of fire reduction on GHG mitigation inside the forest, there is an important side-effect of these measures on the whole community. Decreases in the frequency and severity of fires also lead to a reduction of damage risk of houses, farms and human lives. The reduction of economic risks on a larger scale should be incorporated in the economic analysis of all these measures.

Many of these measures can be used to make areas less easy to burn. However, decreasing the fire risk on some randomly located areas will not contribute much to the overall reduction of fire risk. A regional approach could be much more effective, identifying strategic areas or zones were these measures are most effective. Creation of a network of fire breaks and other zones which are less flammable could lead to the division of the area in compartments, which would facilitate fire fighting and would reduce the risk of very large fires. Application of such a regional approach would call for an integration of the CAP with local, regional and national policies.

2.2.3.12 Increased stability against wind

Wind damage frequently occurs in Europe. Damage can be caused by small-scale events such as thunderstorms and small cyclones, but also by major storms. Wind damage is most frequent in the Atlantic zone, with strong gales occurring every 2-3 years in UK and Ireland. In Central Europe, high windspeeds are recorded less regularly, but the effects can be disastrous. Over the period 1950-2000, Schelhaas et al. (2003) estimated an average annual damage by storms of 18.7 million m^3. The damage in individual years can be much higher; in 1999, more than 180 million m^3, equal to about half of the normal harvest in the whole of Europe. In individual countries, damage was as high as 5 times the annual harvest. Over the last decades the amount of storm damage seems to be increasing. Although climate change is often referred to as a possible cause, it seems more likely that the increase is linked to developments in the forest resources. Forest area and wood volume per hectare has increased markedly since 1950, and thus the resource that can be damaged. Moreover, the average age of the forest has increased, which is generally linked to an increase in the susceptibility of the forest.
Various characteristics of a forest stand are known to increase the chance of storm damage. Such factors include tree species choice (conifers versus broadleaves, mixed versus monocultures), stand structure (even-aged versus uneven-aged), recent (heavy)

thinnings, recent new stand edges, average tree height, height/diameter ratio, limited rooting possibilities (high groundwater table, impenetrable soil layers) and stand history (site preparation and planting techniques, fertilisation).
The influence of storm damage on carbon sequestration in forest is mainly on the biomass and soil pool. Storm damage decreases the amount of live biomass and increases the amount of litter on the ground. Usually not all storm damaged wood is removed from the forest, so the increased amount of litter will last for at least some years. However, it is not clear if this will really affect the soil organic matter pool. The removal of (a large part of) the standing trees will cause a temporary reduction in biomass sink capacity, but could on the longer term lead to an increase in sink strength because old, slow growing trees are replaced with young ones.

Description: The management of stands in areas with a high risk of high wind speeds could aim at increasing stand stability by optimising the factors that influence stand stability. In the UK, a system is developed to estimate the wind risk of individual stands (Miller, 1985). It is recommended that stands in high wind risk areas are not to be thinned. Besides the rather safe no-thinning option there are a variety of management practices that are recommended in the literature. Many of those options involve a gradual reduction of stem number with stand age in order to keep the height/diameter ratio of the trees low. Other recommendations include mixing trees of different species and ages. However, recommendations on optimal thinning regimes differ very much between different literature sources, and possibly also with species and location. Furthermore, there is no conclusive evidence that mixed stands are really more windfirm.
Recently, GIS based tools have been developed to calculate risks for new forest edges as a consequence of the harvest of adjacent stands (Talkkari, 2000, Blennow and Sallnäs, 2004). This would yield possibilities to carefully plan harvest areas to minimise damage to surrounding stands.
Main potential: GHG mitigation by preventing carbon losses from biomass.
Technical feasibility: Many options do not require new techniques. Tree species management and thinning are part of the normal forest management.
Implication for GHG mitigation / biodiversity: The implication for GHG mitigation is a reduced risk on carbon losses through storm damage. The average carbon stock per hectare on larger areas could be increased because of the reduced risk. The implication on biodiversity will be slightly negative, since less deadwood will become available. Furthermore, uprooting of trees creates micro-relief in the soil which is known to be favourable for biodiversity. Windthrow patches also increase the structure of the forest and, if not cleared, can provide shelter and nesting for species.
Revenues and costs (real as well as opportunity): A no-thin regime will have fewer revenues early in the rotation, and not thinning will also negatively influence wood quality in the end. However, longer rotations are possible, which could compensate the lost revenues through larger trees. Costs and revenues of other options (thinning regime, mixtures) are very difficult to access and depend on the situation.
Constraints (Social, institutional, environmental etc.): The no-thinning option for stands at high risks seems to be rather well established. However, literature is not clear about other proposed measures at the stand level (for example Lekes and Dandul 2000 and Mason 2002 versus Quine et al. 1995 concerning evenaged forests).

Wind risk is highly dependent on local conditions (wind climate, topography, surrounding stands), so it is not easy to give general guidelines on the most optimal management.
Potential magnitude of technical measure: In principle, the forest area where a storm could occur is large, but in many areas the return time (risk) is so low that measures will hardly be effective. On the other hand, in high risk areas (like parts of the UK and Ireland) forestry has adapted already to the wind regime, simply because it is economic. Such measures might be most effective in areas with intermediate risk, but especially in this intermediate risk zone it is not exactly clear how measures could contribute to stand stability.
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies:
Possible political measure to support this technical measure:

2.2.3.13 Decrease of impact and occurrence of pests and diseases

The occurrence of pest and disease outbreaks depends on many factors, such as weather, suitable conditions/material for breeding and dispersion and low enemy populations. For example, outbreaks of the bark beetle Ips typographus L. are often connected to the occurrence of storm damage. The large quantities of dead wood provide excellent breeding conditions for this species. Although it is a secondary pest insect (killing only weak trees) it can attack and kill healthy trees if the population density is high enough. Outbreaks are further favoured by warm and dry summers. After some five to ten years population densities decrease again because enemy populations will build up and the amount of breeding material will decrease. Many other secondary insect pests are known to become dangerous if trees are weakened by stress, for example due to severe droughts. The cause of such stresses is difficult to manipulate, but measures can be taken to reduce the negative effects. For example in the case of Ips typographus L., a timely removal of windblown wood can prevent large-scale outbreaks. In general, a healthy and diverse forest will have more possibilities to react to stress and insect occurrence than less healthy and diverse forests. Important for timely measures is a good information and monitoring system, but the development of such a system would fall outside the CAP and is therefore not considered here.

Decreased vulnerability
Description: For many pests and diseases it is known which conditions are favourable. For example, planting of certain conifers on former arable land is known to give high risks for Armillaria infections. Management could take measures to avoid such possible dangerous combinations. However, there are many different species that could be dangerous, all with specific requirements on stand structure and climate. Furthermore, there is always the possibility that new species will appear, either due to natural dispersion under changed climatic conditions or due to (human) introduction from other continents. In general, management can aim at a diverse and healthy forest, which would be more resistant to outbreaks and diseases.
Main potential: both GHG mitigation and biodiversity.

Technical feasibility: Health and diversity are influenced by many factors, of which some cannot be easily influenced by the manager, such as (artificially managed) groundwater levels. Measures within the manager's reach are common practice, such as tree species choice.
Implication for GHG mitigation / biodiversity: The implication for GHG mitigation would be less fluctuations in sink, because of less variations in growth rate due to insect infestations and fewer compulsory fellings. However, it is known that insect infestations can lead to increased availability of resources, which could cause the productivity to increase temporarily. A more diverse and healthy forest would be beneficial for biodiversity as well.
Revenues and costs (real as well as opportunity): Revenues of this measure are indirect as reduced costs for (chemical) treatment or sanitary fellings. Direct costs are costs aimed at increasing tree species and structure diversity, such as creating gaps or planting groups of other tree species.
Constraints (Social, institutional, environmental etc.): It is difficult to define what a healthy forest is. We can only refer to more or less natural conditions, but a healthy forest is also vulnerable to insect outbreaks.
Potential magnitude of technical measure: Basically all forest area in Europe, but especially those areas were the actual tree species deviate from the natural ones and where current insect and disease damage is high. However, there is no complete overview on a European scale with the occurrence of biotic damages.
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies:
Possible political measure to support this technical measure:

Improved treatment
Description: If an outbreak of a certain insect pest or disease is feared or happening, the area could be treated in certain ways: Removal of infested trees, spraying of chemicals, trapping of individuals, or increasing the population of natural enemies.
Main potential: GHG mitigation
Technical feasibility: Measures against pests are rather commonly applied.
Implication for GHG mitigation / biodiversity: Outbreaks will be less severe, with less effect on the growth rate (sink strength) of the forest. The effects on biodiversity depend on the type of application. Chemical treatments will in general not be beneficial for biodiversity, whereas biological treatment will have less averse effects. However, insects and diseases are part of the ecosystem, and suppressing those might contradict biodiversity aims.
Revenues and costs (real as well as opportunity): In many European countries, insects and pests are monitored and treated if dangerous levels are being reached. Increasing treatments might have a marginal effect; large costs for little revenues in terms of carbon.
Constraints (Social, institutional, environmental etc.): The use of chemicals is largely restricted in forestry, and it is not likely that they will be applied again at a large scale. Improved treatment will depend also on more intensive monitoring, which will be costly as well.

Potential magnitude of technical measure: It is unclear how much effect improved insect and disease treatment would have on current growth rates. Probably the effect is rather marginal.
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies:
Possible political measure to support this technical measure:

2.2.4 Aiming at forest products

One carbon pool associated with forestry is the wood products pool. Wood is used in many different ways and in applications with sometimes very long residence times. Several measures can influence the size of the wood products pool, such as improved efficiency of wood, increased use of wood compared to other materials, longer lifespans or improved recycling. However, all these measures fall outside the CAP and are not taken into account in this overview.

2.2.5 Aiming at bioenergy

2.2.5.1 Increased use of logging residues for bioenergy purposes

Description: Harvest residues include all biomass that is not removed from the site after commercial or non-commercial operations, mainly small trees, crown mass and stumps. Harvest residues offer a huge and so far largely unutilized potential. Even in Finland, which is the European leader in generation of power from biomass, less than 10% of the technical potential was used in recent years (Hakkila 2003). Extraction of residues can be quite effective if it is combined with the roundwood removal.
Main potential: GHG mitigation
Technical feasibility: Technologies exist: highly mobile chippers which work in the terrain (chipping at the source), or a combination of forwarder/skidder and chippers for chipping at the landing, or the biomass is transported (loose or in bundles) to the power plant and chipped on site.
Implication for GHG mitigation / biodiversity: Removing biomass will result in slower accumulation of soil organic matter due to the decreased litter input to the soil. However, felling residues make up only a minor part of the total litter input over a rotation period (8-20% in a spruce forest in southern Sweden, (Lundborg 1998)), and stump and roots would remain on the site in most cases. Overall effect is most likely positive if generated bioenergy is used to substitute fossil fuels. The effect on biodiversity is more unclear; harvest residue removals means less deadwood on the site, but in practice at least 30% of the aboveground residues are left for technical reasons, and conifer residues are not very valuable as a substrate for plants and animals (Lundborg 1998). Experience indicates that residue extraction has little negative impact on biodiversity (IEA Bioenergy 2002). Regeneration will be faster after residue extraction, and the cleared site might offer a habitat for a larger variety of plants in the short term. Residue extraction can also help to counteract negative

effects of high nitrogen deposition, such as eutrophication, acidification and the release of toxic aluminium, because the removal of nitrogen is three times higher in whole-tree harvesting than with conventional stemwood removal. The return of wood ash can help to prevent deficiencies of mineral nutrients (except nitrogen).
Revenues and costs (real as well as opportunity): The main barrier is the high price for production of forest chips from residues (Hakkila 2003). However, current high energy prices will make the revenues more attractive.
Constraints (Social, institutional, environmental etc.): Risk of nutrient depletion especially on nutrient poor sites. Concentration of nutrients is highest in foliage and bark, so nutrient depletion can be decreased by leaving the residues on site for one season in the case of conifers, and by harvesting in the winter months in the case of deciduous trees. However, the cost of residue chips increases in that situation, due to reduced biomass recovery and logistical disadvantages resulting from the delay in harvesting schedule (Hakkila 2003). On the other hand, high quantities of needles may cause combustion problems (i.e. corrosion in boiler due to high chlorine concentration). Nutrient depletion with whole tree harvesting would in most cases create the need for fertilization to avoid productivity declines.
Potential magnitude of technical measure: All European countries. See EEA study by Lindner et al. (in press).
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies:
Possible political measure to support this technical measure:

2.2.5.2 Pre-commercial thinnings aimed at harvesting biomass for bioenergy

Description: (Precommercial) thinnings are often neglected because of the high costs and the lack of demand for small-sized trees. Repeated light thinnings in young stands would have favourable effects on the yield compared to untended stands with late thinnings (Richardson et al. 2002).
Main potential: GHG mitigation
Technical feasibility: Technology exists, e.g. bundlers for whole-tree harvesting of young trees in thinning operations.
Implication for GHG mitigation / biodiversity: Reduction of CO_2 emissions if generated bioenergy is used to substitute fossil fuels. Increased utilization of existing forests decreases biomass carbon stock in the short term. Effects on biodiversity are probably small. There is some removal of nutrients as well as (possible) dead biomass while the forest structure is not affected.
Revenues and costs (real as well as opportunity): Pre-commercial thinnings are by definition not economic, due to the low revenues (small trees) and high costs (many trees to harvest). Revenues from current wood prices are not enough to cover the costs. Increasing energy prices may increase the revenues (even current level will make many pre-commercial thinnings cost efficient, if also CO_2 emission credits are utilized for substitution of fossil fuels). Early thinnings have a beneficial effect in the longer term, because the remaining trees will grow better.
Constraints (Social, institutional, environmental etc.): Risk of nutrient depletion with whole tree harvest from thinnings, due to high concentrations of nutrients in foliage

and twigs relative to total tree biomass. Nutrient depletion can be minimized by topping trees before bundling or chipping in the case of conifers, and by cutting deciduous trees during winter.
Potential magnitude of technical measure: The effect of this measure on the hectare scale will probably be rather small, but it can be applied to all Europe's managed forests.
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies:
Possible political measure to support this technical measure:
Subsidies for precommercial thinning operations

2.2.5.3 Complementary fellings

Description: In many European countries, wood harvests are considerably below growth rates. Felling levels could be increased up to a maximum sustainable level, and the balance could be used to generate bioenergy.
Main potential: GHG mitigation
Technical feasibility: No adaptations needed.
Implication for GHG mitigation / biodiversity: Reduction of CO_2 emissions if generated bioenergy is used to substitute fossil fuels. Increased utilization of existing forests probably decreases carbon stock in the short term, but could increase carbon sink capacity over the long term as overall yield will most likely increase due to the higher share of young, productive stands. For biodiversity this measure will probably be (slightly) negative, due to a more intensive felling regime. Furthermore, the share of old forests will be reduced because the harvest level will be higher.
Revenues and costs (real as well as opportunity): Depends on bio-energy price. With high energy prices and utilization of CO2 emission credits, the revenue will be similar to pulp and paper wood. If wood quality is high, forest owners may want to market the wood at higher prices (e.g. as sawlogs). This would create substantial opportunity costs. However, the current wood demand is not high enough to take up more saw logs.
Constraints (Social, institutional, environmental etc.): Risk of nutrient depletion with intensified biomass removal. Lack of awareness, expertise and necessary technology amongst forestry industry in many countries
Potential magnitude of technical measure: All forest area where harvest is lower than current annual increment, which is the case in almost all Europe.
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies:
Possible political measure to support this technical measure:

2.2.5.4 Changing management system to pure bioenergy production

Description: Conversion of unmanaged/less productive forests to management systems that aim only at bioenergy production, such as short-rotation coppice. Management for pure bioenergy production would allow for shorter rotation lengths

than in conventional forestry, i.e. soon after the period of highest productivity around canopy closure. It might also involve a tree species change to fast growing species.
Main potential: GHG mitigation
Technical feasibility:
Implication for GHG mitigation / biodiversity: If the initial standing stock of the forest is large, the conversion to a biomass production system can require several harvest cycles to balance the carbon lost during the removal of the initial carbon stock (Huston and Marland 2003). Conversion of close-to-natural existing forests to a biomass production system can have a net negative effect on biodiversity (Huston and Marland 2003), because in many cases, species rich and partly uneven-aged forests will be replaced by mono-specific even-aged stands. The effect on biodiversity will strongly depend on the species and management system applied. Many natural forests in Europe in the past have been managed for bioenergy and some of these systems e.g. coppice with standards can have high biodiversity values.
Revenues and costs (real as well as opportunity):
Constraints (Social, institutional, environmental etc.): A high rate of nutrients is removed in coppice systems due to the harvest of almost all above-ground biomass at frequent intervals, which might require compensatory fertilization in later rotations (Richardson et al. 2002). Such fertilisation requirements may compromise the overall GHG balance of such systems as industrial fertiliser manufacture is energy intensive. Utilisation of wood ash may be a suitable alternative.
Potential magnitude of technical measure: Unknown
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies:
Possible political measure to support this technical measure:

2.2.5.5 New short rotation plantations for bioenergy production

Description: Utilization of set-aside agricultural land for energy-crop plantations (e.g. with fast growing tree species as *Salix, Alnus, Populus, Eucalyptus*, etc.); these sites can also be used for waste water irrigation from municipal waste water treatment plants; certain species have the capabilities to bind heavy metals.
Main potential: GHG mitigation, biodiversity
Technical feasibility: Technology and harvesting schemes have been established over the last decade and are in use (e.g. Enköping, Sweden).
Implication for GHG mitigation / biodiversity: Energy crop plantations reduce CO_2 emissions if the generated energy is used to substitute fossil fuels. Soil carbon stocks probably increase compared to the former agricultural use. Woody energy crop plantations can offer shelter for wildlife in predominantly arable land, thus increasing biodiversity (Skärbäck and Becht 2005). Biofuel plantations of native species on formerly arable land have a higher animal biodiversity than the annual agricultural system they replace (Cook and Behea 2000). On the other hand, woody bioenergy plantations are intensively managed mono-species plantations, sometimes growing exotic species like Eucalyptus, which may not be very favourable for biodiversity. Furthermore, genetic engineering is often used to produce more productive clones;

and gene flow between the crop and wild relatives may pose a risk to the native vegetation (James et al. 1998).
Revenues and costs (real as well as opportunity): Depends on bio-energy price. Opportunity costs form agriculture are rarely relevant as the land was not used anymore for agriculture.
Constraints (Social, institutional, environmental etc.): At low energy prices, biomass plantations require productive sites to be economically viable, which may result in a competition with traditional agricultural use (Huston and Marland 2003).
Potential magnitude of technical measure: Most bioenergy plantations will be established on agricultural set-aside lands. The potential magnitude of this measure will therefore depend on the availability of such lands, as well as on the development of energy prices and subsidies for biomass crops.
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies:
Possible political measure to support this technical measure:

2.2.6 Other

2.2.6.1 Decrease fossil fuel energy use of forest machinery

Description: Forest machinery (chainsaws, harvesters, forwarders etcetera) could be designed to use less (fossil) fuel. Old, less efficient equipment could be replaced by new, more efficient equipment.
Main potential: GHG mitigation
Technical feasibility: New technology development needed, except for replacement of old equipment.
Implication for GHG mitigation / biodiversity: Fewer emissions due to more efficient fuel use, a more positive GHG balance for the produced wood or biomass.
Revenues and costs (real as well as opportunity):
Constraints (Social, institutional, environmental etc.): For cars, about 85% of the emissions are connected to the production, and only 15% are related to the use. Probably for machinery the same kind of figures are applicable. So early replacement of machinery could actually lead to higher total emissions.
Potential magnitude of technical measure:
Monitoring and control parameter (direct and indirect):
Support and constraints in existing policies:
Possible political measure to support this technical measure: Subsidies for replacement of energy inefficient machinery; subsidies on efficient machinery.

2.3 Ranking of measures

All above mentioned measures can be judged according to various aspects, such as cost effectiveness, GHG potential, etcetera. We evaluated the measures according to the following criteria:

- GHG mitigation potential per ha
- potential area of application
- technical feasibility
- environmental added value
- cost effectiveness
- social acceptance
- state of technology knowledge
- robustness under changing climate
- biodiversity effects
- effect on other forest functions
- leakage risk (i.e. undesired carbon effects outside the area)
- short term effectiveness
- medium term effectiveness
- long term effectiveness

Each of the measures was given a score for each of the aspects mentioned above. Scores ranged from 0-5, where 0 would mean a "killing assumption" and 5 the best score. A "killing assumption" would mean a very negative impact on a certain aspect, overruling any other benefits. For all measures an average score over all aspects was calculated, which allows a ranking of the measures. For the aspect leakage, a 5 would mean no risk of leakage, while a 1 would mean a high leakage risk. Table 2.2 contains the scoring of the different measures for all aspects.

Table 2.2. Scores for all aspects for all measures.

	GHG mitigation potential per ha	potential area of application	technical feasibility	environmental added value	cost effectiveness	social acceptance	state of technology knowledge	robustness under changing climate	biodiversity effects	effect on other forest functions	leakage risk	short term effectiveness	medium term effectiveness	long term effectiveness	**Average**	**Rank**
Article 3.3																
Afforestation/ Reforestation	5	4	5	4	3	3	4	4	3	5	5	1	3	5	**3.86**	**3**
Avoiding deforestation	5	2	5	5	2	4	5	5	4	5	3	5	5	5	**4.29**	**1**
Article 3.4																
Application of fertilizer	3	4	5	2	2	2	4	3	1	2	1	2	3	3	**2.64**	**24**
Improving genetic quality	3	5	4	2	2	3	4	3	2	3	5	1	2	3	**3.00**	**22**
Drainage	4	3	4	1	2	3	5	3	1	3	5	2	3	3	**3.00**	**22**
Irrigation	4	2	4	1	1	1	4	4	1	2	3	2	3	3	**2.50**	**26**
Changing rotation lengths	4	5	5	4	3	4	5	4	5	5	3	2	4	3	**4.00**	**2**
Changes in timing and intensity of thinnings	3	5	5	3	3	4	4	4	3	4	3	3	3	2	**3.50**	**13**
Continuous cover forestry/ selective logging	3	4	4	4	4	4	3	4	4	4	4	3	4	2	**3.64**	**8**
Changes in tree species	3	4	4	3	3	4	4	3	3	3	5	2	4	3	**3.43**	**15**
Protection of forests with high biomass carbon stocks	5	3	4	4	3	5	4	3	5	4	3	4	3	2	**3.71**	**5**
Minimising site preparation	3	4	4	4	3	4	4	5	4	3	5	3	3	3	**3.71**	**5**
Decreasing fuel loads by prescribed burning	4	1	3	2	2	3	3	4	3	3	5	3	3	4	**3.07**	**21**
Decreasing fuel loads by management activities	4	2	4	3	3	4	4	4	3	4	5	3	3	4	**3.57**	**10**
Decreasing fire risk by adapting forest structure through management	4	2	4	3	3	4	3	4	3	3	5	3	3	4	**3.43**	**15**
Decreasing flammability by changing tree species	5	2	4	4	3	4	4	4	3	4	5	1	2	4	**3.50**	**13**
Increased fire prevention (creation and maintenance of fire breaks)	5	2	4	3	3	5	4	5	3	4	5	2	4	4	**3.79**	**4**
Increased stability to wind	2	3	3	4	2	4	3	4	4	3	5	2	3	3	**3.21**	**19**

	GHG mitigation potential per ha	potential area of application	technical feasibility	environmental added value	cost effectiveness	social acceptance	state of technology knowledge	robustness under changing climate	biodiversity effects	effect on other forest functions	leakage risk	short term effectiveness	medium term effectiveness	long term effectiveness	**Average**	**Rank**
Decreased vulnerability to wind	2	3	4	3	3	4	4	4	2	3	5	2	3	3	**3.21**	**19**
Decreased vulnerability for insects	2	3	3	4	2	5	3	4	4	4	5	2	3	3	**3.36**	**18**
Improved treatment of insects	2	2	4	1	1	2	4	3	2	3	5	2	3	3	**2.64**	**24**
Aiming at bioenergy																
Increased use of logging residues	2	5	4	2	3	3	4	5	2	3	5	3	5	5	**3.64**	**8**
Pre-commercial thinnings aimed at harvesting biomass for bioenergy	2	5	4	2	2	3	4	5	2	3	5	3	5	5	**3.57**	**10**
Complementary fellings	3	5	4	2	3	3	4	5	2	3	5	3	5	5	**3.71**	**5**
Changing management system to pure bioenergy production	4	2	4	1	3	3	4	5	2	2	5	3	5	5	**3.43**	**15**
New short rotation plantations for bioenergy production	5	2	4	1	3	3	4	4	2	3	5	4	5	5	**3.57**	**10**
Other																
Decrease fossil energy use of forest machinery	1	4	4	5	3	5	3	5	3	3	0	4	5	5		

All measures that have a rank from1 to 10 are selected as a potential measure to be included in the CAP. Because several measures have the same rank, a total of 12 measures are selected in this way. The selected measures and their rankings are shown in Table 2.3.

Table 2.3. Selected measures for the CAP

Measure	Average score	Rank
Avoiding deforestation	4.29	1
Changing rotation lengths	4.00	2
Afforestation/Reforestation	3.86	3
Increased fire prevention (creation and maintenance of fire breaks)	3.79	4
Protection of forests with high biomass carbon stocks	3.71	5
Minimising site preparation	3.71	5
Complementary fellings	3.71	5
Continuous cover forestry/ selective logging	3.64	8
Increased use of logging residues	3.64	8
Decreasing fuel loads by management activities	3.57	10
Pre-commercial thinnings aimed at harvesting biomass for bioenergy	3.57	10
New short rotation plantations for bioenergy production	3.57	10

Some measures are self-standing and straightforward, such as afforestation. Other measures are linked, or could be combined with others. For example the creation of fire breaks should partly be supported by management activities as mentioned under other measures, such as the use of prescribed fire. In the further detailing process of the selected measures, we might therefore include some measures that were initially not selected. In the further process within MEACAP, the selected measures will be more closely examined and quantified wherever possible.

The carbon cycle in forests is often characterised as 'slow in, fast out'. Avoiding the 'fast out' would generally offer the best options for carbon management, since it will take a long time to recover the lost carbon ('slow in'). This is reflected in many of the selected measures, such as avoiding deforestation, not harvesting stands with high carbon contents, increased fire prevention and minimising site preparation. Some measures are a kind of derivative to this and aim at creating higher average carbon stocks per hectare. A good example is afforestation: in grasslands, harvest takes place every year, resulting in no stock build-up. After afforestation, harvest will be postponed for many decades, allowing the stock to build up. Changing rotation lengths and conversion to continuous cover forestry are other examples, but their effectiveness will be lower, because the initial (or baseline) stock is much higher. Manipulating the 'slow in' process is also possible, but the manoeuvring space is generally limited, since there is a maximum to the production per hectare. This is reflected in the fact that the pure input-based measures have not been selected, such as fertilisation, improving genetic quality, drainage and irrigation. The last group of measures do not aim at maximising carbon storage in the forest, but aim at replacing fossil fuel by bioenergy. This is generally seen as a very effective option, since the effect of avoided emission will last forever, but stocks in the forest will eventually be released to the atmosphere again.

In general, the measures that are finally selected match well with measures that have been proposed earlier (Houghton 1996; Thornley and Cannell 2000). However, no study addressed, quantified and compared all possible options. Most studies concentrated on only one (Kaipainen et al. 2004; Liski et al. 2001; Tilman et al. 2000) or a few options (Chen et al. 2000), and others just listed some measures that might be of relevance (Houghton 1996).

3 Quantification of carbon gains of selected technical and management-based mitigation measures in forestry

3.1 Introduction

As part of the MEACAP project, a survey was made of possible measures in the forest management sector to combat the increase of greenhouse gasses in the atmosphere (Schelhaas et al., 2006, Deliverable 13). These measures were evaluated qualitatively for a range of indicators. In this document, we attempt to further quantify the carbon effects of those measures that were ranked highest. During the analysis, we decided to additionally include the measure "changes in timing and intensity of thinnings", since it showed significant potential compared to earlier estimates. A number of logical combinations of measures were also included. The final list of measures assessed is as follows:

1. Avoiding deforestation
2. Afforestation/reforestation
3. Changing rotation lengths
4. Changing thinning intensity
5. Changing rotation lengths and thinning intensity simultaneously
6. Continuous cover forestry
7. Protection of forests with high carbon stocks
8. Minimising site preparation
9. Increased fire prevention
10. Decreasing fuel loads to reduce forest fire risk
11. Complementary fellings for bioenergy
12. Pre-commercial thinnings for bioenergy
13. Use of logging residues
14. Application of complementary felling and use of logging residues

Additionally, the establishment of new short-rotation coppices was selected in D13. However, here we regard short rotation coppices as agricultural land use, to be treated within the agricultural framework.

Wherever possible, quantification is based on the EFISCEN model (European Forest Information Scenario model; Sallnäs 1990, Pussinen et al. 2001). EFISCEN is a scenario model, especially suited for simulating managed, even aged forests at large scales. It projects the future state of forest resources under scenarios of harvest demand, growth changes, for example due to environmental conditions, and changes in management, taking into account tree species composition and age class structure. The initial state of the forest is usually derived from national forest inventories. Such initial datasets are available for almost all European countries (Schelhaas et al., 2006b). EFISCEN has been applied in many European wide studies (Nabuurs et al., 2003; Pussinen et al.; 2005, Nabuurs et al.; 2006, Schelhaas et al., 2006a). For further details on the model we refer to the manual (Pussinen et al., 2001; Schelhaas et al. in prep/2007). For the simulations, the same country parameterisation and set up was used as Lindner et al. (EEA, 2007). For the projection of future wood demand, the baseline scenario of the same study was used, which is based on downscaling of IMAGE (Image Team, 2001) results for the SRES B2 scenario (IPCC, 2000). This projection is further referred to as the baseline scenario.

3.2 Quantification of selected measures

3.2.1 Avoiding deforestation

Deforestation leads to an immediate loss of carbon from living biomass, and to a rapid decrease of soil carbon caused by decreased litter input and increased decomposition due to soil disturbance and increased temperature as a result of less shade. Despite the importance of deforestation in terms of carbon and the obligation to report it under the Kyoto Protocol, few countries are currently able to estimate gross deforestation. Most European countries report a net increase in forest area (UN-ECE/FAO, 2000), but this is often the result of a small amount of deforestation and a larger amount of afforestation. Despite restrictions on deforestation, the Netherlands, for example, reported an annual gross deforestation of about 2500 hectares (0.7% of the forest area) to the UNFCCC (Nabuurs et al., 2005). Several studies have projected future land use in Europe (CLUE/EURURALIS (Klijn et al., 2005), ATEAM (Kankaanpää and Carter, 2004; Rounsevell et al., 2005)) under different scenarios. The CLUE modelling (Verburg et al., 2006) system is able to differentiate between deforestation and afforestation. Figure 3.1 shows projected deforestation and afforestation area for the EU-25 for the four SRES storylines (Schulp et al., unpublished). See Box 1 for an explanation of the SRES storylines. The consequences of these changes for the carbon balance of these areas are depicted in Figure 3.2 (Schulp et al., unpublished). Despite the fact that deforestation in the B1 and B2 scenarios is more than compensated for by afforestation in terms of area, the affected area only shows a net positive effect at the end of the B2 scenario, where deforestation is minimal. This must be attributed to the fact that deforestation is a quick source of carbon emissions, whereas afforestation is a slow sink. According to these projections, deforestation could be a total carbon emission source of 55 (B2 scenario) to 258 Tg C in the period 2000-2030 (A2 scenario). For the period 2000-2020, the annual source ranges from 1.4 (A1) to 12.3 (A2) Tg C/year. How much of these emissions could be avoided under the respective scenarios by policy measures is unclear. Furthermore, it is not clear how far the underlying land use allocation mechanism is restricted by current legislation, and thus how realistic the projected area changes are.

Box 1. Main Characteristics of the Four SRES Storylines

- The A1 storyline and scenario family describes a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income.
- The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.
- The B1 storyline and scenario family describes a convergent world with the same low population growth as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.
- The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

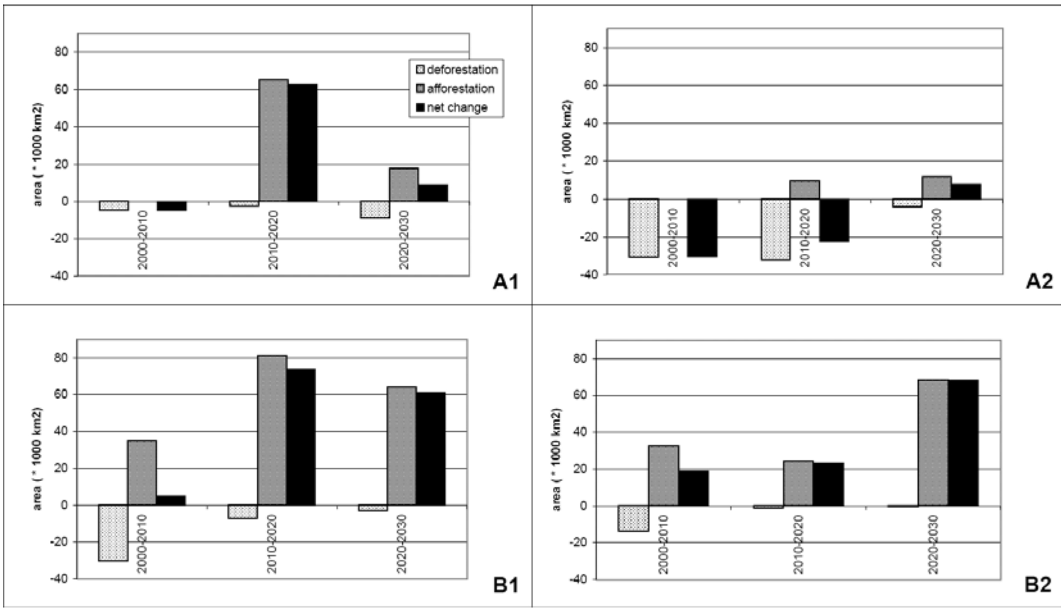

Figure 3.1: Balance of afforestation and deforestation areas for the EU-25 as projected with CLUE for the four IPCC SRES scenarios (Schulp et al., unpublished).

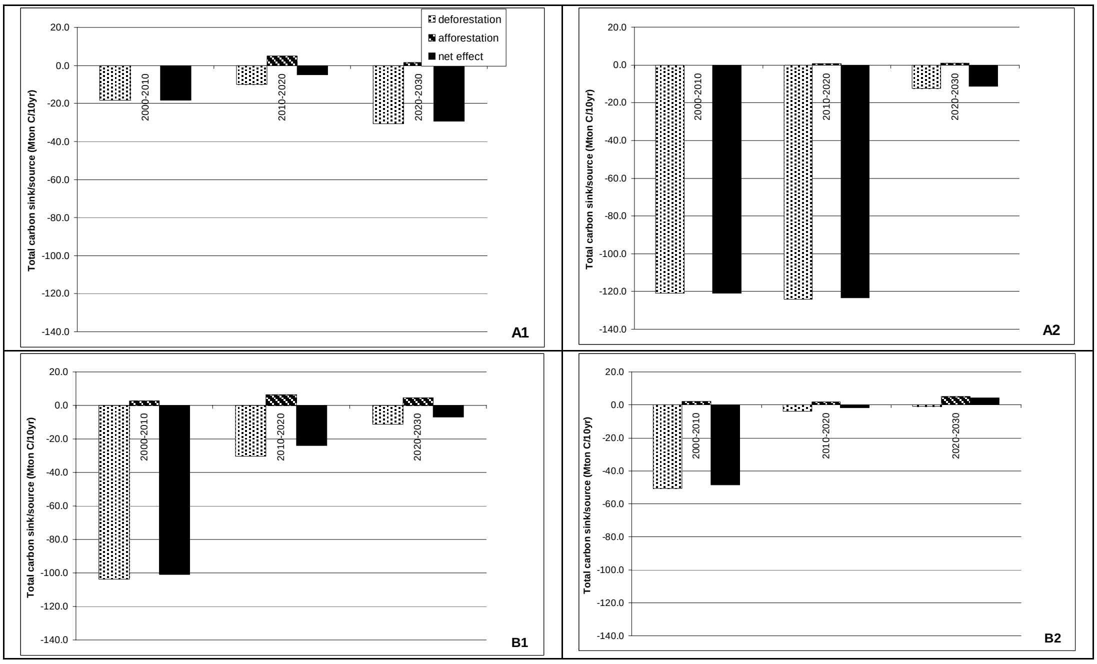

Figure 3.2: Projected carbon dynamics resulting from the changes in forest area of Figure 3.1 (Schulp et al., unpublished data).

3.2.2 Afforestation/reforestation

Afforestation is a slow process, with carbon accumulation rates in biomass of 0.5-3 Mg C ha-1 yr-1 (Hansen and Vesterdal, 2004), depending on the site and productivity of the tree species. An additional sink in the soil of 0.3 to 0.4 Mg C ha-1 yr-1 may be possible if initial soil stocks are low (Post and Kwon, 2000). The potential of afforestation depends largely on the availability of abandoned agricultural land. Although the production potential may not be very high, the available area could be considerable and the increase in carbon stocks would, for a large part, be permanent. The potential of new afforestation is recognised mostly in Eastern Europe, where both available land and low labour costs make afforestation feasible and attractive. On the contrary, a further major increase in forest land is unlikely in Western and Central Europe. Future availability of (marginal) agricultural lands is influenced by many factors, such as demand for agricultural products, CAP subsidies, openness of agricultural markets and possible competition with bioenergy crops. At present in the EU-25 a net afforestation of some 0.4 million hectares per year is occurring (UN-ECE/FAO, 2000). The CLUE projections for the EU-25 range from a gross afforestation of 2.1 million hectares under the A2 scenario to 18 million hectares under the B1 scenario until 2030 (Figure 3.1). This would result in a sink of 1.7 and 13.5 Tg C respectively, over the period 2000-2030 (Figure 3.2). For the period 2000-2020, the annual sink ranges from 0.04 (A2) to 0.46 (B1) Tg C/year.

3.2.3 Changing rotation lengths

Large parts of the European forest are still managed with the aim of increasing productivity via clear-cutting and by establishing even-aged, often mono species stands. The time between regeneration and final harvest is called the rotation length. Increasing the rotation length would generally lead to a higher amount of biomass at the site, and thus to a larger carbon stock. However, tree growth at higher ages is generally smaller, so the actual carbon sink potential would decrease. Moreover, a considerable immediate increase of rotation length would, in many countries, lead to a shortage of wood since there would not be enough mature stands available for harvesting. EFISCEN was used to investigate the maximum attainable increase in rotation length per country (with a maximum of 25 years), under the condition that the projected total wood demand could still be fulfilled. For all countries, the share of thinning in the total felling amount was increased from 33% to 43% to reflect the longer timeframe where thinning can be carried out.

The results are presented in Table 3.1. Under the baseline assumptions, the annual carbon sink estimated for the period 2005-2015 would reach 95 Tg C/year for the 21 European countries analysed. A particularly large build up of carbon storage is prescribed to Germany, France and Austria, followed by Spain and Nordic countries. Estimated for the same reference period, the increased rotation length applicable for 14 countries would result in an additional 23.6 Tg C fixed in forest biomass and soil annually (Table 3.1). This means a sink of almost 119 Tg C/year, an increase of about 25 % with respect to the baseline scenario. The countries with the most pronounced effects of prolonged rotation length on carbon storage were found to be France, Sweden and Finland.

It should be noted that the maximum accountable sink under the first commitment period of the Kyoto Protocol prescribed for those EU-25 countries analysed is 10.8 Tg C/year and only 9.45 Tg C/year for those countries that elected the Forest Management activities for accounting (Table 3.2). These numbers therefore represent only a fraction of the carbon sink that is attained under the baseline scenario shown in Table 3.1, and show that the single measure of increasing rotation length would effectively double the accountable amount under the Kyoto Protocol Art. 3.4. However, in practice, the indicated prolongation of rotation length might not be feasible due to the increased impact of natural disturbances, such as windthrow or insect damage, that would occur. It is also likely that there would be a loss of wood quality due to rotting and this is not taken into account.

Table 3.1: Carbon sink under baseline assumption for individual countries in Europe and the effect of increased rotation length and increased thinning estimated for the period of 2005 to 2015.

COUNTRY	BASELINE	INCREASED ROTATION		INCREASED THINNING	
	Net sink (Tg C/year)	Extra period (years)	Net effect rel. to baseline (Tg C/year)	Max. share rel to total wood harvest (-)	Net effect rel. to baseline (Tg C/year)
Austria	**11.43**	25	0.12	0.70	-0.07
Belgium	**0.59**	np		np	
Czech Republic	**0.59**	10	0.84	np	
Denmark	**0.77**	np		np	
Estonia	**-2.04**	np		np	
Finland	**6.91**	20	3.69	np	
France	**20.17**	25	7.50	0.65	11.53
Germany	**25.02**	10	2.25	0.50	2.95
Hungary	**1.86**	np		0.70	-0.43
Ireland	**0.71**	np		np	
Italy	**3.75**	20	0.59	0.50	0.08
Latvia	**-0.24**	np		np	
Lithuania	**0.74**	5	0.34	0.43	0.20
Luxembourg	**0.02**	15	0.15	1.00	0.23
Netherlands	**0.56**	np		0.85	-0.04
Poland	**-0.13**	10	1.04	0.43	1.04
Portugal	**n/a**	n/a		n/a	
Slovakia	**1.72**	15	0.34	np	
Slovenia	**1.46**	25	0.15	0.55	0.27
Spain	**9.68**	25	0.97	0.75	2.20
Sweden	**8.32**	15	4.86	np	
United Kingdom	**3.15**	10	0.78	np	
Total	**95.05**		+23.61		+17.96

Table 3.2: The maximum accountable carbon sink (cap) for Forest Management activities under the Kyoto Protocol Art. 3.4 in the 1st Commitment Period.

COUNTRY	ART. 3.4 FOREST MANAGEMENT CAP	COUNTRY	ART. 3.4 FOREST MANAGEMENT CAP
Austria	*0.63*	Latvia	0.34
Belgium	*0.03*	Lithuania	0.28
Czech Republic	0.32	Luxembourg	*0.01*
Denmark	0.05	Netherlands	*0.01*
Estonia	*0.10*	Poland	0.82
Finland	0.16	Portugal	0.22
France	0.88	Slovakia	*0.50*
Germany	1.24	Slovenia	0.36
Greece	0.09	Spain	0.67
Hungary	0.29	Sweden	0.58
Ireland	*0.05*	United Kingdom	0.37
Italy	2.78		

Note: Countries with the value in italics did not elect Forest management for accounting (or remained undecided as of February 2007).

3.2.4 Changing thinning intensity

During the lifetime of a forest stand, several thinnings are usually carried out. A thinning is a reduction in the amount of trees per hectare. The major goals of thinning are: i) to increase the quality of the growing stock by removing the low quality trees; ii) to concentrate the increment on fewer, carefully selected trees; and iii) to get early revenues. Thinning reduces the amount of biomass in the stand, but could also stimulate the growth increment, and thus carbon sink potential, of the remaining trees. Moreover, it provides extra litter input to the soil. Schelhaas et al. (2002) found only small effects of a changed thinning regime on the carbon sink for one rotation at the hectare scale. However, at the country scale, increased thinnings may cause fewer final harvests, which would effectively increase the rotation length of other forests. For each country in Europe, the maximum possible shift of final fellings to thinnings was studied. Under the baseline scenario, 33% of the wood demand was fulfilled by thinning. Table 3.1 shows the maximum possible thinning share of the total harvested wood volume per country, while still meeting the wood demand. Increasing the thinning share was only possible in about half of the countries.

The results of increasing the maximum thinning share whilst meeting wood demand on carbon stored in the forests (including biomass and soil) of European countries are shown in Table 3.1. It can be observed that the effect varied largely among the countries. In three countries (Austria, Hungary and the Netherlands) the effect of increased thinning was found to be negative as carbon sink strength decreased. However, the increasing thinning share had a positive effect on the carbon sink in most of the countries. The most pronounced effect was observed for France, which could additionally store 11.5 Tg C/year by adopting this measure. This figure significantly contributed to the overall estimated effect of the increased thinning share in Europe, which reached almost 18 Tg C/year during the period of 2005 to 2015 (Table 3.1). This means a total sink of 113 Tg C/year which is an increase of 19% with respect to the baseline scenario.

3.2.5 Changing rotation length and thinning share simultaneously

An increase in thinning share leads to a lower demand for final felling, which in turn can lead to a higher prescribed rotation age. We investigated all likely combinations of increased thinning share and increased rotation length such that the wood demand could still be fulfilled. Table 3.3 gives the results applicable for individual countries for those combinations of increased felling and thinning share that yielded the highest carbon sink in forest ecosystems. The optimal combination of the two management measures would, over the period from 2005 to 2015, increase the total carbon sink in the studied European countries to almost 155 Tg C/year. This is an increase of 59.5 Tg C/year, or 63 % with respect to the baseline scenario.

Table 3.3: Carbon sink (Tg C/year) estimated under baseline scenario for individual countries in Europe and the effect of increased rotation and thinning measures the period of 2005 to 2015.

COUNTRY	BASELINE	INCREASED ROTATION AND THINNING		
	Net sink (Tg C/year)	Extra period (years)	Thinning share (-)	Net effect (Tg C/year)
Austria	**11.43**	25	0.43	0.12
Belgium	**0.59**	np	np	
Czech Republic	**0.59**	10	0.43	0.84
Denmark	**0.77**	np	np	
Estonia	**-2.04**	np	np	
Finland	**6.91**	20	0.43	3.69
France	**20.17**	25	0.95	24.40
Germany	**25.02**	25	0.70	7.97
Hungary	**1.86**	20	0.90	0.08
Ireland	**0.71**	np	np	
Italy	**3.75**	20	0.95	1.03
Latvia	**-0.24**	np	np	
Lithuania	**0.74**	10	0.55	0.75
Luxembourg	**0.02**	0	1.00	0.23
Netherlands	**0.56**	15	0.95	-0.01
Poland	**-0.13**	25	0.70	3.27
Portugal	**n/a**			
Slovakia	**1.72**	25	0.80	0.20
Slovenia	**1.46**	25	0.80	0.99
Spain	**9.68**	15	0.95	3.90
Sweden	**8.32**	25	0.55	9.52
United Kingdom	**3.15**	25	0.75	2.54
Total	**95.05**			+59.51

Note: The net effect is expressed in Tg C/year relative to the baseline estimation.
The combinations of increased rotation and thinning are those that yield the highest carbon sink in forests in each individual country.

The optimised length of rotation and thinning share with respect to the expected carbon gain may represent a benchmark for classical forest management system of different age classes to aim for. It may also represent a reference for alternative forest management of continuous cover forestry (selective logging system).

3.2.6 Continuous cover forestry

Continuous cover forestry represents an alternative type of forestry that is being increasingly suggested as a necessary approach to strengthen forest ecosystems in Europe, stabilize nutrient balance and return to close-to-nature forestry management. This is becoming a more important issue with the rising concerns about sustainability of forest management, the ability of forests to cope with dynamic changes in environmental conditions and the increased frequency of extreme climatic events, observed during the recent decades, and expected as a consequence of rising greenhouse gas levels in the atmosphere. Forestry is therefore confronted with a challenge to rapidly adapt to such conditions. It must focus on creating structurally rich and more stable forest ecosystems that would, at least partly, replace the even-age single-species stands established, mainly with the purpose of efficient wood production, during the past centuries.

With respect to carbon balance, continuous cover forestry has the advantage of avoiding clearcut areas, which usually represent a source of CO2 due to increased loss from respiration. This loss is usually only counterbalanced by growing forest after it reaches a full crown cover which is prevented by clearcutting. Apart from less fluctuation in carbon stocks and fluxes at the site, a selective logging system would be likely to result in a higher average carbon stock at the site.

At present, continuous cover forestry is in operation on only a fraction of forest land in Europe and there is no expectation that this share will dramatically increase in the near future. The replacement of classical management systems may occur only gradually and will require many decades, and even several centuries.

To rigorously assess the effect of continuous cover forestry requires an application of advanced modelling tools that can handle structurally rich forests. This is a demanding analysis that is beyond the scope of this study. Additionally, any considered scenarios would most likely not bring any significant effect on carbon stocks in the short term. For these reasons, this issue is not further elaborated in this report.

3.2.7 Protection of forests with high carbon stocks

Protection of forests with high carbon stocks would avoid a large carbon source from harvesting. However, in the longer run these high stocks would decrease due to natural reasons such as age-related mortality and natural disturbances. Moreover, other stands will be harvested instead. Currently the European forest is relatively young, and the increment rate is higher than the harvest. This has led to increasing growing stocks over the last decades. This trend is thought likely to continue for at least several more decades (Nabuurs et al., 2003, Schelhaas et al., 2006a). The currently existing difference in many countries between increment and drain could perhaps be used to protect high biomass stands and to shift the harvest to younger age classes. In order to assess this with EFISCEN, we split the initial situation for each country in two parts: one part with high biomass stands that were simulated without harvesting, while the remaining stands were subjected to the normal demand scenario. For four countries along a north-south gradient, we assessed the opportunities and effects (Table 3.4). In three of the four countries a negative effect was found. The effect in Austria amounted to 0.62 Tg C/year, which is about 5% compared to the baseline sink. We therefore conclude that this measure is unlikely to be effective.

Table 3.4. Share of forest area with high biomass stocks set aside and net sink effect over the period 2005-2015 as compared to the baseline.

COUNTRY	SET ASIDE	NET EFFECT
	(% of total forest area)	(Tg C/year)
Sweden	2.6	-0.77
Germany	3.9	-0.84
Austria	6.2	+0.62
Italy	4.5	-0.02

3.2.8 Minimising site preparation

Jandl et al. (2007) recently reviewed forest management effects on soil carbon sequestration. They wrote the following with regards to site preparation:

"Site preparation promotes rapid establishment, early growth and good survival of seedlings. Techniques include manual, mechanical, chemical methods and prescribed burning, most of which include the exposure of the mineral soil by removal or mixing of the organic layer. The soil disturbance changes the microclimate and stimulates the decomposition of SOM [soil organic matter], thereby releasing nutrients (Palmgren, 1984; Johansson, 1994). Another effect is improved water infiltration into the soil and better root development. The recent trend towards nature oriented forest management reduces the importance of site preparation. A review on the effects of site preparation showed a net loss of soil C and an increase in productivity (Johnson, 1992). The effects varied with site and treatment. Several studies that compared different site preparation methods found that the loss of soil C increased with the intensity of the soil disturbance (Johansson, 1994; Örlander et al., 1996; Schmidt et al., 1996; Mallik & Hu, 1997). At scarified sites, organic matter in logging residues and humus, mixed with or buried beneath the mineral soil, is exposed to different conditions for decomposition and mineralization compared to conditions existing on the soil surface of clear-cut areas. The soil moisture status of a site has great importance for the response to soil scarification. The increase in decomposition was more pronounced at poor, coarsely textured dry sites than on richer, moist to wet sites (Johansson, 1994). Sandy soils are particularly sensitive to management practices, which result in significant losses of C and N (Carlyle, 1993). Intensive site preparation methods might result in increased nutrient losses and decreased long-term productivity (Lundmark, 1988). In most of the reviewed studies biomass production was favoured by site preparation and this effect may balance or even outweigh the loss of soil C in the total ecosystem response. In conclusion, there is in general a net loss of soil C with site preparation, which increases with the degree of disturbance. The chosen technique of site preparation is important and will determine if the net C effect of the activity is positive or negative."

Site preparation has already been adapted as a consequence of stronger environmental concerns about forest management, and the increase of nature-oriented forest management systems have reduced the need for site preparation. Because of the different impacts of alternative techniques and the site-specific impacts, it is very difficult to assess the extent to which current practices can still be improved on a larger scale and this exercise was not carried out in the scope of this study.

3.2.9 Increasing fire prevention

Increasing fire prevention is one of the important measures to decrease emissions. Although forest fires occur dominantly in Southern Europe, significant forest areas are also annually burnt in temperate and boreal regions. Forest fires represent a source of CO2, CH4 and N2O, to name the most important gases accounted within the national emission inventories of the Land Use, Land Use Change and Forestry sector under UNFCCC. Unfortunately, many countries have not yet been able to include emissions due to fires in their emission inventories and the relevant dataset available at UNFCCC is largely incomplete.

To understand the likely magnitude of emissions by fires, we may use the results of Van der Werf et al (2006), who utilised satellite observations and modelling to assess fires and amount of carbon burnt on a global scale with a resolution 1° x 1° grid cell. Based on their estimates, we applied a Tier 1 methodology of IPCC (2003) to also estimate the associated CH4 and N2O emissions and expressed the results in units of CO2 equivalent. The resulting emissions due to fires reached 54.5 ±21.5 (SD) Tg CO2 eq. per year (i.e., about 14.9 Tg C/year), with a strong annual variation (Figure 3.3). This figure includes all countries in Europe, except the European part of Russia and Ukraine. With the available modelling tools, such as EFISCEN it is not possible to quantify the effect of fire prevention. However, it is obvious from the above figures that this measure would likely yield less effect on carbon balance as compared to the other measures available in forestry.

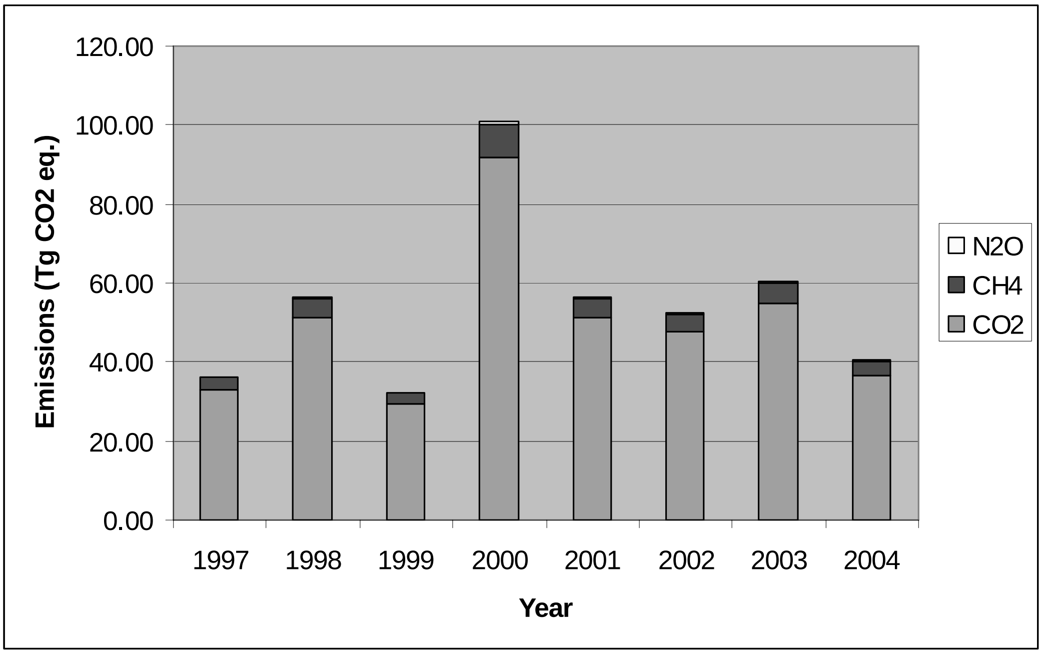

Figure 3.3: Annual emissions of greenhouse-gases due to burning including CO2, CH4 and N2O, for Europe based on the estimation of Van der Werf et al (2006).

3.2.10 Decreasing fuel loads to reduce forest fire risk

See previous paragraph.

3.2.11 Complementary fellings for bioenergy

Currently, the harvest level in Europe is generally lower than the wood increment, which is reflected in increased growing stock. Theoretically, this difference could be harvested and used as a source for bioenergy. Whether this additional amount could really be harvested depends on the age class structure of the forest, but also on technical potential and economic variables. We examined this with the EFISCEN model assuming that the harvest level could maximally be increased by 10% per time step of the model (five years) after 2005. Once the growing stock would start to decline, we assumed a stable harvest level from that time point onwards. The results of these simulations are presented in Table 3.5. The net effect on the carbon sink is given, together with the amount of likely avoided emissions provided the complementary felling volume would be used as a source of bioenergy (see Box 2 for calculations on avoided emissions).

Table 3.5: Carbon sink estimated under baseline assumption for individual countries in Europe and the net effect of complementary fellings, both estimated for the period of 2005 to 2015.

COUNTRY	BASELINE	COMPLEMENTARY FELLINGS	
	Net sink (Tg C/year)	Net effect on sink (Tg C/year)	Avoided emissions when used as bioenergy source (Tg C/year)
Austria	**11.43**	-0.42	0.22
Belgium	**0.59**	0.07	-0.02
Czech Republic	**0.59**	-0.18	0.06
Denmark	**0.77**	0.00	0.00
Estonia	**-2.04**	2.24	-0.50
Finland	**6.91**	-2.37	0.85
France	**20.17**	-3.56	0.99
Germany	**25.02**	-1.52	0.64
Hungary	**1.86**	-0.13	0.05
Ireland	**0.71**	-0.04	0.01
Italy	**3.75**	-0.06	0.02
Latvia	**-0.24**	0.74	-0.19
Lithuania	**0.74**	-0.46	0.14
Luxembourg	**0.02**	0.12	0.01
Netherlands	**0.56**	-0.03	0.01
Poland	**-0.13**	0.78	-0.34
Portugal	**n/a**		
Slovakia	**1.72**	-0.15	0.07
Slovenia	**1.46**	-0.39	0.16
Spain	**9.68**	-0.86	0.27
Sweden	**8.32**	-3.33	1.15
United Kingdom	**3.15**	-0.58	0.22
Total	**95.05**	-10.15	+3.83

Due to the increased harvest as compared to the baseline, the total sink in the forests would decrease overall (Table 3.5). The estimated decrease was over -10 Tg C/year, or almost 11 % relative to the baseline scenario. However, some of that amount could be compensated if the complementary harvest would be used to generate bioenergy. That compensation could reach 3.8 Tg C/year for the 23 countries of the EU-25. Hence, the overall effect of complementary fellings could be assumed as a decrease of total carbon sink by about 6.6 % to about 88.7 Tg C/year. It should also be noted that the estimated resulting carbon sink would still be safely larger than the accountable amount of carbon under Art. 3.4. of the Kyoto Protocol during the 1st Commitment Period.

Box 2. Avoided emissions if wood is used as bioenergy

According to Weiske et al. (2006, D10), 1 ton willow chips (water content 30%) yields 9.48 GJ when combusted for heat in a small scale system. Assuming a carbon content of 50% of dry matter, this equals 0.35 ton biomass carbon. So 1 ton of biomass carbon will yield 27.1 GJ heat, or 7.5 MWh.

According to Jungmeier (2006), emissions from burning wood pellets are 43 g CO_2-eq/kWh heat (taking into account CO_2, CH_4 and N_2O). Emissions from heating oil are 399 and from natural gas 301 g CO_2-eq/kWh heat. So using wood as a heating source avoids the emission of 258-356 g CO_2-eq/kWh heat, depending on the reference system. So burning 1 ton of biomass carbon avoids the emission of 1.94-2.68 t CO_2-eq, equal to 0.53-0.73 t C-equivalents. This figure can vary considerably, depending on water content of the chips, the scale of the operating system, the reference system and if heat or electricity has to be produced. Here we assume that each ton of biomass carbon avoids the emission of 0.63 t C-equivalents.

3.2.12 Pre-commercial thinnings for bioenergy

Thinnings at a young age are usually not economic, due to the low revenues (small trees) and high costs (many trees to harvest) involved. Therefore, such precommercial thinnings are nowadays often neglected. One of the reasons for low revenues is a lack of demand for small-sized trees. A new application for this material is to use it to generate bioenergy. Increasing energy prices may increase the revenues, however even the current price level could make many pre-commercial thinnings cost efficient, if CO2 emission credits are also utilised for substitution of fossil fuels. Repeated light thinnings in young stands would have favourable effects on the yield compared to untended stands with late thinnings (Richardson et al., 2002). With the available modelling system it is not possible to quantify the effects on the carbon balance of the stand and effects on avoided CO2 emissions. In general, the amount of biomass removed on a hectare base is rather small, so this measure is unlikely to yield considerable effects, especially in the short term.

3.2.13 Use of logging residues

Another option available to forestry is removing part of the logging residues and using it for bioenergy purposes. Removing logging residues from forest would decrease the carbon input to soil and lead to a lower sink. However, a part of that biomass would have been decomposed and lost by respiration without enhancing the soil carbon stocks. Together with the compensatory effect of using this resource for bioenergy purposes, the use of logging residues is a management option that was quantified by EFISCEN for the individual countries of the EU-25 (Table 3.6). The estimates of Lindner et al. (EEA, 2007) were used for the maximal proportion of residues that could be removed per country, which takes into account ecological and economic constraints.

Table 3.6: Carbon sink estimated under baseline assumption for individual countries in Europe and the net effect of removing logging residues, both estimated for the period of 2005 to 2015.

COUNTRY	BASELINE	USE OF LOGGING RESIDUES	
	Net sink (Tg C/year)	Net effect on sink (Tg C/year)	Avoided emissions if used as bioenergy source (Tg C/year)
Austria	**11.43**	-0.12	0.37
Belgium	**0.59**	-0.03	0.12
Czech Republic	**0.59**	-0.24	0.70
Denmark	**0.77**	0.00	0.00
Estonia	**-2.04**	-0.06	0.20
Finland	**6.91**	-0.52	1.49
France	**20.17**	-0.81	2.92
Germany	**25.02**	-0.83	2.31
Hungary	**1.86**	-0.07	0.18
Ireland	**0.71**	0.00	0.03
Italy	**3.75**	-0.01	0.11
Latvia	**-0.24**	-0.14	0.56
Lithuania	**0.74**	-0.10	0.30
Luxembourg	**0.02**	0.14	0.01
Netherlands	**0.56**	-0.02	0.05
Poland	**-0.13**	-0.26	0.77
Portugal	**n/a**		
Slovakia	**1.72**	-0.03	0.09
Slovenia	**1.46**	-0.05	0.19
Spain	**9.68**	-0.10	0.35
Sweden	**8.32**	-0.74	2.48
United Kingdom	**3.15**	-0.06	0.23
Total	**95.05**	-4.04	+13.46

For the 23 countries of the EU-25 analysed here, removing logging residues would reduce the total carbon sink in the period 2005-2015 to 91 Tg C/year, a decrease by four Tg C/year (about 4 %) relative to the baseline scenario (Table 3.6). The part likely compensated due to utilisation of the removed residues as bioenergy and avoided emissions would amount to about 13.5 Tg C/year. Hence, the overall estimated effect of using logging residues would represent an increase of total carbon sink by 9.4 Tg C/year or about 10 % relative to the baseline scenario. Additionally, in this case, the expected carbon sink is still much higher than the amount accountable under Art. 3.4. of the Kyoto Protocol during the 1st Commitment Period. It should be noted, however, that removing logging residues may raise environmental concerns in many of the countries in Europe. Logging residues are considered vital to partly compensate nutrient loss during the forest rotation cycle. The current environmental policies in European forestry promote leaving a larger share of biomass in forests in order to further stabilize nutrient balance and increase the biodiversity value of these ecosystems.

3.2.14 Application of complementary felling and use of logging residues

A combination of the complementary fellings and utilisation of logging residues measures represents a measure with maximal utilisation of available biomass in forests. We analysed this effect using EFISCEN by adopting the identical conditions as described above for each of these two measures. The results of applying this two management measures in individual countries are shown in Table 3.7.

Table 3.7: Carbon sink estimated under the baseline scenario for individual countries in Europe and the net effect of joint effect of application of complementary fellings and removing logging residues, estimated for the period of 2005 to 2015.

COUNTRY	BASELINE	COMPL. FELLING AND RESIDUES	
	Net sink (Tg C/year)	Net effect on sink (Tg C/year)	Avoided emissions if used as bioenergy source (Tg C/year)
Austria	**11.43**	-0.57	0.62
Belgium	**0.59**	0.05	0.09
Czech Republic	**0.59**	-0.38	0.77
Denmark	**0.77**	0.00	0.00
Estonia	**-2.04**	2.20	-0.35
Finland	**6.91**	-3.03	2.49
France	**20.17**	-4.72	4.35
Germany	**25.02**	-2.56	3.15
Hungary	**1.86**	-0.21	0.25
Ireland	**0.71**	-0.05	0.05
Italy	**3.75**	-0.08	0.14
Latvia	**-0.24**	0.62	0.31
Lithuania	**0.74**	-0.58	0.48
Luxembourg	**0.02**	0.11	0.02
Netherlands	**0.56**	-0.05	0.06
Poland	**-0.13**	0.58	0.36
Portugal	**n/a**		
Slovakia	**1.72**	-0.20	0.17
Slovenia	**1.46**	-0.47	0.39
Spain	**9.68**	-1.00	0.67
Sweden	**8.32**	-4.23	3.88
United Kingdom	**3.15**	-0.67	0.48
Totally	**95.05**	-15.23	18.39

The application of complementary fellings in combination with removing logging residues would mean a decrease in carbon sink by over 15 Tg C/year, or 16 % relative to the baseline scenario. However, this amount would be more than offset by utilisation of the biomass removed by complementary fellings and logging residues as bioenergy. That resource was estimated to avoid emissions of about 18.4 Tg C/year for the 21 European countries quantified here (Table 3.7). Hence, the net effect of the combined measure of complementary fellings and utilisation of logging residues would be positive in relation to the baseline scenario. It would de-facto increase the total carbon sink by over 3 %. It should be noted, however, that removing logging residues may raise environmental concerns in many of the countries in Europe. Logging residues are considered vital to partly compensate nutrient loss during the forest rotation cycle. The current environmental policies in European forestry promote leaving a larger share of biomass in forests in order to further stabilize nutrient balance and increase the biodiversity value of these ecosystems.

3.3 Conclusion

In Table 3.8 the effects of the different measures are summarised. The carbon emissions source from forest fires is shown to be close to twice the average emission source from expected levels of deforestation. It is worthwhile to trying to reduce both of these emission sources, however the extent to which they can be reduced is currently unknown. Compared to the size of other measures, afforestation is expected to have only a small impact. However, this impact will last for a long time, and might increase in future as newly established forests enter more productive stages. Protection of forests with high carbon stocks will not have as much effect on the carbon sink and might, in some cases, even have negative effects. Changing rotation lengths and/or thinning intensity can considerably enhance the sink, up to 61% above the baseline. Removal of logging residues will reduce the sink somewhat, but is more than compensated for by avoided emissions. On the contrary, complementary fellings reduce the sink more than what is gained through avoided emissions. However, the remaining sink is still considerably higher than the maximum allowed sink under Article 3.4. Moreover, the effect of avoided emissions is permanent, while carbon sequestration in forests is temporary. It was not possible to estimate the effect of the continuous cover forestry, minimising site preparation and pre-commercial thinnings for bioenergy measures.

Table 3.8. Comparison of the effect of different measures, compared to a baseline sink of 95 Tg C/year in existing forests.

	NET EFECT ON SINK	AVOIDED EMISSIONS	NET TOTAL EFFECT
	(Tg C/year)	(Tg C/year)	(Tg C/year)
Changing rotation lengths and thinning intensity simultaneously			59.5
Changing rotation lengths			23.6
Changing thinning intensity			18.0
Source due to fires			14.9
Source due to deforestation			10.9
Use of logging residues	-4.04	13.46	9.42
Application of complementary felling and use of logging residues	-15.23	18.39	3.16
Afforestation/reforestation			0.04 - 0.46
Complementary fellings for bioenergy	-10.15	3.83	-6.32
Protection of forests with high carbon stocks			~0
Continuous cover forestry			n/a
Pre-commercial thinnings for bioenergy			n/a
Minimising site preparation			n/a

4 Biodiversity evaluation of selected forestry measures

4.1 Introduction

In this chapter we evaluate the possible impact on forest biodiversity of the forest measures that were selected in Deliverable 13 (D13) to combat the increase of greenhouse gasses in the atmosphere. We do this in a qualitative way by evaluating the expected effect of each measure on a range of biodiversity indicators.

4.2 Indicator selection

Within the agricultural biodiversity work, the following statement is made:
"Within any agricultural landscape, biodiversity is generally greater within areas that (a) contain a wide range of niches (e.g., different habitats, different vegetation structures),
(b) are subject to medium levels of disturbance (e.g. through climatic or management factors),
(c) occur at a large enough scale to allow enough individuals to survive and maintain viable populations and
(d) provide a sufficient amount of similar habitats (though with varied environmental conditions) within close proximity to each other to allow the individuals of each species sufficient choice of potentially suitable habitats at any one time." (McCracken et al. 2005, MEACAP WP5 ND1). Roughly the same is valid for a forestry landscape. To represent these categories we selected the following indicators:

a) Range of niches:
   i. Presence of different canopy layers
   ii. Homogeneity
   iii. Variation in tree species
   iv. Presence of gaps
b) Level of disturbance
   i. Frequency of human interventions
   ii. Intensity of human interventions
   iii. Frequency of natural disturbances
   iv. Severity of natural disturbances
c) Scale
   i. Size of management unit
d) Sufficient amount of similar habitats in close proximity
   i. Landscape fragmentation

Additionally, there are many indicators specifically for forests (see for example Larsson (2001) and European Environment Agency (2004)). From the existing sets we selected the following additional indicators:

- Fraction of area with indigenous tree species
- Fraction of area protected

- Amount and size distribution of deadwood
- Number of large trees per hectare
- Coverage of regeneration by natural means
- Share of old stands
- Total forest area

The final list of indicators can be found in Table 4.1.

4.3 Measure evaluation

The effect of the selected measures on forest biodiversity is compared to the current management, situation or trend. Most indicators can be only described in a qualitative way, like increasing or decreasing as compared to the current ("baseline") management. We used a subjective scoring between -2 and +2, where -2 means a strong negative effect, -1 a weak negative effect, 0 indifferent, +1 weak positive effect and +2 a strong positive effect. Table 4.1 shows the scores of the selected measures on the biodiversity indicators.

Table 4.1. Biodiversity indicator scores of selected measures

	Presence of different layers	presence of gaps	homogeneity	tree species variation	fraction indigenous tree species	deadwood	number of large trees per ha	presence of old stands	way of regeneration	intervention frequency	intervention intensity	natural disturbance frequency	natural disturbance severity	size of management unit	fragmentation	protected area	total forest area	**Total**
Avoiding deforestation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	**2**
Afforestation/ Reforestation	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2	0	2	**6**
Changing rotation lengths	1	0	1	0	0	1	1	2	0	1	0	0	0	0	0	0	0	**7**
Protection of forests with high carbon stocks	1	-1	2	0	0	1	2	2	0	1	1	0	-1	0	0	2	0	**10**
Minimising site preparation	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	**3**
Continuous cover forestry	2	1	0	1	1	1	2	1	1	0	1	0	0	1	0	0	0	**12**
Increased fire prevention	0	1	1	1	1	0	1	1	0	0	-1	1	1	0	-1	0	0	**6**
Decreasing fuel loads	-1	0	0	0	0	-1	1	1	0	-1	-1	1	1	0	0	0	0	**0**
Complementary fellings	0	0	-1	0	0	-1	0	-1	0	-1	-1	0	0	0	0	0	0	**-5**
Pre-commercial thinnings	0	0	0	-1	0	0	0	0	0	-1	0	0	0	0	0	0	0	**-2**
Use of logging residues	0	0	0	0	0	-2	0	0	0	0	-1	0	0	0	0	0	0	**-3**
New SRC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**

The main effects of avoiding deforestation is the prevention of forest area decrease and prevention of further fragmentation. It might also influence the number of old stands and large trees, since deforestation could take place in stands of all ages. In specific cases there might be side-effects on the frequency and intensity of natural disturbances. Harvesting or deforestation of stands might lead to wind damage in adjacent stands. On the other hand, deforestation might act as a fire break and thus reduce the forest fire risk.

Afforestation clearly has an effect on the forest area. If planned carefully, it could contribute to a fragmentation reduction. It also provides an opportunity to increase the variation in tree species and the forest area covered with indigenous species. A negative effect could occur in fire-prone areas, since the forest area might become more contiguous. However, appropriate planning and species choice might assist to keep the fire risk low.

Increasing rotation lengths will lead to more old stands, with possibly more large trees per hectare and more dead wood. Older stands generally have more possibilities to develop multiple layers. Longer rotation lengths will also lead to more heterogeneity, since the variation in stands ages will be greater. The effect of longer rotations on frequency and intensity of natural disturbances differs per disturbance type. Usually the vulnerability to wind throw increases with stand age. The same is valid in some cases of insect damage. However, older forests could be less susceptible to fires, depending on the structure of the stand.

The protection of forests with high carbon stocks is likely to be beneficial for biodiversity. In general, such stands will be relatively old, multi-layered and will contain many large stems and much dead wood. The survival of such stands in an otherwise managed forest area will lead to more heterogeneity. Human interventions in such stands will be less intense, since the management is aimed to keep the high stocks. A disadvantage might be that stands with high biomass stocks are less likely to contain gaps. Further, such stands might be more vulnerable to disturbances such as wind, and fire if the stands are multi-layered.

Minimising site preparation might have some positive effects on biodiversity. Most important is the decrease in intensity of human intervention. Generally, intensive soil preparation will homogenise the start situation of the new stand. Less preparation might therefore lead to a more heterogeneous forest, at least for a certain period. Some site preparation techniques involve the fragmentation or removal of the remaining dead wood.

Continuous cover forestry generally aims at multi-layered, richly structured forests, with trees of different species and sizes. In many cases biodiversity is an explicit aim. This is implemented through attention to deadwood, use of indigenous tree species and the use of natural processes, such as natural regeneration. Within the stands there will be more heterogeneity, but the variation between the stands might decrease. Generally, this kind of management works with larger management units.

Creation and maintenance of fire breaks might have an effect on many indicators. This depends on their type and the share they have in the landscape. Fire breaks may be large open spaces, or parts of the forests managed in a way to minimize fire risk and spread. The latter may be done by using species that do not burn easily. Often those are indigenous broadleaved species. Their use will also influence the tree species variation in the landscape. Management in such areas will be rather intense to keep the desired fire susceptibility characteristics. The use of open spaces might be beneficial to biodiversity by creating more gaps and adding heterogeneity. However, it might also lead to increased fragmentation. If this measure is successful, it will lead to less fire area and perhaps less intense fires. In turn, this will on the long run increase the area of old stands and the average number of large trees per hectare. The effect on dead wood is difficult to asses: Fewer fires will lead to less dead wood, but older forests might again provide more dead wood. However, dead wood will probably be removed from the fire breaks, so the effect will partly depend on their share in the landscape.

Management aimed to decrease fuel loads has several effects on the selected biodiversity indicators. Generally, such a management strategy will include the removal of shrub layers and dead wood. Furthermore, such a management requires heavier and more frequent interventions. If the strategy is effective, there will be a positive effect on the frequency and intensity of fires. As a consequence, stands will be able to get older and more large trees will be present.

Complementary fellings to obtain biomass for bioenergy might be done as additional final fellings and/or additional thinnings, with possibly different implications on biodiversity. In general, more harvest means a higher human intervention intensity and probably also frequency, probably leading to a more homogeneous forest with less dead wood. Additional thinnings might remove understory layers, but might also favour the development of a shrub layer because the canopy will be more open. Additional final fellings will mean a reduction of the share of old stands.

A related measure is the (re-)implementation of pre-commercial thinnings. Traditionally these thinnings are used to influence the tree species composition and future wood quality. This influence can be used with different goals: undesired (less productive) species can be removed, so the homogeneity will increase. However, this thinning can also be used to favour certain (indigenous) species that otherwise would be out competed. In any case, it means a higher human intervention frequency and intensity.

Increased use of logging residues will have a direct negative impact on the amount of available dead wood. Also the intervention intensity will increase, since more biomass is extracted from the forest. Increased extraction might lead to changes in the nutrient balance, with possibly effects on tree species choice or other indirect effects on biodiversity. Extraction of logging residues might help to reduce forest fire impact.

We see new short rotation coppices as an agricultural landuse, and assume no forest is converted to such coppices. Therefore they do not have an influence on forest biodiversity.

5 Discussion

The indicators in this study are very general and give only a hint how forest biodiversity might be influenced. Specific taxonomic groups or species might react in totally different ways. Some species are adapted to intensively managed systems (such as coppices) and will decline if management will become more extensive, even if this would increase the overall indicators score. Many indicators are derived from relationships studied in the field. For example, many insect species are known to be dependent on pieces of large dead wood. However, increasing the amount of dead wood in a forest will not automatically lead to an increase of such insect species. Existence of source populations and migration ability play a major role as well.

The approach taken in this study mostly evaluates the biodiversity of the forest area, and ignores aspects related to previous landuse and incorporates only marginally the surrounding landscape. Afforestation of centuries old, species rich cultural landscapes will be evaluated as positive, since the forest area will increase, and possibly also the situation regarding forest fragmentation. However, a major loss in agricultural biodiversity would occur. Therefore, it is necessary to cross-check forest biodiversity with agricultural biodiversity. On the level of individual measures, the forest approach will be sufficient, but when applied to specific cases, the linkage with agriculture should be made.

Not all indicators will be of equal importance in all cases and as judged by different stakeholders. A true comparison between the measures should include careful weighting of different indicators, for example by using a multi criteria analysis. However, this falls outside the scope of the study. We therefore only calculated the total score of each measure (last column in Table 4.1). This score must therefore be interpreted as an indication about the direction and total effect of the measure, and not as an absolute ranking.

Taking into account the notes above, we can still try to generalise the outcomes of Table 4.1. The measures can roughly be divided in those affecting landuse (afforestation and avoiding reforestation), changes in current management (rotation lengths, protection, continuous cover forestry and site preparation), fire management (increased prevention and reducing fire loads) and measures aimed at bio energy (complementary fellings, pre-commercial thinnings and residue extraction).

Landuse options show no negative effects. They only influence the area and possibly the fragmentation of the landscape. Adaptation of the current management mostly shows high scores and little negative impacts. Especially continuous cover forestry and protection of sites show high scores. Management aimed at reducing forest fire risk has a somewhat ambiguous effect. An important way of reducing fire risk is to increase fragmentation, which can be negative for biodiversity. Another important point in risk reducing strategies is reducing fuel loads, which could lead to a reduction of dead wood and shrub layers. On the other hand, a reduction of the sometimes high fire frequency and intensity could be beneficial for biodiversity as well. Careful planning, taking into account the local situation and more research will help to resolve possible conflicts. The measures aimed at bio energy invariably show negative outcomes. This can be mostly attributed to increased human intervention frequency and intensity and a possible loss of dead wood available in the forest. This outcome shows a possible conflict between biodiversity and bio energy use of the forest. It does not mean that forest resources should not be used for bio energy purposes, but it calls for a careful assessment where both functions could be combined or where one should prevail over the other.

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