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

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Executive summary

Forest ecosystems in Europe represent a manageable resource that can partly be used to offset emissions of CO_2. In this report, we provide a quantitative analysis of feasible management measures in European forestry to enhance carbon sink capacity in the short-term (2005 to 2015). For the analysis, we utilise an accounting-type matrix model EFISCEN, which is driven by harvest demand and permits incorporation of major management constraints and actual ecological and production characteristics typical for individual countries of the EU-25. Wherever possible, the effect of individual measures is compared to the baseline scenario, i.e. without any changes in management. Under the baseline model scenario, European forests (EU-25 except Cyprus, Malta, Greece and Portugal) would store approximately 95 Tg C/year. The most important measures in terms of sink enhancement are increased rotation length and increased thinning. The application of these measures would increase the annual sink by 25% and 19% respectively, as compared to the baseline scenario. A joint application would result in a 63% increase of the annual sink. Other management options available to forestry such as complementary felling up to the level of increment and utilization of harvest residues would result in decreasing sink capacity as compared to the basline scenario. However, if the complementary felling and harvest residues were used for bioenergy in order to avoid other emissions, the overall net effect on the carbon sink would improve. It would reach -6.6% in the case of complementary felling and approximately +10 % for utilization of harvest residues. Applied jointly, the net effect of the two measures would be positive, giving +3.3% above the level under the baseline scenario. Another source of biomass could be the (re-)introduction of pre-commercial thinnings, however we were unable to estimate the effects of this measure. Protection of stands with large amounts of biomass were found to be less effective, in some cases yielding even lower sinks than the baseline scenario. Although the above mentioned measures could increase the sink in the forest, and in some cases this increase could be considereable, it is important to note that the there is a limit on the contribution that forest management measures can make to the Kyoto Protocol targets. The total allowed sink for the EU countries that include forest management measures in their Kyoto Protocol targets amounts to 9.45 Tg C/year, which is about 10% of the sink under the baseline scenario.

Based on landuse projections, we estimated an expected Carbon source due to deforestation in the order of 1.4 to 12.3 Tg C/year for the period 2000-2020. Afforestation in the same period would yield a sink of 0.04 to 0.46 Tg C/year. Avoiding deforestation is extremely important whenever possible. Afforestation yields a rather low sink, but one which is likely to be sustained for a long time. Another important source of greenhouse gasses is due to forest fires. We roughly estimate this source at 14.9 Tg C/year, however it is currently impossible to estimate by how much these emissions could be reduced. We were unable to quantify the effects of a gradual conversion of clear-cut management systems to continuous cover forestry, nor those of minimising site preparation.

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 a*l., 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.

2 Quantification of selected measures

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 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 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.

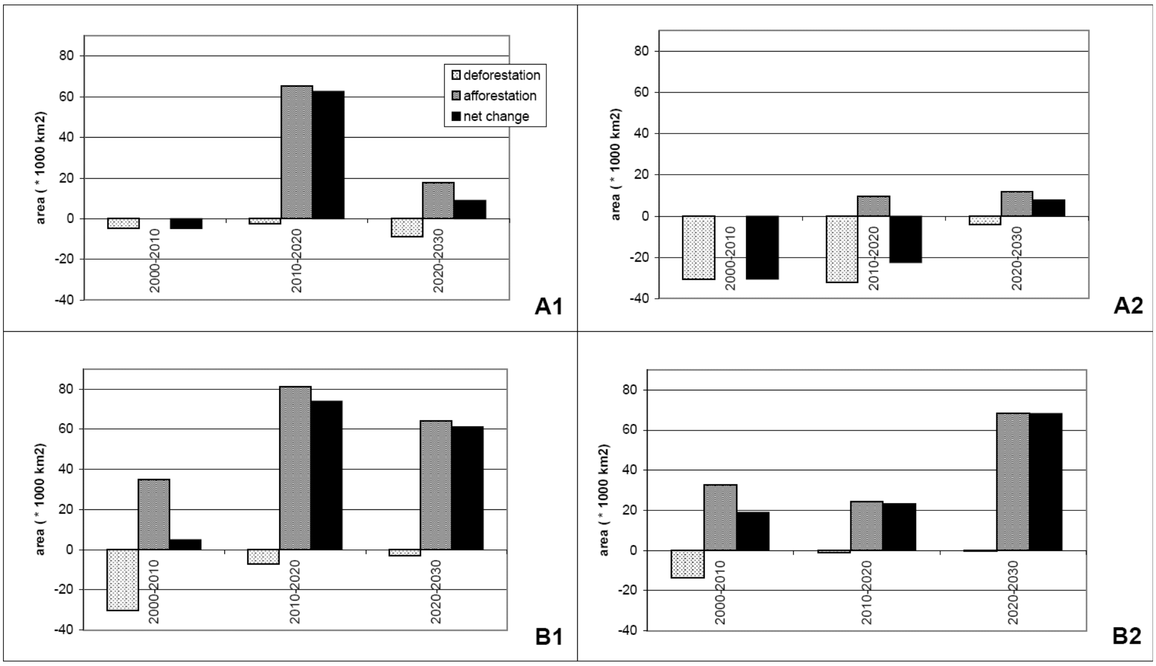

Figure 1: Balance of afforestation and deforestation areas for the EU-25 as projected with CLUE for the four IPCC SRES scenarios (Schulp *et al.*, unpublished).

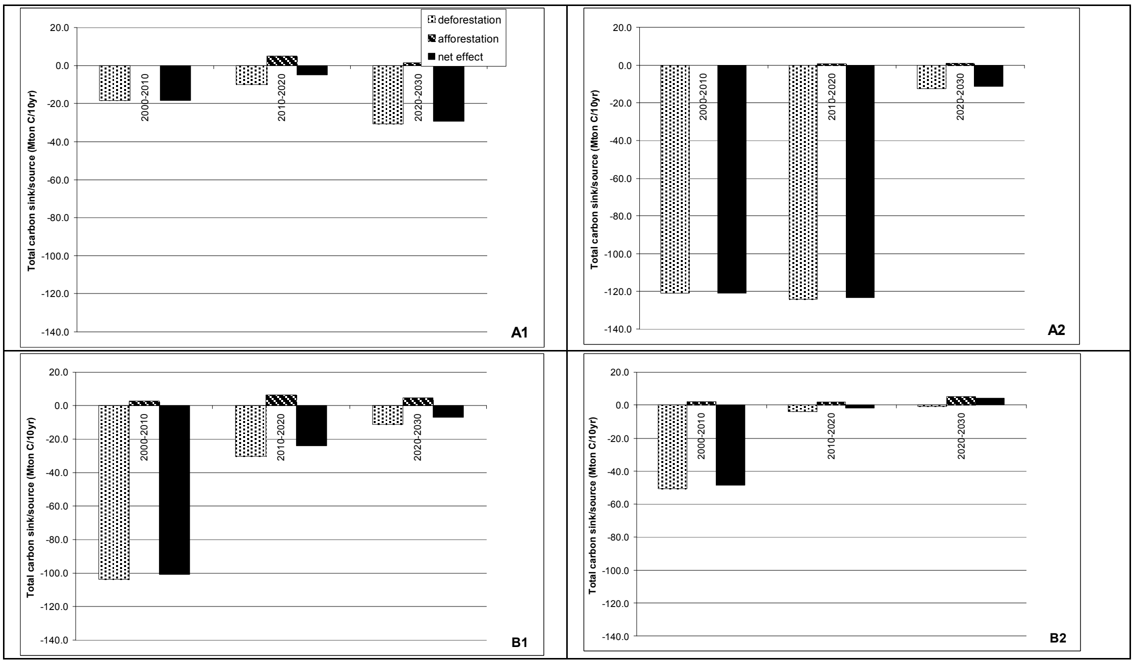

Figure 2: Projected carbon dynamics resulting from the changes in forest area of Figure 1 (Schulp *et al.,* unpublished data).

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 1). This would result in a sink of 1.7 and 13.5 Tg C respectively, over the period 2000-2030 (Figure 2). For the period 2000-2020, the annual sink ranges from 0.04 (A2) to 0.46 (B1) Tg C/year.

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 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 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.

Table 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

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 2). These numbers therefore represent only a fraction of the carbon sink that is attained under the baseline scenario shown in

Table 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 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).

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 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 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 1). This means a total sink of 113 Tg C/year which is an increase of 19% with respect to the baseline scenario.

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 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: 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 combintations 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).

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 CO_2 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.

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 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 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

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.

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 CO_2, CH_4 and N_2O, 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 CH_4 and N_2O emissions and expressed the results in units of CO_2 equivalent. The resulting emissions due to fires reached 54.5 ±21.5 (SD) Tg CO_2 eq. per year (i.e., about 14.9 Tg C/year), with a strong annual variation (Figure 1). 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.

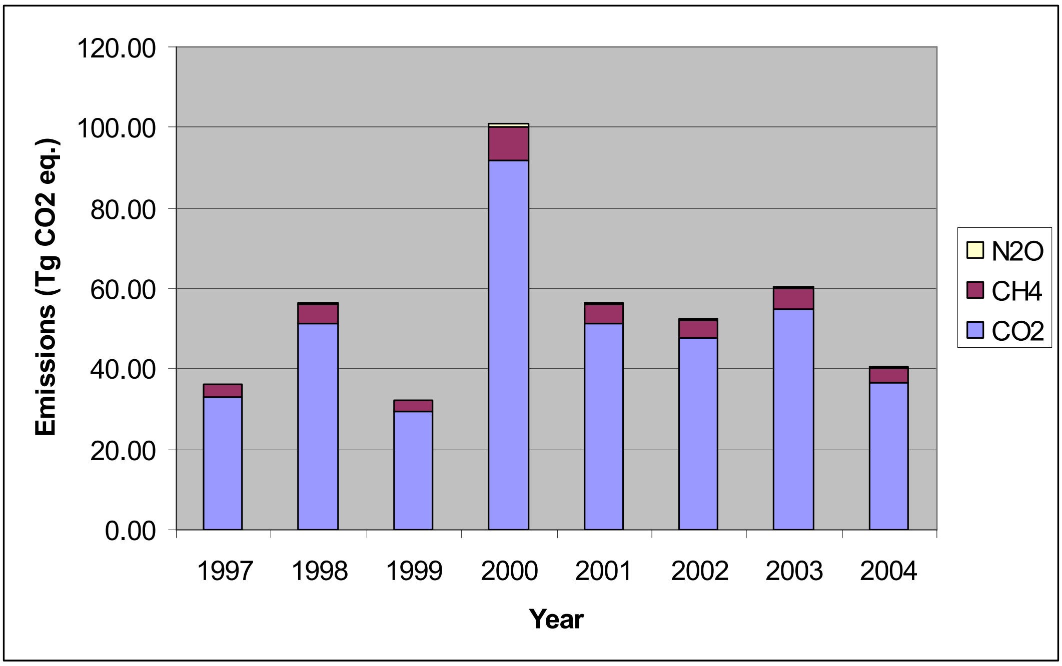

Figure 1: Annual emissions of greenhouse-gases due to burning including CO_2, CH_4 and N_2O, for Europe based on the estimation of Van der Werf et al (2006).

2.10 Decreasing fuel loads to reduce forest fire risk

See previous paragraph.

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 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 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 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.

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 CO_2 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 CO_2 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.

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 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 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 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.

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 7.

Table 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 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 Conclusion

In Table 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 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

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