Opportunities for forest management

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Introduction

Terrestrial ecosystems have accumulated about three times of the carbon stored in the atmosphere. One half of the terrestrial carbon stocks is in forest ecosystems. Forests play therefore a key role in the global carbon balance. Land use changes in the past centuries reduced the global forest cover from one half to one third of the earth's land surface. The current deforestation rate is accounted to 0.02% per year, contributing about one quarter of the global human-induced carbon emissions to atmosphere (FAO, 2005).

More than one half of the growing stock is managed for commercial objectives (FAO, 2007). To maintain a high annual increment the life-time of trees is reduced under management in comparison to natural forests. Hence, forest management can basically influence the sequestration of carbon from atmosphere (Kohlmaier et al., 1998; Kaipainen et al., 2004).

The objective of the Kyoto Protocol is to reduce carbon emissions by improving technical processes and by modified land use practices, which avoid deforestation and enhance carbon stocks in biosphere (United Nations, 1998). The mission of the Carbon-Pro project was to create a link between the global aspects of the Kyoto Protocol and local land use management. Special focus was given to forest management strategies and their potential to increase carbon stocks according to the Kyoto rules. In this paper, case studies for carbon balances based on experimental data and simulation results are presented for different regions of the project area. Conclusions for decision makers are derived.

Forest management and carbon ecology

Maximum values of carbon stocks in terrestrial ecosystems are observed in natural forest. Its development follows principally three development phases (Bormann, Likens, 1979; Burschel, Huss, 1987):

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- *Increment of biomass & carbon sequestration (phase 1)*
  When forest develops on new lands or after previous disturbance, natural succession induces an increase of growing stock over decades, while sequestering high amounts of atmospheric carbon in forest biomass and soil. At the end of phase 1 the maximum of carbon stocks in forest can be observed.
- *Reduction of biomass by natural mortality & carbon release (phase 2)*
  When trees achieve their maximum life time and die because of physiological deficiencies and increased sensitivity against biotic and non biotic factors, ecosystem respiration increases and a net carbon release to the atmosphere is induced.
- *Equilibrium & carbon neutrality (phase 3)*
  Finally a balance between death of old trees and regeneration is achieved. Carbon sequestration and carbon releases are in equilibrium. Therefore, old growth forests are considered to be neutral in the global carbon budget.

Consequently, natural forests offer an important opportunity to sequester carbon in younger development phases and to store high amounts of atmospheric carbon in terrestrial ecosystems. The most important effects in regard to carbon sequestration are achieved during phase 1: Carbon dioxide is sequestered in biomass and carbon accumulation achieves maximum values.
Sustainable forest management generally concentrates silvicultural actions on phase 1 to produce timber. Trees are harvested before the end of their natural life span, because then the proportion of timber failures is low and forest ecosystems achieve maxima in timber production. In the course of timber production maximum rates of carbon sequestration can be observed and are maintained in a sustainable manner. If timber is used to produce wood products, carbon stocks in biomass are transformed into carbon stocks in timber products outside the forest ecosystem.
Timber products are generally characterized by a very low amount of embodied fossil energy and therefore offer the opportunity to avoid carbon emissions, when they are used instead of products from other materials. Furthermore energy produced from timber or wood products at the end of their life-time can replace the use of fossil energy (Burschel et al., 1993; Nabuurs, Schelhaas, 2003). Consequently, the effects of forest management and the utilization of timber on carbon mitigation options are manifold (Kim Phat, 2004) and have therefore to be assessed within the context of ecological, socioeconomic and technological conditions of the investigated area:

- *Areas dominated by deforested lands*
  Any development of forest – by natural succession, afforestation or reforestation – will increase carbon stocks on the long term and will restore the carbon sequestration potential of the landscape. Succession phases can be manipulated by silvicultural actions to reduce the time span, until forests achieve their natural level of biomass production.
- *Areas dominated by overused forest*
  Any reduction of forest exploitation to a sustainable level will increase biomass increment and carbon stocks. Silvicultural treatment can be applied to optimize increments and carbon stocks in biomass and wood products.
- *Areas dominated by sustainably managed forest*
  The forest management strives for a maximum carbon sequestration and a maximum of carbon stocks in forest ecosystems and products respectively at the same time. Any reduction in timber harvest increases temporarily the carbon stock in the forest ecosystem until trees die naturally, but decreases carbon sequestration and carbon stocks in products.
- *Areas dominated by old growth forest*
  The non-use of old growth forest conserves high amounts of carbon already accumulated in these forests for centuries. Any use will disturb the equilibrium conditions leading to a net release of carbon to the atmosphere (Weber, 2003).

Figure 1. Italy and Veneto Region.

In the following chapters case studies from two areas in Northern Italy and Southern Germany are presented to demonstrate the effects of the Kyoto mechanism on areas characterized by sustainable managed forests.

Case studies: Veneto Region and tertiary highlands of Southern Bavaria

1. *Veneto Region*

General introduction to Veneto Region
Veneto Region is in north-eastern Italy and extends from the Adriatic Sea to the Dolomites. Its surface area is about 18391 km² and the population exceeds 4.7 million. The climate is influenced by the local morphology. It is continental on the plains, but milder along the Adriatic coast, around Lake Garda and in the open hilly areas.

The forests in Veneto Region
Italy has approximately 8800000 ha of forest land (about 29% of the total national surface area) of which about 30% is public forest. About 90% of the forest area comes under the national forest policy (INFC, 2007). In northern Italy, forests are dominated by conifers, whereas broadleaves are predominant in the rest of the country.
Veneto Region has about 397889 ha of forest (INFC, 2007), divided into public forests, which are about 33% of the total (131303 ha), and private forests that are 67% of the total. Coppices cover approximately 154229 ha, mainly composed of beech, and high forests cover about 240000 ha of mixed and multi-stratified stands of spruce, fir, beech and larch.
Public forests are managed by selective cutting and defined in about 144 forest plans (6300 compartments), renewing every 10-12 years.

Private forests are mainly coppices composed of beech and mixed broadleaves. Since these areas are not usually subjected to a specific forest plan, there is a gap of information about them.

Material and methods

- Selection of management types and management strategies

Given the gap of information about private forests, the target areas (TAs) are identified among the public forest compartments (Pilli and Anfodillo, 2006). We have therefore selected the following Vegetation Types (VT):

VT1 Coniferous Forests

- Fir forest with mixed coniferous forest of fir (*A. alba*), spruce (*P. abies*) and beech (*F. sylvatica*); about 1041 Forest Compartments (FCs).
- Spruce pure high forest (*P. abies*); about 21721 FCs.

As both these kinds of forest are characterized by a strong presence of spruce and similar management conditions, they can be joined into one VT and general Management Type (MT1), called Coniferous High Forest. They are usually managed as a commercial forests, with natural regeneration by clear cutting with reserves in even-aged stands, or single tree selection with a cutting cycle of 15-20 years in uneven-aged stands.
Each FC was classified according to aboveground density (number of trees and total basal area per ha) and diameter distribution (number of trees of each species distinguished in diameter size classes).
The second task was to select the Target Areas (TAs) and the subsequent steps have been taken.
In order to obtain the largest amount of information only the FCs with an angle count sampling or a complete diameter sampling were selected; in total we had 802 Fir FCs and 1223 Spruce FCs.
The mean parameters (tree density, basal area, aboveground biomass, age and diameter at breast height) of each density class and structural class were analysed. We selected the third density class for the following steps among the 8 classes (4 for Fir forests and 4 for Spruce forests) with the largest number of compartments.
Starting from this dataset we considered only the FCs where a time series with two diameter distributions taken during two following plans were available.
Comparing for each FC the aboveground tree commercial volume assessed during the two following plans we calculated the current annual increment (CAI) and the rate of drawing (RD) as:

(1)
$$CAI = V_2 \times \frac{Ip}{100}$$

where V_2 = commercial volume ($m^3\,ha^{-1}$) relative to the 2nd measurement
Ip = percent increment relative to the 2nd measurement

(2)
$$RD = \frac{CAI \times \Delta t - (V_2 - V_1)}{CAI \times \Delta t} \times 100$$

where V_1 = commercial volume ($m^3\,ha^{-1}$) relative to the 1st measurement
Δt = years between the 2nd and 1st measurements

The FCs with a negative value of RD (probably due to a wrong CAI estimation) were excluded. The other FCs were classified into four groups, corresponding to different Management Strategies (MS).
MS1 – Business as usual: high coniferous forests where about 100% of the annual increment is harvested.
MS2 – Less forestry: high coniferous forests where about 50% of the annual increment is harvested.
MS3 – More forestry: high coniferous forests where more than 150% of the annual increment is harvested.
MS4 – No forestry: high coniferous forests where less than 10% of the annual increment is harvested.
Two TAs for each MS have been selected comparing the altitude, the mean parameters and two available diameter distributions of each FC.

VT2 Beech forest
This VT includes 842 FCs of pure semi-natural beech forests managed both as high forest and coppice. We identified two different MTs that are (i) Beech high forests and (ii) Beech coppices.
MT2 (Beech high forests) includes commercial forests, managed by shelterwood with a rotation of 120 years with natural vegetation and regeneration. This MT also includes young beech ex-coppice forests, recently (less than 30 years) assigned to timber production and subjected to thinning every 15-25 years.
We analysed the mean parameters (basal area, aboveground biomass, age and diameter at breast height) and the diameter distribution of the beech high forest compartments to identify the following two Management Strategies; an FC was identified for each MS:
MS5 – Timber: beech mature high forests assigned to timber production (more than 30 years old).
MS6 – Transitory silvicultural system: ex coppices recently assigned to timber production and managed as high forest.
MT3 (Beech coppices) includes commercial forests regenerated by coppice with reserve; the rotation length is between 20 and 30 years. A new MS and target area was also identified for this MT:
MS7 – Firewood: FCs assigned to firewood production and managed as coppices with reserves.

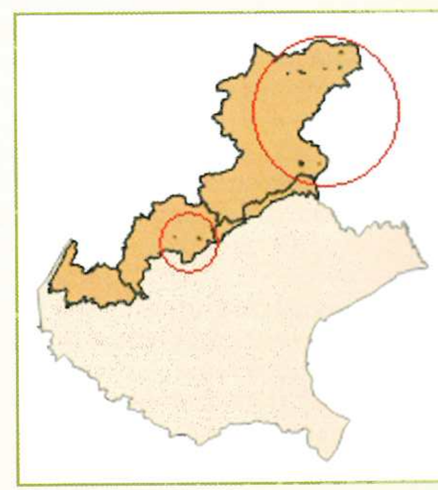

Figure 2. TAs in Veneto Region.

- Target area geographical positions and mean parameters

The selected TAs are all forest compartments in the mountain area (Figure 2); 8 plots are in the Province of Belluno (in the alpine area of the region) and 3 plots in the

Plot ID	MS	Forest Plan code	FC code	Size (ha)	Alt. (m)	CAI ($m3\ ha^{-1}\ y^{-1}$)	Age (y)	Density (Trees ha^{-1})	Basal area ($m^2\ ha^{-1}$)	Comm. volume ($m^3 ha^{-1}$)	Diameter distribution 1st meas.	Diameter distribution 2nd meas.	RD (%)
1	1	012_3	A0420	20.10	1300	7.7	160	325	36.3	425.1	1985	1996	96.6
2	1	012_3	A0910	23.40	1250	8.2	155	374	37.1	429.5	1985	1996	100.8
3	2	012_3	B0050	31.70	1275	7.5	165	384	36.4	394.5	1985	1996	46.8
4	2	012_3	B0010	23.50	1275	6.5	155	353	31.7	342.4	1985	1996	52.5
5	3	023_3	A0122	32.27	1400	6.6	170	302	30.0	327.9	1985	1996	183.2
6	3	032_3	A0231	15.80	1430	6.2	170	321	31.5	343.0	1986	1997	189.8
7	4	001_2	A0200	39.50	1450	6.3	140	326	29.0	347.9	1982	1995	4.6
8	4	064_2	A0470	10.90	1230	7.5	160	422	34.8	358.8	1984	1999	9.3

Table 1. Main parameters of the target areas selected for the VT1 (Spruce and Fir forest).

Plot ID	MS	Forest Plan code	FC code	Size (ha)	Alt. (m)	Age (y)	Density (Trees ha^{-1})	Basal area ($m^2\ ha^{-1}$)	Comm. volume ($m^3\ ha^{-1}$)	Diameter distribution	
9	5	045_2	A0100	11.20	1190	70	420	30.7	311.4	1985	-
10	6	070_1	A0100	21.42	1075	45	274	10.3	93.4	1983	1994
11	7	070_1	B0070	16.60	1015	-	-	-	-	-	1997

Table 2. Main parameters of the target areas selected for the VT2 (Beech forest).

province of Vicenza (in the pre-alpine area). The following tables show the main average parameters of the forest compartments estimated from the previous field measurements (Table 1, Table 2).

Data of 8 TAs were collected in the Province of Belluno; the territory of the province is about 3678 km^2 and it is a mountainous area in the Alpine region with elevation from 500 m to 3000 m a.s.l. Three TAs were in the Province of Vicenza; the territory of the province is about 2723 km^2 and it is a pre-alpine area with elevation from 0 m to 2300 m a.s.l.

- Field measurements

General standard measurements were taken in the Spruce and Fir forests (TA 1-8) and beech forests (TA 9 and 11):

- Relascope plots (1 plot/ha) to obtain complete Dbh distribution with size classes 1 cm.
- Height measurement in order to obtain H-Dbh relationship.
- Core sampling: mean annual increment, age and wood density.

In TA 10 (Beech forest) we made specific aboveground biomass analyses; The TA at 1075 m a.s.l., represents a typical mountain beech forest, ex-coppice, recently assigned to timber production and managed as high forest; the area of the compartment is about 13.5 ha.

In order to obtain direct estimates of total aboveground biomass 41 trees were harvested. The diameter at breast height (Dbh) of the selected trees, spanning between 7 and 31 cm, represented the diameter distribution of the study area.

The Dbh and total height of each tree were measured directly in the field. Moving from the base towards the top, stem and larger branches were measured considering blocks having a regular form similar to a truncated cone. The volume (V) of each block was determined by a mathematical relationship.

The basal diameter (D) was then measured of all other branches not considered as blocks and having a D of between 10 and 1 cm. Two branches including leaves were collected from each tree, in order to have a total sample of 50 branches with a D between 1 and 10 cm.

For all blocks, disks with a thickness proportional to about 2% of the volume of the block (V_b) were collected at intermediate points of the length using a chainsaw.

Basic wood density (oven dry mass/fresh wood volume) was determined on disks taken from each block. The volume was determined by the Archimedes principle (Nogueira et al., 2005); the dry weight was determined in a vented electric oven at 103 °C. Basic wood density of each disk was used to estimate the dry weight of each block.

For each sample, branch leaves and wooden parts were weighed and a fraction of the total fresh weight was used to estimate the dry weight of each branch (W_B). For the allometric relationship between D and W_B the total branch dry weight of each sampled tree was estimated.

Using a logarithmically transformed power function (Niklas, 1994), a species and site specific relationship between Dbh and the total aboveground biomass was estimated.

- Carbon stock assessment: allometric equations based on the WBE model

Estimating tree and forest biomass is essential for assessing ecosystem yield and carbon stock in compliance with the Kyoto Protocol on greenhouse gas reduction (Brown, 2002; Körner, 2005). Measuring tree biomass in the field is extremely time consuming and potentially limited to a small tree sample size, so, empirical relationships based on species-specific equation have been used to estimate total biomass from predictive biometric variables such as breast height diameter (D) or height (H) (Curtis, 1967; Loetsch and Haller, 1973; Wirth et al., 2004). A different approach was proposed by West et al. (1999), who presented a general model, known as the WBE model, to estimate values of scaling exponents using a functional relationship (Enquist et al., 1999; Enquist, 2002). We remind to the material and methods chapter of this publication in order to have more information regarding this model (all the information are accessible also consulting the "Common Transnational Guidelines on how to match models", available at the website www.carbonpro.org).

The belowground biomass has been estimated through a default value proposed by the IPCC GPG (2003) as 30% of the aboveground biomass (Table 3A.1.8).

Chronosequence and comparison of different Management Strategies

For all the TA the values of total biomass (above and belowground biomass) have been estimated in the different years of the survey, using the proposed allometric approach and the specific allometric equation for TA 10.

The carbon stock variations give us the carbon sink net of the cuts.

EQUATION 3.1.1
ANNUAL CARBON STOCK CHANGE IN A GIVEN POOL AS A FUNCTION OF GAINS AND LOSSES

$$\Delta C = \Sigma_{ijk} [A_{ijk} \bullet (C_I - C_L)_{ijk}]$$

Where:

ΔC = carbon stock change in the pool, tonnes C yr^{-1}

A = area of land, ha

ijk = corresponds to climate type i, forest type j, management practice k, etc...

C_I = rate of gain of carbon, tonnes C ha^{-1} yr^{-1}

C_L = rate of loss of carbon , tonnes C ha^{-1} yr^{-1}

EQUATION 3.1.2
ANNUAL CARBON STOCK CHANGE IN A GIVEN POOL

$$\Delta C = \Sigma_{ijk} (C_{t_2} - C_{t_1}) / (t_2 - t_1)_{ijk}$$

Where:

C_{t_1} = carbon stock in the pool at time t_1, tonnes C

C_{t_2} = carbon stock in the pool at time t_2, tonnes C

Figure 3. General equations provided by IPCC GPG for LULUCF for the assessment of carbon stock changes in the land use, land-use change and forestry sector (source: IPCC, 2003).

To estimate the carbon sink we used the Stock Change Method proposed by the IPCC Guidelines. In the IPCC Guidelines two general methods are described for calculating carbon stock changes, the "Flux Method" based on rates of carbon losses and gains by area of land use and the "Stock Change Method" based on the difference between the measurements of carbon stocks at two points in time (Figure 3). The required information can be obtained from inventory data but also through modelling and default data.

Because the Forest Plans also give us the amount of cut wood, it is also possible to evaluate the amount of carbon stocked in harvested wood products.

Between the same vegetation types (VT) it has been possible to compare the different management strategies in terms of carbon stock, carbon sink and HWP.

We also collected all the available information on the amount of the products from the Forest Compartments Plans; in this way it was possible to estimate the amount of carbon in the products and the average lifespan, which was divided into 4 possible values due to the type of products obtained from the harvested biomass:

- Short lived products lifespan 1 year
- Long lived lifespan 30 years
- Landfill lifespan 140 years
- Bio energy lifespan 1 year

Carbon stock and sink in the Target Areas

The predicted aboveground biomass of each target area was estimated using the three mean b values (2.08, 2.64 and 2.51 for the juvenile, adult and mature stage, respectively), while parameter *a* was estimated with eq. (5) and eq. (6). Only the aboveground biomass of TA 10 was estimated using specific allometric equations obtained from the specific measurements taken.

Table 3 shows the wood density value used for each species.

Species	Wood Density (Mg m^{-3})
Silver fir	0.44
Norway spruce	0.45
European larch	0.65
European beech	0.73
Scots pine	0.55

Table 3. Average values of wood density, expressed as the ratio between mass and volume at 12% moisture content (Giordano, 1980, 1988).

In the first Vegetation Type (Spruce and Fir forest) we had 4 different management strategies and 2 sample plots (TA) in each MS. We report one average value of carbon stock (aboveground + belowground) and sink for every MS (Table 4).

VT	MS	Target Area	Years	Sink (Mg C ha^{-1} y^{-1})	Stock 2007 (Mg C ha^{-1})
Fir & Spruce forest	BAU	012_3 A091	1985-2007	+1.80	194.74
		012_3 A042	1985-2007	-0.03	146.46
		Average of the MS		+0.88	170.60
	Less Forestry	012_3 B005	1985-2007	+0.13	132.92
		012_3 B001	1985-2007	+2.90	178.80
		Average of the MS		+1.52	155.85
	More Forestry	023_3 A0122	1985-2007	-1.50	118.17
		032_3 A0231	1986-2007	-2.72	96.82
		Average of the MS		-2.11	107.49
No	001_2 A0200	1982-2007	4.17	171.81	
	Forestry	064_2 A0470	1984-2007	+3.28	171.80
		Average of the MS		+3.72	171.81

Table 4. Carbon sink (Mg ha^{-1} y^{-1}) and stock (Mg ha^{-1}) of the Target Areas referred to the first Vegetation Type and different Management Strategies.

In the second Vegetation Type (Beech forest) we had 2 different management types, 3 MS and 1 sample plot (TA) in each MS. We report the value of carbon stock (aboveground + belowground) and sink for every MS (Table 5).

VT	MT	MS	Target Area	Years	Sink (Mg C ha-1 y-1)	Stock 2007 (Mg C ha^{-1})
Beech forest		Timber Production	045_2 A0100	1985-2007	+5.44	256.12
	High forest	Transitory Silvicultural System	045_2 A0100	1983-1994 1994-2005 1983-2005	+2.59 +2.39 +2.49	139.52[2]
	Coppices	Firewood	070_1 B007	1984-2007	+0.62	55.99

Table 5. Carbon sink (Mg ha^{-1} y^{-1}) and stock (Mg ha^{-1}) of the Target Areas referred to the second Vegetation Type and the different Management Strategies.

Only for he MS6 (Transitory silvicultural system: ex-coppices recently assigned to timber production and managed as high forest) we had three different years of the measurements as we show in the next table.
The different management strategies have a different amount of harvested biomass and also diverse type of products, due to the MS, MT and VT (Table 6).

VT	Management Strategy	C Sink (Mg C ha^{-1} y^{-1})	Total harvested (Mg C ha^{-1})	Products	Products Lifespan (Years)	C in the products (Mg C ha^{-1} y^{-1})
Spruce & Fir Forest	BAU	+0.88	21.26	30% short life 70% long life	1 30	0.50
	Less Forestry	+1.52	10.77	30% short life 70% long life	1 30	0.25
	More forestry	-2.12	23.04	30% short life 70% long life	1 30	0.54
	No forestry	+3.72	1.77	Short life	1	0.00
Beech Forest	Timber Production	+5.44	23.56	40% short life 60% long life	1 30	0.47
	Transitory Silvicultural System	+2.49	18.5	Bio energy	1	0.00
	Beech Coppices	+0.63	12.9	Bio energy	1	0.00

Table 6. Total harvested biomass (Mg ha^{-1}) and carbon (Mg ha^{-1} y^{-1}) in the products for each MS.

Comparison of the Management Strategies in Veneto Region
This approach to the project allowed a comparison of the different MS and therefore provides a valid tool to the policy-makers, who must manage the forests. The following figures show a simple comparison of the sample plots for the two VT considered in this case study.

[2] Final stock referred to 2005.

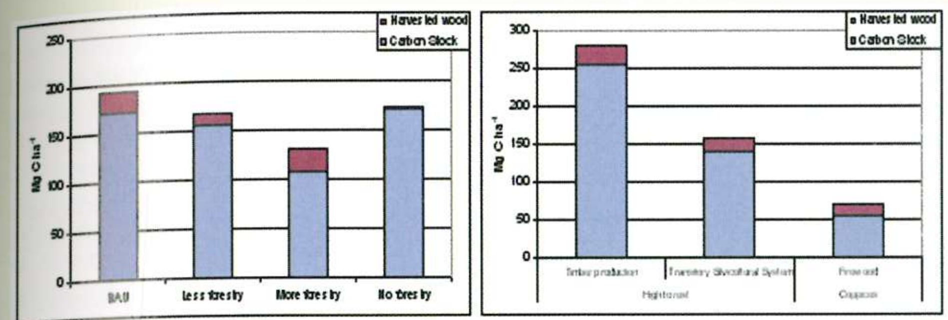

Figure 4. Carbon stock and carbon in the harvested biomass (Mg C ha^{-1}) in the VTI and VTII.

As can be seen in Figure 4, on the left, in the TAs managed with business as usual (MS1 – 100% of the current annual increment cut) the carbon stock is more or less the same as that in the plot with less than 10% of the CAI cut (MS4 – No Forestry), but in this strategy there is no carbon in the products and no profit from the forest; if we look at the sink of these two MS (Table 6), it is clear that the MS4 has a higher sink (+3.72 Mg C ha^{-1} y^{-1} against + 0.88 Mg C ha^{-1} y^{-1}).
The MS2 (Less forestry) accumulate half of the increment of the forest and the results of the measurements highlight this effect (carbon sink is +1.52 Mg C ha^{-1} y^{-1}); the harvested biomass and therefore the carbon in the products is half that of the BAU strategy.
The More Forestry strategy has, as expected, the lowest carbon stock, a negative carbon sink (-2.12 Mg C ha^{-1} y^{-1}) and the highest amount of harvested biomass and profit for the landowner in the short-term.
According to what the goal of the management is it is possible to choose a different strategy in order to improve the wished for aspect.
For example, in Veneto Region there are 23657.82 ha of Spruce and Fir forests (Regione Veneto, 2006), if all these hectares were managed in order to save the carbon stock it would be possible to choose different strategies, taking into count the social and economic situation of the area:

MS	Sink (Mg C ha^{-1} y^{-1})	Regional level (Mg C y^{-1})	C in products (Mg C y^{-1})
BAU	+0.88	20818.88	11829
Less forestry	+1.52	35959.89	5914
No forestry	+3.72	88007.09	0.00

Table 7. C sink and C in the products for the different MS related to the regional Spruce and Fir forest surface.

Considering that a person releases about 9 Mt C per year, it is possible to estimate how many people's annual emissions can be compensated by the Spruce and Fir forests of the region with the different management strategies:

- BAU about 2300 persons y^{-1}
- Less forestry about 4000 persons y^{-1}
- No forestry about 10000 persons y^{-1}

Concerning the VT2, once more in Figure 4, on the right, the difference in carbon stocking is marked between forest managed as high forest and beech coppices; the Firewood management strategy has a lower carbon stock and sink; in this strategy the products are used as bioenergy and so the displaced fossil fuel is accountable (but not for the Kyoto First Commitment Period). The transitory silvicultural system, managed as high forest, shows a higher carbon stock and sink, but still not as for the beech high forest managed for timber production.

Also in this case the policy-makers must have a clear idea of the general situation, because the type of management is strictly connected with the social economic situation. A change in management strategies also entails a variation in the local economy, in the potential income for the landowner and in jobs for the local population.

The study highlights the possible rules of the different management strategies. In fact the utilisation of the entire increase in aboveground biomass destined for energy uses gives an energy substitution effect but, according to the Marrakesh Accords, it can not be accounted for the KP. On the other hand, an accumulation strategy gives the maximum possible carbon absorption and retention (Hellrigl, 2004).

Stocking carbon is a priority nowadays because of the impact of the Kyoto Protocol on the forestry sector, but it is necessary to know the rules of the game and to also take into account the traditional role of the forest and the effect of the decision on the local economy.

We would like to underline some aspects that could be important for future decisions in land management.

The carbon stored in the products is not now accountable in the Kyoto rule, but may become an opportunity for the future; the challenge is to face the problem analysing the whole lifecycle of the products. In this way it will be possible to certify wood products throughout their life. It is also interesting to analyze the use of wood as bioenergy in order to quantify the displaced fossil fuel.

Another challenge is to organize a local carbon market, independent from the European carbon market in which the credits produce by AFOLU (Agro forestry and other land use) sector are not utilizable.

2. *Tertiary highlands of Southern Bavaria*

General introduction to Bavaria

Bavaria is located in south-western Germany and includes the Bavarian Alps (maximum elevation 2962 m a.s.l), the foothills of the Alps to the Danube, the highlands in the central and northern parts and low elevations in the north east (107 m a.s.l).

The climate conditions are temperate with cool summers and humid conditions through the whole year (Cfb climate according to Köppen, 1936). In the Alps cold climates dominate at higher elevations (Dfb climate according to Köppen, 1936). Western parts of Bavaria have subatlantic, eastern regions subcontinental character.

The forests in Germany and Bavaria

Germany ranks among the densely wooded countries in Europe. Around 11 million hectares corresponding to one third of the national territory are covered with forests. Forest area increased by approx. 0.5 million hectares over the past four decades. The percentage of over 80-year old stands also rose from one quarter to one third of the forest area. The timber stocks per hectare are one of the highest in Europe. This is largely a result of the efforts to rebuild high-yielding and ecologically valuable forests after the destruction of large forest tracts over the past centuries and, more recently, after the clear-cuttings due to both World Wars. The forest- and timber industry, including processing and paper as well as printing and publishing, comprise nearly 1 million jobs with an annual turnover of over 120 billion € (Federal Ministry of Food, Agriculture and Consumer Protection, 2007)

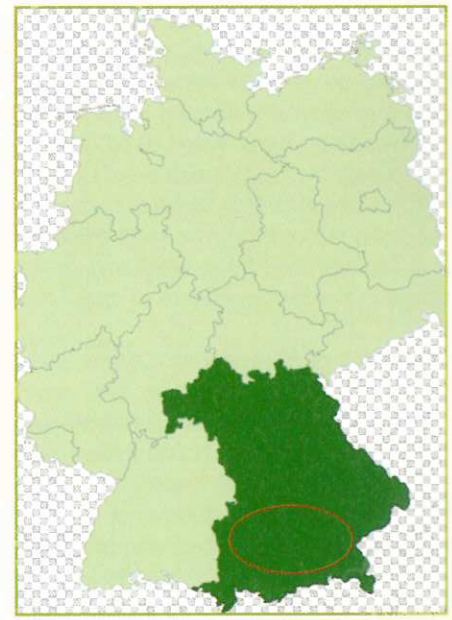

Figure 5. Federal states of Germany, Bavaria (dark green), project area (red).

Bavaria comprises an area of around 7 million hectares. The natural vegetation is widely dominated by beech. Most of the forest area is presently managed as even-aged forest with artificially increased proportions of conifers – mainly spruce and pine (Bayerisches Staatsministerium für Landwirtschaft und Forsten, 2006).

Material and methods

- Study area

The study region includes the tertiary highlands of the governmental district Schwaben and ranges from an altitude of 450 to 650 m a.s.l. The area of the region is 638000 ha and comprises 169000 ha of forest land. The natural vegetation – dominated by beech forest (Walentowski et al., 2001) – is replaced by pure and even-aged spruce stands involving high risks for storm damage and bark beetle attack. Nevertheless the forests of

	State Forest of the Federal Government	State Forest of Federal States	Communal Forest	Private Forest	Conifers	Broadleaved
Germany	3%	30%	20%	47%	59%	41%
Bavaria	2%	30%	13%	55%	68%	32%

Table 8. Characteristics of forestry in Germany and Bavaria (Federal Ministry of Food, Agriculture and Consumer Protection, 2007; Bayerisches Staatsministerium für Landwirtschaft und Forsten, 2006).

the region are very productive due to the favourable site conditions, and forest owners can choose very different options of forest management.
The discrepancy between economic importance of these forests and high natural risks led to the decision to install network of long term observation plots to investigate different management options in regard to ecological, economic and social aspects in the area. Research plots were established covering the most important management options based on tree species as Douglas fir, spruce, fir, beech and oak. Each vegetation/forest type (VT) is treated by one characteristic management type (MT) consisting of specific harvesting methods depending on stand age. Each harvesting method and VT is represented by at least one research plot. Almost equal site conditions between all plots allow the formation of chronosequences.

- Selection of management types and management strategies

This study was conducted for two vegetation types to demonstrate the effect of different management options on carbon sequestration:
- VT1 Even-aged pure spruce stands. This vegetation type dominates the region today.
- VT2 Even-aged pure beech forest. This vegetation type represents the natural vegetation of the observation area.

The majority of present spruce and beech stands are treated by the management type medium thinning from below (MT1). Therefore, following management strategies (MS) were defined for the analysis:
- MS1 Medium thinning from below and a rotation period of 100 years (VT1) and 130 years (VT2).
- MS2 Intensive thinning from above and a rotation period of 80 years (VT1).
- MS3 Extensive thinning from below and a rotation period of 120 years (VT1).
- MS4 No treatment and a natural live span of trees of 200 years (VT1).

- Field measurements

Each plot is located in a research stand with a minimum size of 4 hectares. Within each stand intensive measurement areas were established with a size ranging from 0.1 to 1 hectare depending on stand height. Field measurements were taken from the soil, forest stand, forest regeneration and ground vegetation:
- Mineral soil (selected plots): pH, total organic carbon, nitrogen, cations at soil depths of 0-5, 5-10, 10-30, and 30-60 cm.
- Humus layer (selected plots): pH, total organic carbon, nitrogen at different morphologic layers.
- Trees (all plots): Tree species, diameter at breast height, tree height, crown length, crown width, social class, vitality class, damages, tree position.
- Regeneration (selected plots): Root collar diameter, tree height, tree length, damages.
- Ground vegetation (selected plots): Species group, vegetation cover, mean height, maximum height.

The results of the tree measurement are summarized in Table 9.

- Application of simulation models

Time series were developed from field measurements by the application of the distance dependent growth simulator SILVA 2.1 (Pretzsch et al., 2002). The parameters of the

Vegetation Type	Plot Id	Age (years)	Density (stems/ha)	Top Height (m)	Mean DBH (cm)	Merchantable Volume (m³/ha)
Spruce (VT1)	11	20	2880	5,7	4,9	9
Spruce (VT1)	12	30	1839	12,8	12,3	142
Spruce (VT1)	13	62	680	28,4	26,4	589
Spruce (VT1)	14	89	433	36,1	34,4	833
Beech (VT2)	21	18	4873	5,7	5,2	13
Beech (VT2)	22	30	1121	13,0	12,6	137
Beech (VT2)	23	75	517	29,5	29,5	695
Beech (VT2)	24	90	450	31,1	31,1	764
Beech (VT2)	25	110	389	32,4	32,3	781

Table 9. Main parameters of the forest types VT1 spruce and VT2 beech.

simulation model were adapted to the measured data and then time series were produced for the MS1 to MS4. The simulated tree data were then used to calculate timber assortments by the application of the timber assortment model HOLZERNTE 6.0 (Schöpfer et al., 2003). Based on the simulated time series the carbon model CO2FIX 3.1 (Schelhaas et al., 2004; Masera et al., 2003) was applied to derive carbon balances for the different VT's and MS's.

- Calculation of carbon stocks

The time series of the carbon balances were then transferred to a "normal forest model". For example, VT1 and MS1 are represented by an ideal-typical working cycle of 100 ha, whereby each stand age is represented by one hectare. The application of the "normal forest model" enables the comparison of different management options over the whole rotation period.
The carbon stocks were then analyzed (i) without the influence and (ii) with the influence of natural risks caused by storm and insects. Data for natural risks were derived for MS1 from literature analysis (König, 1996; Rottmann, 1983, 1985, 1986). Due to the lack of scientific data the risks for MS2 to MS4 were estimated based on expert knowledge:
- MS2: Risk of damage reduced by 50% compared to MS1 because of improved stand stability.
- MS3: Risk of damage increased by 50% compared to MS1 because of less stand stability.
- MS4: Risk of damage increased by 100% compared to MS1 because of less stand stability and missing salvage cuttings.

As a further simplification it has been assumed, that after stand destruction the VT does not change.

Calculated Carbon stocks

The study results are presented in Figure 6 as the ratio values for the base scenario "Business as Usual (VT1+MS1) without consideration of natural risks". The simulation runs without consideration of natural risks show, that carbon stocks can theoretically be increased by less harvest (MS3), no harvest (MS4) or change to beech forest types (VT2)

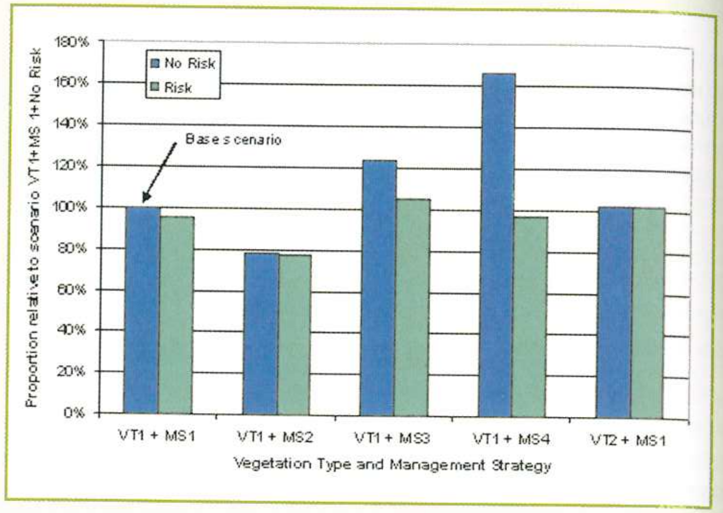

Figure 6. Results of the analysis. Values are calculated in percentage to the base scenario "Business as Usual (VT1+MS1) without consideration of natural risks".

and be decreased by more harvesting (MS1). When natural risks were included into the computations the results differ:

(1) VT1+MS1: Significant decrease by natural risks.

(2) VT1+MS2: No decrease by natural risks because of improved stand stability and reduced losses in carbon stock compared to (1).

(3) VT1+MS3: Decrease of carbon stocks caused by natural damages. Similar stocks compared to (1).

(4) V1+MS4: Strong reduction of carbon stocks below the level of (1) caused by natural damages.

(5) VT2+MS1: No significant influence by natural risks and therefore significant higher stocks than (1).

Comparison of the Management Strategies in the Tertiary hillside region in Southern Bavaria

The present composition of forest land in the model region is dominated by pure spruce stands introduced artificially in the 19th century replacing natural beech stands, destroyed forests or abandoned agricultural areas. Spruce was favoured because of good timber quality, modest artificial regeneration, resistance against higher deer population, and the expectation of high financial income. Spruce forestry relies on silvicultural intervention. Otherwise this artificial system tends to low resistance against natural hazards and catastrophic disturbances.

The calculated carbon stocks reflect these processes. Compared to the present common silvicultural treatment of spruce forests the following conclusions can be summarized for forestry practice in the model region:

- The reduction of timber harvest by less intensive silvicultural treatments cannot in-

crease the carbon stocks in spruce forests and will lead to low carbon stocks over a long period of time, when salvage cuttings are not applied.
- Silvicultural treatments, focussing on a stabilisation of spruce stands by continuous intensive thinning and shorter rotation periods, lead to a reduction of carbon stocks in the forest.
- The use of beech as natural tree species increases carbon stocks, due to its good site adaptation and high resistance against natural risks. Therefore the enrichment of the forests with beech can be recommended.

Forest management and the Kyoto Protocol: Conclusions for decision makers

The case studies demonstrate the impact of different management strategies on the carbon balance of forest lands at the northern and southern edges of the Alps. Generally a reduction of timber harvest can increase the carbon stocks in biomass as long as no natural disturbances occur. However, risk analyses indicate, that under the regime of natural disturbances a reduction of silvicultural intervention can reverse this effect and forest may develop to carbon sources for the atmosphere.

Hence, the assessment of the role of forests and forest management on the sequestration of carbon requires a complete analysis of the forest development including natural risks and the storage of carbon in timber products. Any other approach will induce misleading prognoses and incorrect decisions.

Actually, the Kyoto Protocol does only account for changes in carbon stocks of ecosystems. Therefore, the real options of forest management are not completely considered by the Kyoto rules. Finally the coupling of forest management with the Kyoto carbon trading system may lead to undesirable forest developments not taking into account the potential of forestry and timber industry for climate protection.

It can be recommended for political decision makers and forestry in practice:
- to examine the present structure of forest in the region of interest (i.e. Pilli et al., 2006),
- to make scenario analysis of the possible developments of forest and the different carbon stocks (i.e. Burschel et al., 1993; Karjalainen, 2002),
- to assess the entire opportunities of forest management to sequester carbon from atmosphere (i.e. Burschel et al., 1993; Weber, 2003; Felbermeier, 2004), and
- to undertake an economic impact analysis (Boyland, 2006), especially if forestry is coupled with the carbon trading system.

In general it can be concluded, that the application of the Kyoto mechanisms:
- can increase carbon sequestration in deforested lands and overused forests,
- may reduce carbon sequestration in already sustainable managed forests, and
- can protect huge C-reservoirs in old growth forests.

References

Anfodillo T., Carraro V., Carrer M., Fior C., Rossi S. (2006), *Convergent tapering of xylem conduits in different woody species*, New Phytol. 169, 279-290.

Bayerisches Staatsministerium für Landwirtschaft und Forsten (2006), *Wald & Holz in Bayern: Zahlen und Fakten*, www.forst.bayern.de.

Bormann F.H., Likens G.E. (1979), *Pattern and process in a forested ecosystem*, New York, Heidelberg, Berlin, Springer.

Boyland M. (2006), *The economics of using forests to increase carbon storage*, Can. J. For. Res., 36, 2223-2234.

Brown S. (2002), *Measuring carbon in forests: current status and future challenger*, Environmental Pollution, 116, 363-372.

Burschel P., Huss J. (1987), *Grundriß des Waldbaus*, Hamburg, Berlin.

Burschel P., Kürsten E., Larson B., Weber M. (1993), *Present Role of German Forests and Forestry in the National Carbon Budget and Options to its Increase*, Water, Air, and Soil Pollution, 70, 325-340.

Curtis R.O. (1967), *Height-diameter and height-diameter-age equations for second-growth Douglas-fir*, For. Sci. 13, 365-375.

Enquist B.J. (2002), *Universal scaling in tree and vascular plant allometry: toward a general quantitative theory linking plant form and function from cells to ecosystems*, Tree Physiol. 22, 1045-1064.

FAO (2007), *State of the world's forest*, Rome, FAO.

Felbermeier B. (2004), *Kohlenstoffhaushalt unterschiedlicher Waldbehandlungsoptionen in Mittelschwaben*, Ökosystem Management 1, 94-97.

Federal Ministry of Food, Agriculture and Consumer Protection (2007), *German forests: Nature and economic factor*, www.bmelv.de.

Finney D.I. (1941), *On the distribution of a variate whose logarithm is normally distributed*, Journal of the Royal Statistical Society Series B 7, 155-161.

Giordano G. (1980), *I legnami del mondo. Dizionario enciclopedico*, Second edition, Il Ceriolo.

Giordano G. (1988), *Tecnologia del legno*, Vol. 3. *I legnami del commercio*, Second edition, UTET.

Hellrigl B. (2004), *Gestione del bosco e CO2: un contributo per i cedui di faggio*, Aula Magna, 1: 1-74. Reperibile al sito: http://www.compagniadelle-foreste.it/sherwood/AulaMagna/DAulaMagna.htm.

INFC (2007), *Le Stime di Superficie. Inventario Nazionale delle Foreste e dei Serbatoi Forestali di Carbonio*, C.R.A. ISAFA. Reperibile al sito: http://www.sian.it/inventarioforestale/jsp/dati_introa.jsp.

IPCC (2003), *Good Practice Guidance for Land Use, Land Use Change and Forstry*, edited by Penman J., Gytarsky M., Hiraishi T., Krug T., Kruger D., Pipatti R., Buendia L., Miwa K., Ngara T., Tanabe K. and Wagner F., Institute for Global Environmental Strategies for the Intergovernmental Panel on Climate Change, Hayama, Kanagawa, Japan.

Kaipainen T., Liski J., Pussinen A., Karjalainen T. (2004), *Managing carbon sinks by changing rotation length in European forests*, Environmental Science & Policy 7: 205-219.

Kaitaniemi P. (2004), *Testing allometric scaling laws*, Journal of Theoretical Biology 228, 149-153.

Karjalainen T., Pussinen A., Liski J., Nabuurs G., Erhard M., Eggers T., Sonntag M., Mohren G.M.J. (2002), *An approach towards an estimate of the impact of forest management and climate change on the European forest sector carbon budget: Germany as a case study*, Forest Ecology and Management, 162, 87-103.

Ketterings Q.A., Coe R., Van Noordwijk M., Ambagau Y., Palm C.A. (2001), *Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests*, For. Ecol. Manage. 146, 199-209.

Kim Phat N., Knorr W., Kim S. (2004), *Appropriate measures for conservation of terrestrial carbon stocks - Analysis of trends of forest management in Southeast Asia*, Forest Ecology and Management 191, 283-299.

Kohlmaier G.H., Weber M., Houghton R.A. (1998), *Carbon dioxide mitigation in forestry and wood industry*, Berlin, Heidelberg, New York, Springer.

Körner C. (2005), *Slow in, rapid out-carbon flux studies and Kyoto targets*, Science, 300, 1242-1243.

König A. (1996), *Sturmgefährdung von Beständen im Altersklassenwald: ein Erklärungs- und Prognosemodell*, Frankfurt am Main, Sauerländer.

Kyoto Protocol (1997), Available at website: http://www.minambiente.it/Sito/settori_azione/pia/docs/protocollo_kyoto_it.PDF.

Loetsch F., Haller K.E. (1973), *Forest Inventory*, 2nd ed., vol. 1. BLV Verlagsgesellschaft Muenchen, Bern, Wien.

Masera O., Garza-Caligaris J.F., Kanninen M., Karjalainen T., Liski J., Nabuurs G.J., Pussinen A., de Jong B.J. (2003), *Modelling carbon sequestration in afforestation, agroforestry and forest management projects: the CO2FIX V.2 approach*, Ecological Modelling, 164, 177-199.

Nabuurs G.J., Schelhaas M.J. (2003), *Spatial distribution of whole-tree carbon stocks and fluxes across the forests of Europe: where are the options for bio-energy?*, Biomass and Bioenergy, 24, 311-320.

Niklas K.J. (1994), *Plant Allometry, The scaling of form and process*, University of Chicago Press, Chicago and London.

Niklas K.J. (2006), *A phyletic perspective on the allometry of plant biomass-partitioning patterns and functionally equivalent organ-categories*, New Phytol., 171, 27-40.

Nogueira E.M., Nelson B.W., Fearnside P.M. (2005), *Wood density in dense forest in central Amazonia, Brazil*, Forestry Ecology and Management, 208, 261-286.

Pilli R., Anfodillo T. (2006), *L'impiego dei dati assestamentali per la stima dello stock di carbonio ai fini delle richieste poste dal protocollo di Kyoto*, Forest@ 3 (1): 22-38. [online] URL: http://www.sisef.it/

Pilli R., Anfodillo T., Carrer M. (2006), *Towards a functional and simplified allometry for estimating forest biomass*, Forest Ecology and Management, 237, 583-593.

Pretzsch H., Biber P., Dursky J. (2002), *The single tree-based stand simulator SILVA: construction, application and evaluation*, Forest Ecology and Management 162, 3-21.

Rottmann M. (1983), *Schneebruchschäden bei Fichten: Ergebnisse einer Bestandesaufnahme und Analyse*, dargestellt am Beispiel der Schneebruchschäden von 1979 und 1980 im Stiftungswald der Ludwig-Maximilians-Universität München, Dissertation, University of Munich.

Rottmann M. (1985), *Schneebruchschäden in Nadelholzbeständen: Beiträge zur Beurteilung der Schneebruchgefährdung, zur Schadensvorbeugung und zur Behandlung schneegeschädigter Nadelholzbestände*, Frankfurt am Main, Sauerländer.

Rottmann M. (1986), *Wind- und Sturmschäden im Wald: Beiträge zur Beurteilung der Bruchgefährdung, zur Schadensvorbeugung und zur Behandlung sturmgeschädigter Nadelholzbestände*, Frankfurt am Main, Sauerländer.

Regione Veneto (2006), *Carta Regionale dei tipi forestali: documento base*, Regione del Veneto - Direzione regionale delle foreste e dell'economia montana in collaborazione con l'Accademia Italiana di Scienze Forestali.

Schelhaas M.J., van Esch P.W., Groen T.A., Kanninen M., Liski J., Masera O., Mohren G.M.J., Nabuurs G.J., Pedroni L., Pussinen A., Vallejo A., Palosuo T., Vilén T. (2004), *CO2FIX V3.1 – A modelling framework for quantifying carbon sequestration in forest ecosystems*, ALTERRA Report 1068, Wageningen, The Netherlands.

Schöpfer W., Kändler G., Stöhr D. (2003), *Entscheidungshilfen für Forst- und Holzwirtschaft – zur Abschlussversion von HOLZERNTE*, Forst und Holz, 18, 545-550.

United Nations (1998), *Kyoto protocol to the United Nations Framework Convention in Climate Change*.

Walentowski H., Gulder H.J., Kölliung C., Ewald J., Türk W. (2001), *Die regionale natürliche Waldzusammensetzung Bayerns*, Berichte aus der Bayerischen Landesanstalt für Wald und Forstwirtschaft Nr. 32.

Weber M. (2003), *Kohlenstoffökologische Effekte der Überführung von Primärwald in Wirtschaftswald*. In: Waldbau - weltweit Hrsg.: Mosandl R., El Kateb H., Stimm B., München, Forstliche Forschungsberichte 192, 2003, S. 123-146.

West G.B., Brown J.H., Enquist B.J. (1999), *A general model for the structure and allometry of plant vascular systems*, Nature, 400, 664-667.

Wirth C., Schumacher J., Schulze E.D. (2004), *Generic biomass functions for Norway spruce in Central Europe. A meta-analysis approach toward prediction and uncertainty estimation*, Tree Physiol., 24, 121-139.