PRESENT ROLE OF GERMAN FORESTS AND FORESTRY IN THE NATIONAL CARBON BUDGET AND OPTIONS TO ITS INCREASE

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Abstract. The carbon stock in forests and wooden products is quantified for the Federal Republic of Germany. In addition the sink effects of • the actual forests and • the pool of wooden products are determined. The mitigation obtained by • substitution of high energy raw materials by wood, • substitution of fossil fuels by wood as source of energy were evaluated. Finally the C-ecological effects of the following silvicultural measures were quantified: • lengthening of rotation time • underplanting • change of tree species • afforestation of non forest land • increased use of slash and wood from thinning operations as energy source.

1. Introduction

One of the great global C-reservoirs is the biosphere, with forests - because of their great storage capacity - playing a paramount role. Quantification of this role with respect to the actual state and management potentials is an important issue, elaborated here for a highly industrialized and densely populated but small country as far as area is concerned.

2. Methods

To quantify the role of forest and forestry in the national C-budget it was considered to consist of five components:

- C stored in the standing forest,
- C stored in wood products originated from this forests,
- Increase in storage of both the forest and product pool,
- Avoidance of C-emissions by using wood products in place of more energy demanding materials,
- Reduction of emissions by use of wood as source of energy substituting fossil fuels.

The simultaneous effects of all these C-ecologically important components of forestry are exemplified for a spruce stand in figure 1.

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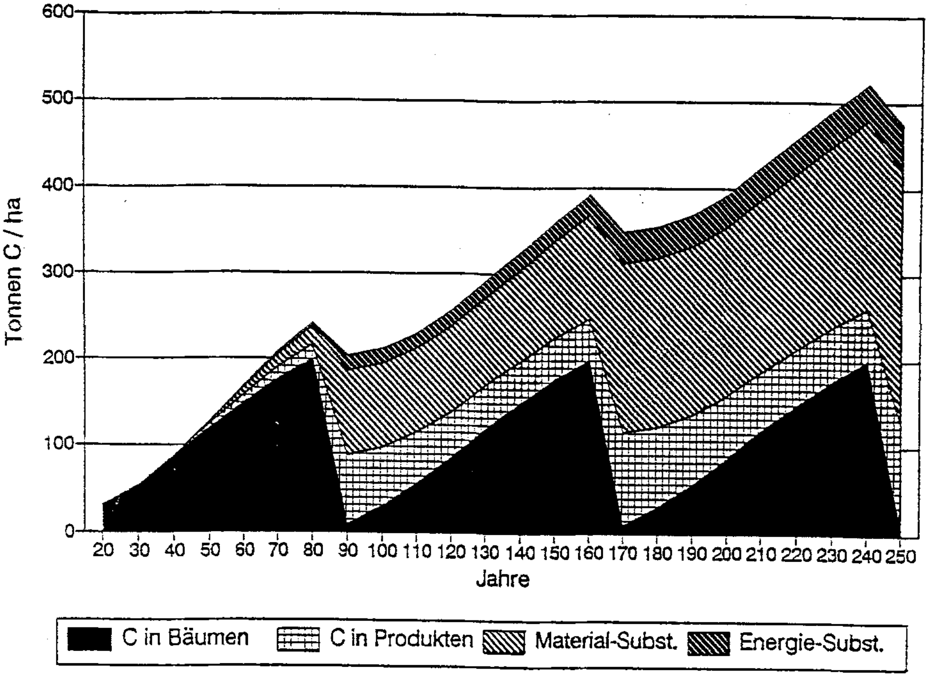
Figure 1: CO_2-Mitigation Effect of a Spruce Stand (rotation 80 yrs)



The amount of C stored in the forest and in wood products is determined by an instantaneous measurement, while energy and product substitution effects as well as the increase in forest and product storage is a dynamic measure including a time reference. The equations used for calculation are shown in Table 1.

To assess the validity of the results it is important to know that the inventories of standing volumes, the annual timber cut as well as the calculation of biomass and C-contents are well founded, while all the values pertaining to increment and corresponding increases of stocks are based on estimations made by various authors, referred to in table 1.

C-contents of forest soils are approximations derived from ZIEGLER 1991. Representative studies for the total forest area are not existing. There is an immediate need for additional surveys in this matter. Although the soil is a very large store, no marked and rapid changes are likely. Since many sites in Central Europe are still in a phase of recovery from soil devastation (overcutting, overgrazing, litter raking) in the past, a decrease of C-content is very unlikely. Therefore a low sink-effect has been attributed to it. With respect to possible decreases of soil-C with increasing temperatures however, representative monitoring is advisable.

ɔle 1: Equations for the calculation of different components of C pool and C mitigation. All data expressed as metric tons.

'MPARTMENT	EQUATION and LEGEND
REST Living tree biomass	TOTAL BIOMASS CARBON= ([BOLE]+[BRANCH]+[ROOTS]*[DENSITY])*BIOMASS CARBON BOLE= volume of standing wood > 7 cm diameter (including branches). Data source: Western Germany: 1987 forest survey (BML 1992); Eastern Germany: 1985 complete forest inventory (VEBFP 1986). Volume separately by species and age class BRANCH= volume of branches < 7 cm diameter calculated as % of BOLE based on species, mean diameter and height according to age class (GRUNDNER, SCHWAPPACH 1952). This percentage ranges from 8% (old larch and pine) to 200% (all species when very young) ROOTS= volume of living roots based on % of BOLE. Three percentages were used: for all trees under 20 yrs of age 100% was used, for older spruce 30%, and for older trees of all other species 25% (DAUBER, ZENKE, 1978) DENSITY= fresh volume/dry weight factor which was applied separately by species, but kept constant for different tree parts (including bark) and age classes. The values ranged from 0.377 kg m^{-3} (spruce) to 0.561 kg m^{-3} (oak) (KNIGGE, SCHULZ 1966; TRENDELENBURG, MAYER-WEGELIN 1955) BIOMASS CARBON= constant C percentage of 50 % was assumed (KNIGGE, SCHULZ 1966).
Dead biomass	DEAD BIOMASS CARBON = [NON-HARVEST CARBON]+[FOREST FLOOR CARBON]+[STANDING DEAD CARBON] HARVEST RESIDUE= ([UNHARV WOOD]+[BRANCH AND ROOT])*[HARVEST]*[DECAY] UNHARV WOOD=volume of wood over 7 cm left in the woods, including wood contained in stumps and sawdust calculated as a percentage of HARVEST based on species and size of harvested trees (SCHÖPFER, DAUBER 1990; BAYER. STAATSMIN. 1990). This percentage ranged from 3% (spruce) to 13% (oak) BRANCH AND ROOT= volume of wood < 7 cm and roots calculated as a percentage of HARVEST (SCHÖPFER, DAUBER 1990). It ranged from 35% (pine) to 45% (spruce). HARVEST= annual volume of wood harvested. 40 x 10^6 $m^3$was used based on statistics from 1981-1989 (BARTELHEIMER 1990; AGDW 1991) DECAY: time factor based on the decay rate of harvest slash. Assuming that half of the original volume remains in 5 years the factor was 5 (HARMON et al. 1986).
Ground vegetation biomass	GROUND VEGETATION CARBON Based on local studies this was considered as a constant of 1 t ha^{-1} C (BURSCHEL, BINDER 1993; HÖHNE 1962; ELLENBERG et al. 1986). Compared to most other forest systems in the world there is little ground vegetation in German forests, because they are intensively managed and kept at high density
Soil	SOIL CARBON Based on a fairly comprehensive survey the soil carbon was considered as a constant of 157 t ha^{-1} (ZIEGLER 1991)
ODUCTS	[RES CARBON] = [RES NUM]*[WOOD/RES]*[CARBON/WOOD] [NON-RES CARBON] = [NON-RES NUM]*[WOOD/NON-RES]*[CARBON/WOOD] RES NUM = number of residences in western Germany kept separately by single, double and multiple family dwellings (STAT. BUNDESAMT 1990). WOOD/RES = wood per dwelling based on type of residence (KROTH et al. 1991). CARBON/WOOD = percentage of 20 %, which assumes a dry mass density of 45 % and 50 % C/dry mass NON-RES NUM = number of non-dwelling structures in western Germany kept separately by 3 categories of building (STAT. BUNDESAMT 1990) WOOD/NON-RES = wood per non-dwelling structure based on type of building (KROTH et al. 1991).
ATERIAL BSTITUTION	[MATERIAL SUBSTITUTION EMMISSION AVOIDANCE] = [CONSTRUCTION WOOD]*[AVOIDANCE FACTOR] CONSTRUCTION WOOD: volume of stemwood harvested and then used as for construction (kept separately by species) per year (BARTELHEIMER 1990; CMA 1987) AVOIDANCE FACTOR: a complex value based on energy used for production of alternative products minus energy used for production of wood corrected for the relative amounts of alternative material and wood needed to build a comparable structured multiplied by the amount of C emitted per production of unit energy in western Germany (EK 1988). This total factor varies from 0.099 to 0.491 per m^3 in different studies. 0.28 was used here after review of studies as typical, but conservative (low) for overall construction types in Germany (BOYD et al. 1976; BURSCHEL, KÜRSTEN 1992; BAIER 1982). This factor could also be low because most substitution for wood would probably be steel which has a higher carbon emission level than energy production as a whole.
ERGY- BSTITUTION	[EQUIVALENT OIL] = [ENERGY WOOD]*{[HEATING $VALUE_W$]/[HEATING $VALUE_O$]}*{[HEATING $EFFICIENCY_W$]/[HEATING $EFFICIENCY_O$]} [MJ OIL SAVED] = {[EQUIVALENT OIL]*[HEATING $VALUE_O$]+[$PRODUCTION_O$] - [$PRODUCTION_W$]}* [$EMISSION_O$] [EMISSION AVOIDED] = [MJ OIL SAVED]*[CARBON RELEASED/MJ] ENERGY WOOD: amount of wood used for energy purposes (including mill residues) measured in dry weight HEATING $VALUE_W$: actual energy that can be released by wood combustion which depends on chemical constituents of wood and moisture content. An average value of 25% moisture was used because some of the wood is mill residues with a low moisture content. We used a value of 13 MJ kg^{-1}. HEATING $VALUE_O$: actual energy that can be released by combustion of oil. A value of 42.7 MJ kg^{-1} was used HEATING $EFFICIENCY_W$: an efficiency value based on piece size, moisture content and type of combustion chamber. A percentage of 72 was used. HEATING $EFFICIENY_O$: an efficiency value based on combustion type. A percentage of 85 was used $EMISSION_O$: amount of C emitted upon combustion of oil. A value of 0.0218 kg C/MJ was used (EK 1988). $PRODUCTION_O$: energy used to produce oil. A value of 30.7% of the oil was used (KÜRSTEN, BURSCHEL 1991) $PRODUCTION_W$: energy used to harvest and transport wood. A value of 0,5 MJ kg^{-1} was used, assuming part of the energy is mill residues with no additional energy input CARBON RELEASED/MJ: the amount of C released for each MJ of energy produced

All values for product storage should be treated as estimations from which only magnitudes can be taken. The same caution applies to the substitution effect which can be attained by utilizing wood instead of other materials or fossil fuels.

In spite of these limitations, the results presented here give an idea of the C-ecological role of forests and forest industries in a densely populated and highly industrialized country. A comprehensive version of this study containing more methodological details is published by BURSCHEL et al. 1993.

3. Results

3.1 THE FOREST AS STORE OF CARBON

The amount of C in the forests is the total sum of C stored in living biomass, dead biomass and soil. The estimations for each of these compartments as well as for the whole ecosystem are presented in table 2 .

Table 2: Carbon Pools and Net Carbon Increment in German Forests

Compartments		Stock		Increment
		10^6 t	%	10^6 t yr^{-1}
Living biomass	trees	888	36	5.5
	ground vegetation	10	0	0.0
Dead wood	snags and snails	2	0	0.0
	slash	30	1	0.0
Humus	litter	392	16	(1.0)
	soil organic matter	1174	47	
Forest ecosystems	**total**	**2496**	**100**	**5.5 (6.5)**

Accordingly 900 x 10^6 t C are stored in the living biomass of forests in the FRG. Most forests here are under sustained management, normally as compartmented high forest (i.e., compartment as management unit). These forests are in the aggradation phase of forest ecosystems. Although this phase is not as densely stocked as a mature natural forest, it is characterized by a high increment. This annual increment in German forests amounts to 57.5 x 10^6 m^3 (UNITED NATIONS 1986), only about 40 x 10^6 m^3 of which are harvested. So, approximately 17.5 x 10^6 m^3 of the increment remain in the forests contributing to C-storage and turning the forest into a C-sink. This sink effect may be even greater, since there are indications that the actual increment is higher than the estimation made in this study. But even our conservative estimates show that the forests in the FRG in their present state are an effective sink for C.

The amount of C stored as humus in the forest soil is considerably higher than in the living biomass. However, this reservoir of nearly 1.6 x 10^9 t of C is most probably in a fairly balanced state where input of fresh litter and decomposition are in equilibrium. Nevertheless, it is likely that there are soils which have not fully recovered from past devastative practices and are still rebuilding to a formerly larger humus body. The magnitude of this process is roughly estimated to be 0.1 t ha^{-1} yr^{-1} corresponding about 1 x 10^6 t yr^{-1}.

Even if humus is viewed as a fairly static reservoir in this study, it must be given careful consideration for two reasons: First, should temperatures rise markedly, the conditions for the decomposition of organic matter would improve to such an extent that a release of CO_2 could result from this huge reservoir turning it into a potent C-source. Second, if the present amount of humus is not in equilibrium but accumulating C more rapidly than assumed here, the sink-effect would be accordingly higher. A large accumulation however is not possible, since the total annual addition of fresh organic matter (litter) only amounts to between 2 and 4 t ha^{-1} (MOSANDL 1991) of which half is C, and of which almost all eventually gets mineralized (mostly to CO_2) through natural decomposition processes. Therefore it appears reasonable to accept the forest soils as having a more or less neutral role in C-cycle, although they are huge C-pools. However, observation of its behavior through a systematic monitoring is important because it not only may act as moderate sink of C, as is assumed here, but also can turn into a strong source.

The contribution of the dead biomass to the total C-storage of the forests is very small compared with the other two components. Dead wood and harvest residues together make up only 1.3 % of the total amount of 2496 x 10^6 t.

Finally it can be summarized that the German forests presently act as an annual sink of about 5.5 to 6.5 x 10^6 t C.

3.2 WOOD PRODUCTS AS STORE OF CARBON

The C remains fixed in the wood until it is released by decomposition or combustion. For their duration-time timber products lengthen the storage effect of the forests, therefore they have to be taken into consideration for a comprehensive estimation of the total effect of forests and forestry for the C-budget.

In Germany 28 % of the harvested wood is used for construction wood, 19 % for furnitures and other products, 28 % for paper and packing (CMA, 1987). Based on mean durations of 65, 15 and 1 yr for these categories, the existing C-stock in timber products was calculated as shown in table 3. With a total of 128 x 10^6 t C-storage in products represents about 15 % of the C stored in the trees.

The estimated product storage of 1.6 to 1.7 t C per capita is significantly less than the 2.1 t which BRAMRYD 1982 has calculated for highly industrialized countries. The difference is mainly due to his evaluation being based on data from Scandinavia and the USA, where the quota of construction wood as a long-term store is significantly higher than in Central Europe.

Table 3: Carbon Storage in Wood Products in Germany.

Product group	stock	annual increase
	10^6 t C	
Construction wood	89	1.0
Furnitures, other wood products	34	0.1
Paper, packing, fuel wood	5	0.0
Sum	**128**	**1.1**

Because of a continuous increase of buildings in the Federal Republic of Germany, this storage represents a C-sink. The magnitude of the sink-effect has been assumed to be 1 x 10^6 t C yr^{-1} annually. Considering the total emissions in Germany, the magnitude of the sink-effect appears to be low. Nevertheless, there can be no doubt that any utilization of wood for long lasting purposes is advantageous as far as C-ecology is concerned.

3.3 WOOD AS SUBSTITUTE FOR OTHER MATERIALS

3.3.1 Wood as raw material of low energy-input

Considering economic activities not only in commercial terms but also in terms of C-ecology, wood has favorable characteristics, since sustained management of forests in Central Europe, which closely follows natural processes - no soil treatment, no herbicids, no fertilizing, no tree breeding -, requires an extremely low energy-input. And timber processing is relatively little energy-dependent too. Since energy-input is linked with release of CO_2, utilization of wood in place of materials which demand higher energy-inputs results in a considerable mitigation of CO_2 emissions.

While C-storage in wooden products eventually reaches a maximum, mitigation of emission by the use of wood instead of other materials is permanent: Emissions once avoided for a given purpose are permanently avoided (fig. 1). In these calculations, although only the stemwood utilized for construction purposes was considered, the annual mitigation-effect has been estimated at 2.6 x 10^6 t (table 4).

Table 4: CO_2-mitigation (10^6 t C) by Use of Wood in Germany

Item	Stock	Annual increase
Storage	128	1.1
Material substitution	--	2.6
Energy substitution	--	1.4
Sum	**128**	**5.1**

3.3.2 Wood as energy source

By using wood as energy source, burning of fossil fuels can be avoided. Presently, wood as a source of energy in Germany is mainly burning of industrial waste; heating of residential buildings plays a minor role. However, even then the effect of this substitution is in the range of 1.4 x 10^6 t C (table 4). As in the case of material-substitution, this effect has no maximum (as does storage in forests and products) but is cumulative.

3.4 POTENTIALS FOR STRENGTHENING THE ROLE OF FORESTS FOR CO_2-MITIGATION

The C-budget data presented refer to the actual situation and demonstrate the "business as usual" state. However, there are significant possibilities to further influence the CO_2-mitigation capacity. These possibilities have been compiled in table 5 and are explained below.

3.4.1 Silivicultural measures in existing forests

3.4.1.1 Lengthening of rotation period

Lengthening of rotation periods in managed forests increases the accumulated timber volume per unit area. A similar effect can be achieved in selection forests by increasing the final harvesting diameter (SMITH, 1962). The effect of these changes in German forests has been calculated for three fairly realistic options (table 5) as follows:

Actual situation:

Actual management will be continued and the number of hectares currently in each of the older classes is maintained by harvesting an appropriate number of hectares in these age classes every year.

Medium Option:

The distribution of age classes in private and corporative forests is allowed to reach the distribution of state owned forests in western Germany. This option increases the rotation period for those forests which currently have comparatively short periods of production.

Maximum Option:

An overall lengthening of rotations in all forests was assumed, with the limitation that some stands will be destroyed in catastrophic storms and that some regeneration cutting will have to be made because of general silvicultural requirements (details ref. to BURSCHEL et al. 1993).

As was to be expected, the present timber volume and, accordingly, the C in forests can be considerably increased. By lengthening the rotation period by two decades, an additional 0.7 to 1.8 x 10^6 t C can be fixed annually. However, this effect will be reduced when considered for time periods longer than 20 yrs because of the actual age class distribution. In fact the effect is even reversed for the time period between 40 and 60 yrs.

However, the increase of the average standing volume in German forests by lengthening the rotation periods will only have a limited and transient effect on CO_2-mitigation. The actual not absolutely regular age class distribution together with the reduction of storage in products and substitution effects resulting from a decreased timber harvest partially compensate the increase of standing volume.

3.4.1.2 Spacing, thinning, fertilization

Traditionally German forests are densely stocked, with respect to risks like storm and snow they often can be considered as overdense. Therefore changes in spacing of plantations or decrease of thinning activities cannot be considered as means for an improved C-fixation.

Fertilization never has played an important role in German forestry. Nowadays it is even considered undesirable for ecological reasons (except for liming to compensate acidic immissions). Therefore fertilizing was not included as a means to increase the storage or productive capacity of forests here.

Table 5: Options of CO_2-Mitigation by Forestry in Germany (all values 10^6 t C)

Period (yrs)	**20**		**40**		**60**	
Options in existing forests						
Lengthening of rotation periods						
actual situation	85.1		160.4		226.1	
medium option	99.8	*+14.7*	163.4	*+3.0*	209.5	*-16.6*
maximum option	120.2	*+35.1*	179.2	*+18.8*	181.4	*-44.7*
Underplanting						
0.5 x 10^6 ha yr^{-1} in 20 yrs	0.2		1.7		6.0	
Substitution of Scots pine by Douglas Fir						
10.000 ha yr^{-1}	1.5		5.0		9.2	
5.000 ha yr^{-1}	0.7		2.5		4.6	
Afforestations						
Real model						
5.200 ha yr^{-1}	1.3		5.3		13.2	
Eco model						
1.2 x 10^6 ha in 20 yrs	15.9		63.6		137.9	
0.655 x 10^6 ha shelter belts	4.2	*+18.8*	25.4	*+ 83.7*	51.9	*+176.6*
Maximum model						
4.5 x 10^6 ha in 20 yrs	92.8		323.4		673.3	
0.5 x 10^6 ha energy plantations	15.5	*+107.0*	46.5	*+364.6*	77.5	*+737.6*
Increased use of wood as fuel						
1. step: 1.4 x 10^6 t wood waste, 3.1 x 10^6 t thinning material	26.0		52.0		78.0	
2. step: wood waste, thinning material, 5.3 x 10^6 t slash	54.0		108.0		162.0	
All options						
medium - sum	**61.2**		**145.4**		**253.2**	
- per yr	**3.1**		**3.6**		**4.2**	
maximum - sum	**197.0**		**495.6**		**865.5**	
- per yr	**9.9**		**12.4**		**14.4**	

Italic and underlined = differences to "actual situation" resp. "real model"

Nevertheless it has to be repeated what was already mentioned in chapter 3.1: there is a profound increase of productivity of forests occuring. It is a consequence of three elements:

- recovery of sites after hundreds of years of degradation by misuse
- immission of considerable amounts of nitrogen, emitted by technical processes and agriculture
- increase of CO_2-content of the air.

These elements are not included in the range of silvicultural measures discussed here, but show up in the annual increment and mitigation estimate stated for the German forests in table 2.

3.4.1.3 Underplanting

The effect of CO_2-mitigation by forests can also be enhanced by underplanting of forests with shade-tolerant tree species. This option was evaluated for large scale underplanting of Scots Pine with European Beech. For this purpose it was assumed that during the course of 20 yrs, 0.5 x 10^6 ha of pine stands on better sites could be treated in this manner. However, an increased C storage will become effective only on a long-term basis. Over a time-period of 40 yrs the approximate rate of C-accumulation would amount annually to 40 000 t ha^{-1}. By age 60 this value would rise up to 100 000 t. This procedure of underplanting already occurs to a small degree for silvicultural, ecological and economic reasons. The motivating aspects of CO_2-mitigation may further accelerate this practice.

3.4.1.4 Substituting Scots Pine by Douglas Fir

Fast growing exotic species are often considered as alternatives for the regeneration of forests in place of less productive but native ones. Worldwide estimations of C-fixation by forests are often based on such tree species. In Central Europe a higher C-storage could be achieved if western north american Douglas Fir replaces native conifers. Due to its considerably faster growth and higher wood density the effective C-fixation rate by this species would be almost 50 % above that of Norway Spruce stands.

The results presented in table 5 are based on a conversion rate of Scots Pine stands on better sites to Douglas Fir stands such that 6 % of the total forest area would be converted within 60 yrs. A higher proportion of this species is not considered realistic because of stand stability problems and lack of acceptance among people. Based on this conversion rate an additional annual CO_2-mitigation of roughly 1.5 x 10^5 t C can be achieved, a value which would clearly increase with the increase in age. This mitigation does not represent the total growth of Douglas Fir stands but the additional effective CO_2-mitigation compared to the replaced Scots Pine .

3.4.2 *Afforestation of non-forest areas*

Afforestation of farm lands in Central Europe is gaining importance. The primary, political objective is to reduce surplus agricultural production. However, little is known about the effect on C-ecology which results from afforestation of such land. The area available for this purpose is under debate. In this investigation three options were developed and calculated:

Real model:

The rate of afforestation remains at its low actual level: 5 200 ha yr^{-1} (Spruce 50 %; Beech 20 %; Douglas Fir 20 %; Oak 10 %)

Eco model:

a) Afforestation is supposed to be realized on an area of 1.2 x 10^6 ha within 20 yrs (Beech 40 %; Spruce 30 %; Oak 20 %; Douglas Fir 10 %).

b) In addition on 0.65 x 10^6 ha hedges and shelterbelts will be established exclusively with broadleafed species which can be managed as coppice forests for fuel wood production.

Maximum model

a) 3.85 x 10^6 ha are afforested (Douglas Fir 40 %; Spruce 40 %; Beech 20 %) within 20 yrs

b) 0.65 x 10^6 ha of hedges and shelterbelts are established within the same time.

c) 0.5 x 10^6 ha energy plantations of fast growing broadleafed species with a rotation of 10 yrs are to be created within two decades. For these plantations a production of 12 t of dry matter per year was considered realistic.

The first option is to maintain the actual afforestation rate. Even if continued for 60 years and finally covering an area of 3 x 10^5 ha, afforestations of this type would result an annual sink of only 2.2 x 10^5 t of C.

If really significant efforts should be made in the shortest possible time - as assumed by second option - a considerable effect can be achieved. This option which is feasible and in many regards ecologically advantageous, results in annual C-storage of 1 x 10^6 t during the initial 20 yr phase of afforestation. By 60 yrs this value would increase to 3 x 10^6 t, including substitution effects.

The maximum option requires a great but feasible effort in the first two decades, but an annual 5.5 x 10^6 t C could be stored or their emission as CO_2 mitigated. For a time-period of 60 yrs this amount would equal 12.3 x 10^6 t yr^{-1} considering both storage and substitution effect. With an increased duration of this growing stock, this value would increase continuously.

Afforestation in Central Europe represents a major possibility for the mitigation of CO_2-emissions. Depending on the option considered, the annual magnitude of this fixation during the establishment phase of two decades would range between 1 to 5.5 x 10^6 t, whereas the amounts estimated for 60-yrs would range between 3 and 12 x 10^6 t. Therefore this possibility is clearly more effective than all measures which can be taken in already existing forests.

3.4.3 Greater use of wood as fuel

The use of wood as fuel is not exploited to the extent that is theoretically possible. This is principaly due to low prices of fossil fuels. There are considerable amounts of wood which could be used as energy sources with a corresponding potential to prevent CO_2 to be emitted from fossil fuels. Two options for greater exploitation of this potential are presented in table 5.

A conservative option - called *first step* in table 5 - considers a more complete use of wood waste, resulting p.e. from demolition of houses, and an increased amount of thinning material to be used as energy source. This would produce an annual CO_2-mitigation effect of approximately 1.3 x 10^6 t C. The *second step* option assumes that additionally wood currently remaining as slash on the forest floor could be utilized for the same purpose, amounting to approximately 2.7 x 10^6 t yr^{-1}.

3.5 The role of forests and forestry in the C budget

The results of this investigation about the role of forests and forestry for C-ecology are condensed in table 6. All the data refer to annual storage or substitution values expressing the respective CO_2-mitigation.

The highest estimate corresponds to 10 % of annual emissions, which in 1988 amounted to 272 x 10^6 t C for the Federal Republic of Germany and the German Democratic Republic (Boden et al., 1990). Since the mining of lignite in eastern Germany has been considerably reduced, the actual magnitude of emissions in Germany may not be over 250 x 10^6 t yr^{-1}.

Table 6: Forests and Forestry as C-Sinks

Item	Minimum	Maximum
	10^6 t C yr^{-1}	
Forests	5.5	6.5
Wood utilization	5.1	5.1
Intensification of forestry	4.2	14.4
Sum	**14.8**	**27.0**

Two characteristics of the presented data have to be kept in mind:

- The current sink-effects are given for both the forest and wood utilization. The storage in forests continues as a sink of C as long as increment exceeds timber harvesting. Wood utilization however, can clearly be expanded if more timber is harvested. In this way, biological increment would be fully processed and accordingly the sink-effect shifted from forest storage to product storage as well as to material and energy substitution.

- The intensification and extension of forestry instead represent a possibility, and consequently a potential yet to be developed, but could attain a considerable magnitude of CO_2-mitigation even in a densely populated and highly industrialized but small country.

4. Discussion

To evaluate the significance of forests and forestry in the C budget, the total CO_2-emission of anthropogenic origin in the investigated area must be considered. Approximately 250 x 10^6 t C yr^{-1} produced on a land area of 36 x 10^6 ha reflects a very high density of 7 t ha^{-1} yr^{-1}. If these emissions are considered only for the forested area of 10 x 10^6 ha, above density increases to 25 t ha^{-1} yr^{1}. These data clearly show that on a land area equivalent to that of the Federal Republic of Germany, the mitigation of an emission of this range is absolutely ruled out. Even if the whole of Germany would support a forest cover, and storage as well as the additional substitution effects amount to 3 t ha^{-1} yr^{-1} - a value, reasonably attainable by afforestation on farm lands - a maximum of 100 x 10^6 t yr^{-1} storage capacity could be attained. On the present forest area it would amount to only 30 x 10^6 t yr^{-1}. So, forestry and timber industries although contributing towards the mitigation of the CO_2-problem, under no circumstances would represent its national solution. According to estimates presented here the possible CO_2-mitigation rate would range between 15 to 27 x 10^6 t C yr^{-1}, which corresponds to 6 to 10 % of the emissions.

The actual accumulation of additional biomass in existing forests and reduction of emissions through timber utilization are producing mitigation effects which are already occurring. A further effect of up to 14 x 10^6 t C yr^{-1} could be achieved by intensification of forestry. These estimates, however, do not consider the C-ecological potential of an extended use of timber for construction purposes and an increased production of long lasting wood products. At present the magnitude of a generally increased use of timber is difficult to estimate. Considering in addition, that all compilations concerning the mitigation effect of afforestations are made on the basis of low estimates, the figures presented can be taken as conservative.

Table 7 : Most important Potentials of CO_2-Mitigation by German Industry shown on the Basis of Branches with highest Energy Consumption (together 2/3 of Industrial Energy Consumption) (WIEHN, 1990)

Industry, energy consumption 1987 10^6 t coal equivalent/yr	Options	CO_2-mitigation potential 10^6 t C yr^{-1}
Iron and steel 20	Heat recovery from blast furnace and from slag; recovery of converter gas; warm and direct use of rolled steel in steel works	2.7
Chemistry 16	Cl-generation by diaphragm process; H_2-generation by helical coil reactor; NH_3-production by AMV process	1.4
Mining 6	Cement: Extern pre-calcining in furnaces; shortened rotary furnaces Bricks: improved supply air control; flue gas heat exchanger Lime: coke firing in ring shaft kiln; new type of wall up rotary furnaces	0.4
Non-ferrous metals 4	Al-production: Cathodes made of titanium boride;Al-chloride electrolysis after ALCOA	0.8
Pulp and paper 4	Pulp production by continuous boiling processes; new bleaching methods; improved paper dehydrating	< 0.3
	Sum	**≈ 5.6**

The significance of the potential of mitigation becomes obvious if compared with corresponding ones of the industry (table 7). The figures clearly indicate that mitigation potentials of German industry are estimated to be considerably lower than the ones achievable by forestry. They even are below the potential represented by the afforestation of farm lands alone. Therefore, the role of forestry and timber industries can be considered as remarkably great.

One gets to a similar conclusion if the intention of the actual German government is considered to reduce national emissions by 30% until 2005. At the present there is no hint that such an ambituous goal can be reached. Probably it will already be considered a success if emissions will not increase. Here again the forestry options should be looked at as one realistic means to achieve progress in this matter.

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