CARBON ACCOUNTING AND COST ESTIMATION IN FORESTRY PROJECTS USING CO_2FIX V.3

THOMAS GROEN[1,2], GERT JAN NABUURS[2] and MART JAN SCHELHAAS[2]

[1]*Resource Ecology Group, Wageningen UR, Bornsesteeg 69, 6708 PD Wageningen, The Netherlands*
E-mail: thomas.groen@wur.nl
[2]*Alterra, P.O. Box 47, 6700 AA Wageningen, The Netherlands*

Abstract. Carbon and financial accounting of projects in the Land Use, Land-Use Change and Forestry sector is a topic of hot debate. Large uncertainty remains concerning the carbon dynamics, the way they should be accounted and the cost efficiency of the projects. Part of the uncertainty can be alleviated by standardisation and transparency of reporting methods. For this reason we further developed CO_2FIX, a forest ecosystem carbon model, with modules for carbon and financial accounting. The model is applied to four cases: 1) Joint implementation afforestation project in Romania, 2) Forest management project in Central Europe, 3) Reduced impact logging possibly under the Clean Development Mechanism (CDM) in the future, and 4) Afforestation with native species under the Clean Development Mechanism. The results show the wide applicability of CO_2FIX, from degrading grasslands as baseline cases to multiple cohort forest ecosystems. Also the results show that Forest Management in the European case can generate considerable amounts of carbon emission reductions. Further, the results show that although reduced impact logging is not yet an allowed option under the Clean Development Mechanism, it shows promising results in that it is 1) very cost effective, 2) seems to be able to generate intermediate amounts of credits and 3) seems to us as a project type that is not prone to leakage issues. These results are yet another indication to seriously consider reduced impact logging as an eligible measure under the CDM.

1. Introduction

The terrestrial biosphere inherently shows large temporal dynamics: long periods of build up of biomass (in peat lands, forests, grassland, soils, etc.) alternate with often much shorter periods of net breakdown. The latter can be caused by natural mortality, natural disturbances or human induced harvesting. These temporal dynamics are visible as spatial variation of vegetation patches in the landscape. Within this frame of large temporal and spatial variations, policy makers have agreed to reduce anthropogenic emissions of greenhouse gases of industrialised countries by on average 5.2% by 2008–2012 compared to their 1990 emissions (Conference of the Parties 3, United Nations Framework Convention for Climatic Change UNFCCC, 1997). In order to achieve part of this reduction, the industrialised countries may use some options in the Land Use, Land-Use Change and Forestry sector (LULUCF) either inside their own borders (Art 3.3, 3.4 and 6) or outside in the non-industrialised countries (Art 12; Clean Development Mechanism (CDM)).

However, the accounting of carbon credits derived from LULUCF projects has given rise to fierce political discussions (UNFCCC, 2002a). A topic that is recently

Climatic Change (2006) 74: 269–288
DOI: 10.1007/s10584-006-1827-z

decided upon is the way carbon credits gained from CDM Afforestation and Reforestation (CDM-AR) should be accounted (UNFCCC, 2003). There are two options available for CDM-AR projects, and logically the chosen method will have an effect on the amount of merchantable certified emission reductions (CERs). Therefore, the chosen method may have a large impact on the feasibility of projects.

Next to the effect of CERs calculation on the feasibility of projects, the way in which cost efficiency is calculated has an effect as well. Many financial data presented in literature are calculated with different methods concerning this cost efficiency. This makes comparison of projects difficult (Boscolo et al., 1998).

A uniform way to calculate C-fluxes, production of CERs and cost effectiveness estimations can therefore help in clarifying the feasibility of different carbon reduction projects in the LULUCF domain. A good basis was found in CO_2FIX. The model CO_2FIX is a multi-cohort forest carbon flux calculation model (Nabuurs et al., 2002).

The aim of this study was therefore threefold:

1. To broadly discuss the topics of importance under the Kyoto protocol that affect the calculation of carbon credits, and that were used as guides in the design of the CO_2FIX V.3.
2. To further develop the CO_2FIX model with modules for carbon and financial accounting. In this way, a uniform method for calculating carbon fluxes in project cases and baselines, CERs generated by the projects and the costs invested per CER becomes available, allowing comparison of projects, and
3. To assess cost efficiency for four realistic forest cases: a) Joint Implementation Afforestation project in Romania (JI-A); b) Forest management project in Central Europe (FM); c) Reduced impact logging (possibly in the future) under the Clean Development Mechanism (CDM-RIL); and d) Afforestation with native species under the Clean Development Mechanism (CDM-A).

2. Accounting for LULUCF, the Kyoto Protocol Context

Under article 3.3 of the kyoto protocol (KP) it is agreed that Annex I countries can use "*net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation (ARD) since 1990*" (UNFCCC, 1997), to meet their commitment to the KP. Later, in the Bonn agreements of 2001, it was agreed *that "forest management (FM), cropland management (CM), grazing land management (GM) and revegetation (RV) are eligible land-use, land-use change and forestry activities under Article 3, paragraph 4, of the Kyoto Protocol*" (UNFCCC, 2001). For agricultural activities (i.e. CM, GM and RV*) "application of net-net accounting (net emissions or removals over the commitment period less net removals in the base year, times five)*" is required for the first commitment period.

TABLE I
Overview of accounting rules under the KP

	Baseline	Net-net	Exclusion of carbon in wood products
ARD			X
FM			X
CM, GM and RV		X[a]	X
JI	X		X
CDM-AR[b]	X		X

[a]Only for the first commitment period (2008–2012).
[b]For the first commitment period, only afforestation and reforestation are allowed for Clean Development Mechanism projects under Article 12 (LULUCF) of the Kyoto protocol.

For Forest management a National level maximum is set (a CAP as described in Annex Z of the KP).

Article 6 of the KP allows Annex I countries to "*transfer to or, acquire from, any other such party reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing anthropogenic removals by sinks of greenhouse gases in any sector of the economy, provided that (. . .. . .) any such project provides a reduction in emissions by sources, or an enhancement of removals by sinks, that is additional to any that would otherwise occur*" (UNFCCC, 1997). In other words, this so-called joint implementation (JI) of projects requires that a baseline is subtracted (Table I).

Article 12 allows Annex I countries to acquire certified Emission Reduction Units (ERUs) from non-Annex I countries, the so-called Clean Development Mechanism. Provided that projects are "*additional to any that would occur in the absence of the certified project activity*" (UNFCCC, 1997), thus requiring a baseline scenario as well. According to the Bonn agreement (UNFCCC, 2001) "*the eligibility of LULUCF activities under Article 12 is limited to afforestation and reforestation (AR)*". In order to prevent liability problems with possible emission of carbon that was sequestered under the CDM mechanism, ERUs earned or purchased under the CDM mechanism are only temporarily valid and are called certified emission reductions. CERs issued under the CDM can be purchased in two forms: Long-term CERs (lCERs) that are valid until the end of the project crediting period and Temporary CERs (tCERs) that are valid from the time of issuance to the end of the next commitment period (usually 5 years) (UNFCCC, 2004).

Finally, in the Marrakech accords it was decided that changes in the following carbon pools shall be accounted: above-ground biomass, below-ground biomass, litter, dead wood and soil organic carbon (UNFCCC, 2002b). This means that carbon stored in wood products has to be excluded from carbon accounting calculations.

3. Methods

The basic C-flux calculation of CO_2FIX V.2 is conceptually described in Masera et al. (2003) and Nabuurs et al. (2002). Therefore, this paper describes only the carbon and financial accounting calculations that are newly introduced in the model. A more detailed description can be found in Schelhaas et al. (2004).

We leave the discounting of credits outside consideration, as it goes beyond the scope of this paper. However, it is an important topic in the debate of how to calculate carbon credits (Fearnside et al., 2000; Moura Costa and Wilson, 2000). Therefore, it is important to mention that within CO_2FIX V.3 specification of a discounting rate for carbon credits is included as a possibility. For a good overview and discussion on the application of discounting rates we refer to Hoen and Solberg (1995).

3.1. APPROACHES FOR CARBON ACCOUNTING

Two approaches for carbon accounting are used in this study, stock change and merchantable certified emission reductions. The latter is used for trading between Annex I countries and non-Annex I countries, while the former is common in making carbon balances for national budgets and JI projects.

3.1.1. *Stock Change Approach*

The stock change calculates the difference between the stocks of carbon in year t minus the stock in year $(t - 1)$. In formula:

$$C_{\text{credit},t} = C_t - C_{t-1} \tag{1}$$

where $C_{\text{credit},t}$ is the amount of carbon credits at year t and C_t is the stock of carbon at year t. In real life projects, credits will be issued during a so-called 'crediting period'; an agreed upon period of time during which the project continues and the carbon is sequestered. The amount of credits that can be obtained then becomes the difference between the start year of that period (or base year, t_b) and the last year of that period where crediting is carried out (or crediting year, t_c). In formula:

$$C_{\text{credit},t_c} = C_{t_c} - C_{t_b} \tag{2}$$

In case a baseline is applied, the amount of carbon sequestered according to this baseline has to be subtracted as well (Figure 1).

There are a number of disadvantages with the stock change approach. The main disadvantage of the stock change approach is that it does not account for possible future emissions through forestry management, or disturbances outside the project time period. For Annex I countries under the Kyoto protocol, the latter point is not a problem, because these countries will be held eligible for emissions at the appropriate point in time. However countries other than Annex I countries do not

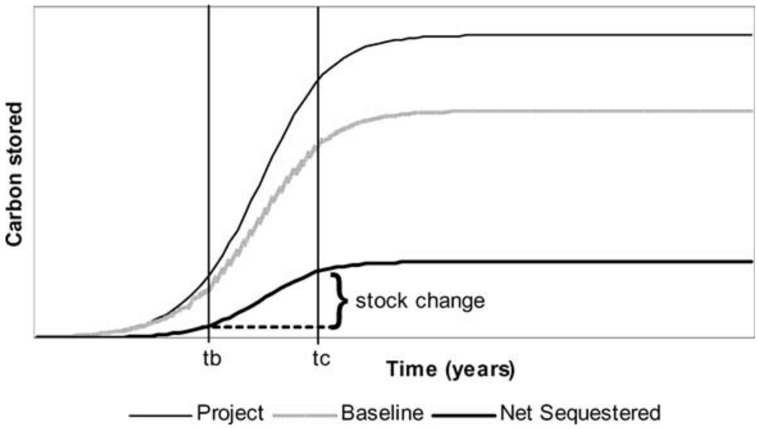

Figure 1. A visual example of carbon stocks in a CDM-AR project and baseline, the difference between the two and the calculation of the amount of credits according to the stock change approach.

have an emission reduction target, and therefore do not have to account for possible future emissions in land-use changes. Here a conflict appears. Annex I countries obtaining carbon sequestration credits from non-Annex I countries using the stock change approach for afforestation and reforestation in CDM projects, will not be held eligible for the possible future emission of the same carbon that the credits are obtained over. To avoid this problem alternative approaches are proposed. Under the UNFCCC, two purchasing methods have now been selected, temporary CERs and long-term CERs (FCCC/CP/2003/6/Add.2).

3.1.2. *Temporary Certified Emission Reductions*

A temporary CER or tCER is a certified emission reduction (CER = 1 Mg of CO_2e) issued for an afforestation or reforestation project activity under the CDM that expires at the end of the commitment period following the one during which it was issued. A tCER can be used only in the commitment period for which it was issued. When it expires, its buyer must replace it in full. The amount of tCERs that can be earned at each verification is equal to the amount of sequestered CO_2 at that moment, taking into account the baseline scenario (Figure 2).

3.1.3. *Long-Term Certified Emission Reductions*

A long-term CER or lCER is a certified emission reduction issued for an afforestation or reforestation project activity under the CDM, which expires at the end of the crediting period of the afforestation or reforestation project activity for which it was issued. The amount of credits that can be earned at the first verification is equal to the amount of tCERs at that moment, but they will be valid during the whole crediting period. The amount of credits at subsequent verifications is therefore equal to the amount of CO_2 sequestered since the last verification. If for example a logging is planned during the crediting period, the amount of sequestered carbon

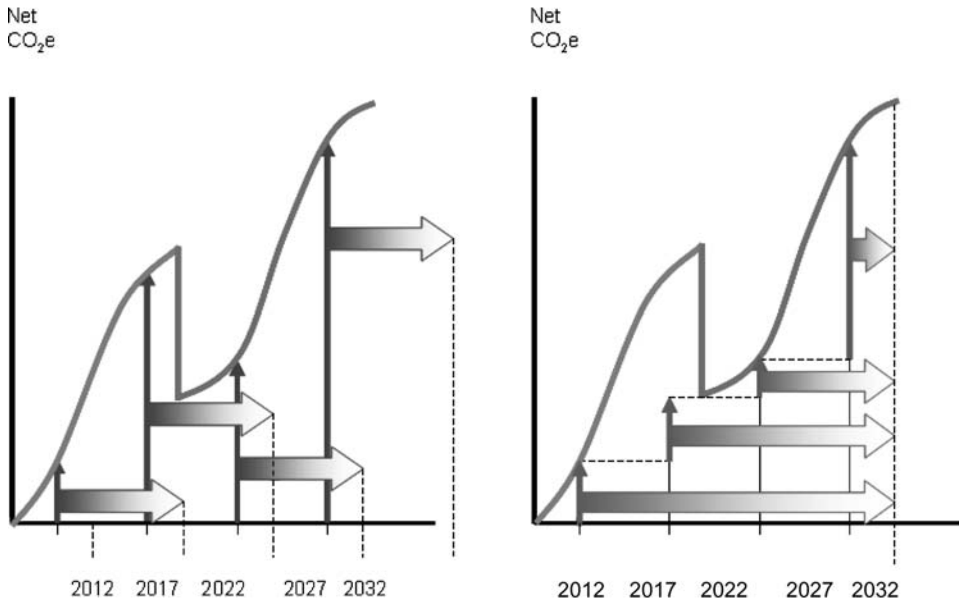

Figure 2. The way of quantifying tCERs (*left*) and lCERs (*right*). The tCERS are simply the stock of carbon at a certain point in time. They stay valid for 5 years. In case of lCERs the additional amount of carbon is assessed compared to the lCERS that were issued the previous time. In the case as depicted here (without reversal) any loss of carbon in the future is taken into account (after Locatelli, B. and Pedroni, L.: in press, 'Accounting Methods for Carbon Credits: Impacts on the Minimum Size of CDM Forestry Projects', *Clim. Pol.*).

will temporarily decrease. In that case, the project owner may choose to sell those credits for a lower price, since their lifetime will be shorter than the actual crediting period. Another option is not to sell these credits at all (lCERs without reversal, see Figure 2). In this study, we used the latter option.

3.2. METHODS FOR FINANCIAL CALCULATIONS

Costs like site preparation, planting, thinning and harvesting can be specified, either as recurring every year, or as a fixed value for a year. The same applies for income from wood, tourism, etc.

CO_2FIX V.3 calculates the discounted costs and income, as well as the Net Present Value (NPV). Since income from carbon credits is not asked as an input, the NPV per carbon credit can be seen as the cost or benefit per credit. If the result of the case is a negative NPV, this can be seen as the costs per carbon credit (or CER) produced.

The calculation of the net costs and income balance (B_t) in a year is the sum of all costs made and benefits earned in that year. To calculate a balance over all years, the balances of each year have to be discounted to a common year, usually the base year of the project. The discounted balance ($B_{t,\text{discounted}}$) of costs of a year is its balance multiplied with a financial discount factor ($D_{F,t}$),

$$B_{t,\text{discounted}} = B_t D_{F,t} \quad (3)$$

where $D_{F,t}$ is calculated with:

$$D_{F,t} = \frac{1}{1+r_{F,1}} \frac{1}{1+r_{F,2}} \cdots \frac{1}{1+r_{F,t}} = \frac{D_{F,t-1}}{1+r_{F,t}} \quad (4)$$

in which $r_{F,t}$ is the financial discount rate specified for year t. The discount rate is not considered constant, but can be specified for each year, allowing a trend in discounting the costs.

The net present value of a forest in a given year t is obtained through summing the total amount of $B_{t,\text{discounted}}$ from the beginning of the project up to that year,

$$\text{NPV}_t = \sum_{t_b}^{t} B_{t,\text{discounted}} \quad (5)$$

4. Cases

Four case studies are presented based on different project types: 1) Joint Implementation afforestation project in Romania; 2) Forest management project in Central Europe; 3) Reduced impact logging under the Clean Development Mechanism; and 4) Afforestation with native species under the Clean Development Mechanism.

The first case is based on a real life project carried out in Romania in co-operation with the prototype carbon fund (PCF) (Brown et al., 2002). The other three cases are partly based on generic cases that were earlier presented by Masera et al. (2003).

4.1. AFFORESTATION IN ROMANIA

Case 1 is a monoculture of Robinia (*Robinia pseudoaccacia* L.) on degraded soils that were formerly used for agriculture. This case is based on a small part of a larger real life afforestation project that is currently carried out in Romania (Brown et al., 2002). Figures and practices presented in this paper were followed in the current parameterisation as good as possible (Giurgiu et al., 1973, Tables II and III). The real life case has a project duration of 30 years, but in this paper a total project life of 60 years will be assumed in order to harmonise this with the assumptions made for the parameters for accounting. A mortality of 2% per year is assumed for the first 10 years, which decreases after 10 years to 1%. Thinning took place at 6, 13, 20 and 30 years after the start of a rotation (Table II). No logging related mortality was

TABLE II
Overview of the parameters used for the Jointly Implemented afforestation case in Romania

Cohorts	Robinia			
Rotation (years)	30			
Initial carbon content of the soil (Mg C ha^{-1})	54			
Basic wood density (kg m^{-3})	737			
Carbon content (% of dry weight)	50			
	Year			
	6	13	20	30
Fraction removed during thinning or harvest	0.15	0.20	0.30	1
Financial benefits				
	Pulp logs	Saw logs	Fire wood	
Stumpage Robinia ($ m^{-3})	14	14	14	
Costs				
Planting of Robinia ($ ha^{-1})	1802			
Maintenance costs ($ ha^{-1} $year^{-1}$)	592			

assumed. Products are completely excluded from the carbon calculations. An initial soil carbon content of 54 Mg C ha^{-1} was assumed (Brown et al., 2002). Because this is a JI project (carbon credits are purchased by the prototype carbon fund) a baseline is required. Degrading grassland is simulated in the CO_2FIX V.3 program serving as a baseline with an NPP of 9 tonnes DM ha^{-1} $year^{-1}$ at the beginning, declining to 5.9 tonnes DM ha^{-1} $year^{-1}$ at the end of the simulation after 200 years. Sixty percent of the grass is harvested every year by grazing and turnover rates are 0.8 for foliage and 0.9 for roots. Costs and benefits are based on original project literature, but may deviate from the real life case due to interpolation from project scale costs to hectare scale costs and possible omissions of costs (Table II, Brown et al., 2002; Phillips, 2002). For revenues of harvested timber see Table II. Because wood is sold as stumpage, no harvesting costs are calculated. For soil weather data the site 'Bucharest' was used from http://www.worldclimate.com.

4.2. Forest Management in Central Europe

Case 2 is based on a case presented earlier by Nabuurs and Mohren (1993) and Masera et al. (2003) that dealt with an even aged monoculture of Norway spruce (*Picea abies* L. Karst.) on a fertile site in the middle mountain regions in Central Europe. This case is now extended with 'forest management', i.e. it is assumed that through management, the increment has increased and that instead of a clearcut after

TABLE III

Stem volume increment rates for different species used in the JI-Romania and FM Europe cases. In the latter case, the increments are multiplied with competition factors in the project scenario to take into account that it is a mixed stand where each species comprises about half of the stand

Robinia		Norway spruce		Beech	
Age (year)	Stem current annual volume increment (m^3 ha^{-1} $year^{-1}$)	Age (year)	Stem current annual volume increment (m^3 ha^{-1} $year^{-1}$)	Simulation year	Stem current annual volume increment (m^3 ha^{-1} $year^{-1}$)
5	2.70	0	0.5	45	1
10	7.09	10	8	55	2
15	8.89	20	20	60	7
20	10.42	25	21	65	8.4
25	10.69	30	21.5	70	11.4
30	10.09	35	22	75	12.4
		40	21.5	80	13
		45	20	85	13.4
		50	20	90	13.4
		55	18	95	13.4
		60	18	100	13.2
		65	17	105	13
		70	16	110	12.4
		75	16	115	12
		80	14.6	120	11.4
		85	14.4	125	11
		90	13.8	130	10.4
		95	13.2	135	9.6
		100	12.6	140	9.2
		105	12.1	145	8.4
		110	11.6	150	7.8
		115	11	155	7.4
		120	10.6	160	6.8
		140	8	165	6.6

95 years, regeneration of beech (*Fagus sylvatica* L.) is stimulated when Norway spruce has reached an age of 45 years, resulting in a mixed stand of Norway spruce and beech. Selective logging is applied in this stand.

The harvesting regime of the spruce cohort is adjusted. The initial non-commercial thinning of 20% and the three follow up thinnings of 20% remain. However, no final logging is carried out, but four follow up thinnings of 15% of standing biomass follow until the year 200. The beech cohort is also thinned at year 140 with 20% and at year 200 with 30%. Products are completely excluded

TABLE IV
Overview of the parameters used for the Forest Management case in Central Europe

Cohorts	Norway spruce				Beech			
Rotation (year)	200				200			
Initial carbon content of the soil (Mg C ha^{-1})	91.3				0			
Basic wood density (kg m^{-3})	430				550			
Carbon content (% of dry weight)	50				50			
					Year			
Fraction removed during thinning or harvest	25	45	55	70	100	140	170	200
Norway spruce	0.2	0.2	0.2	0.2	0.15	0.15	0.15	0.15
Beech	–	–	–	–	–	0.2	–	0.3
Financial benefits								
	Pulp logs			Saw logs			Fire wood	
Stumpage Spruce ($ m^{-3})	15			70			5	
Stumpage Beech ($ m^{-3})	15			90			5	
Other returns (starting at year 1 increasing linearly up to year 200)					10–15			
Costs					Thinning year			
	25	45	55	70	100	140	170	200
Thinning costs of spruce ($ ha^{-1})	150	150	130	100	100	100	100	100
Thinning costs of Beech ($ ha^{-1})	–	–	–	–	–	200	–	200
		Spruce				Beech		
Planting costs ($ ha^{-1})		1137.7				400		
Maintenance costs ($ ha^{-1} $year^{-1}$)					300			

from the carbon calculations. Because it is a regular forest management project, no baseline is needed. For other parameter values see Tables III and IV (SBB, 2000; Hänninen, 2002).

Previous land use was assumed to be Norway spruce as well: thus the soil was initialised with 90 Mg C ha^{-1}, of which 10 Mg C coarse woody litter from logging slash. For soil weather data site Freiburg was used from http://www.worldclimate.com.

4.3. REDUCED IMPACT LOGGING UNDER THE CLEAN DEVELOPMENT MECHANISM

Case 3 is an option for a lowland wet tropical rainforest in Central America. The baseline is conventional (heavy) logging (CL) every 20 years, followed by

TABLE V
Stem volume increment rates for tropical species used in the Costa Rica cases

Tropical species	
Biomass/Max. biomass	Stem current net annual increment per cohort (m^3 ha^{-1} $year^{-1}$)
0.00	0.1
0.25	4.0
0.40	3.5
0.60	2.0
1.00	0.01

further degradation. Under the project scenario, reduced impact logging is applied to the area. It is realised that this type of management is not eligible under the CDM yet. However, RIL may be accepted in the future. Four cohorts are distinguished: 1) Traditionally commercial species; 2) Potentially commercial species; 3) Other species; 4) Pioneers. Cohorts 1, 2 and 3 used to be harvested at a 20-year cutting cycle. Growth in this forest is not specified in relation to age, but in relation to standing biomass (Table V, Masera et al., 2003). Growth data are from Camacho and Finegan (1997) and provide an NPP of around 4–5.5 tonnes C NPP at its maximum. Competition is important, and has a profound impact on the pioneer species in the forest (Table VI, and Masera et al., 2003).

Under the RIL scenario, the harvest at 40 and 60 years are left out. The relative amount of wood harvested is assumed to be lower, as well as the related management mortality. On average a higher roadside price for wood from the RIL project can be expected (\$200 versus 160 m^{-3}) because less wood is damaged. We work with rather high harvesting costs here, because roadside prices are used. No other costs or returns are expected. The soil carbon was initialised with a stock of 111 Mg C ha^{-1}. For soil weather data the site San Jose, Costa Rica was used from http://www.worldclimate.com.

4.4. AFFORESTATION WITH NATIVE SPECIES UNDER THE CLEAN DEVELOPMENT MECHANISM

Case 4 deals with the afforestation of an area in Central America that is currently used as a pasture. Initial grass NPP is 10 tonnes dry matter ha^{-1} $year^{-1}$. The site is degrading due to overgrazing, reduced litter input to the soil and subsequent loss of soil organic matter. The soil is initialised with 58 Mg C ha^{-1}.

TABLE VI
Overview of the parameters used for the CDM-RIL case in Costa Rica

Cohorts	Commercial species	Potentially commercial species	Other species	Pioneers
Initial carbon content of the soil ($Mg\,C\,ha^{-1}$)	36.5	31.2	33.2	10.6
Basic wood density ($kg\,m^{-3}$)	600	600	600	300
Carbon content (% of dry weight)	50	50	50	50

Conventional logging	Year				
	0	20	40	60	80
Fraction removed during thinning or harvest					
Pioneers	0.1	0	0	0	0
Commercial species	0.2	0.2	0.2	0.3	0.3
Potentially commercial species	0.3	0.2	0.2	0.2	0.3
Other species	0.2	0.2	0.3	0.3	0.4

Reduced impact logging	Year		
	0	20	80
Fraction removed during thinning or harvest			
Pioneers	0.1	0	0
Commercial species	0.1	0.15	0.15
Potentially commercial species	0.15	0.15	0.2
Other species	0	0.15	0.15

Financial benefits	Pulp logs	Saw logs	Fire wood
Roadside price (Pioneers) CL ($\$\ m^{-3}$)	0	0	0
Roadside price (Commercial) CL ($\$\ m^{-3}$)	15	160	2
Roadside price (Potentially commercial) CL ($\$\ m^{-3}$)	15	160	2
Roadside price (Other) CL ($\$\ m^{-3}$)	4	20	0
Roadside price (Pioneers) RIL ($\$\ m^{-3}$)	0	0	0
Roadside price (Commercial) RIL ($\$\ m^{-3}$)	15	200	2
Roadside price (Potentially commercial) RIL ($\$\ m^{-3}$)	15	200	2
Roadside price (Other) RIL ($\$\ m^{-3}$)	4	20	0

Costs	Thinning year				
	0	20	40	60	80
Thinning costs RIL ($\$\ ha^{-1}$)	752	406	0	0	673
Thinning costs CL ($\$\ ha^{-1}$)	1200	411	125	132	136

TABLE VII
Overview of the parameters used for the CDM-A case in Costa Rica

Cohorts	Commercial species	Potentially commercial species	Other species	Pioneers
Initial carbon content of the soil (Mg C ha^{-1})	14.7	14.7	14.7	14.7
Basic wood density (kg m^{-3})	600	600	600	300
Carbon content (% of dry weight)	50	50	50	50
	Initial planting costs	Yearly maintenance costs		
Costs ($ ha^{-1})	400	44		

The project scenario assumes an active reforestation with native species in four functional groups: 1) Traditionally commercial species; 2) Potentially commercial species; 3) Other species; and 4) Pioneers. No harvesting is carried out, the forest is left to its natural dynamics with some 2–3% natural mortality per year. The same growth rates are applied as in the CDM-RIL case (Table V). Costs data are from Boer (2001), and are estimated at $400 for initial establishment (in a landscape level scheme) and at $44 recurring annually (Table VII).

5. Results

Figures 3–6 show the results of the four presented cases.

Figure 3 shows the total carbon stock development (i.e. carbon in above-ground biomass, below-ground biomass, litter, dead wood and soil organic carbon) of the project scenarios and their baselines as such. Largest gains in carbon stocks on the long term are acquired in the FM Central Europe case where carbon stocks increase from 90 Mg C ha^{-1} in year 0 to 270 Mg C ha^{-1} in year 150. The JI case gains roughly 100 Mg C ha^{-1} over a time span of 200 years in the project case but fluctuates considerably, while the CDM afforestation case gains some 60 Mg C ha^{-1} after an initial loss of 20 Mg C ha^{-1} in the first 20 years. The project scenario in the CDM-RIL case (less logging and reduced impact logging) just manages to bring the biomass carbon stock back to its original value of $\pm$200 Mg C ha^{-1}.

The picture changes for three cases when taking into account the required discounting of baselines (for CDM-RIL, CDM-A and JI-A) (Figure 4). For FM Central Europe, the change is zero because a baseline does not have to be subtracted.[1] For FM, the net stock change over 200 years amounts to 160 Mg C ha^{-1}. The JI and CDM-A case roughly gain 89 respectively 73 Mg C ha^{-1}, comparable to the stock change mentioned above, because the baselines (grassland) show only a small

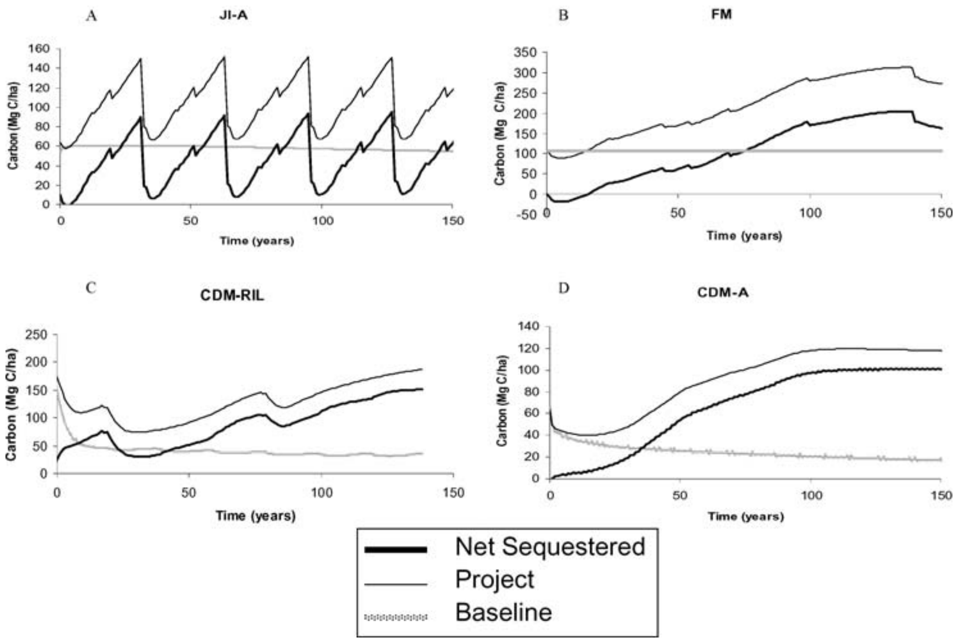

Figure 3. Carbon stock development for the project and baseline scenarios for the JI case in Romania (A), the FM case in Central Europe (B), the CDM-RIL case (C) and the CDM-A case (D).

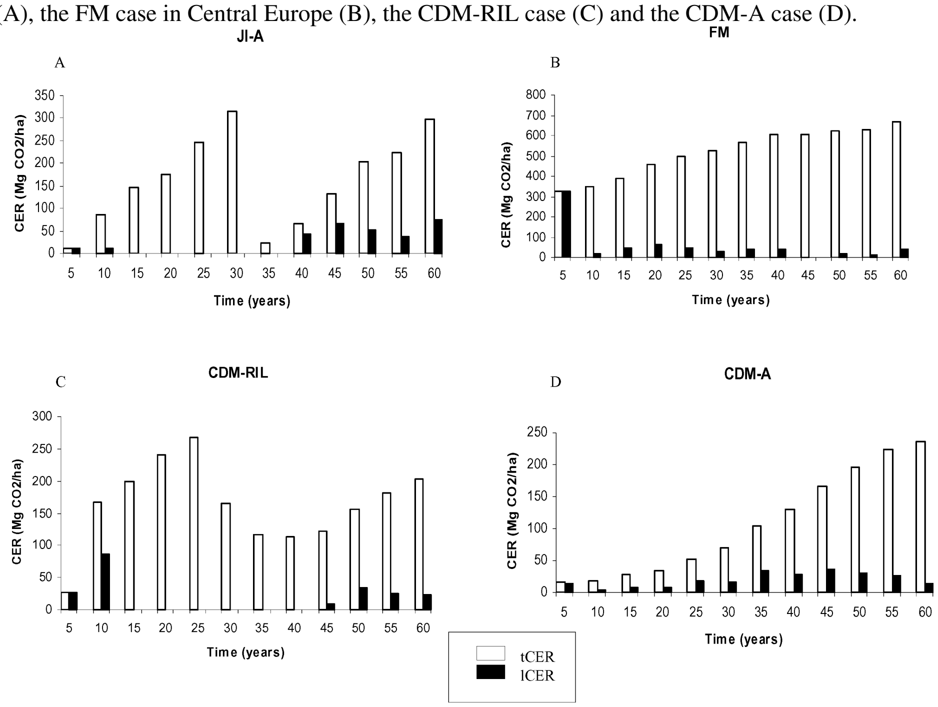

Figure 4. Development tCERs and lCERs of the project scenario minus the baseline scenario for the JI case in Romania (A), the FM case in Central Europe (B), the CDM-RIL case (C) and the CDM-A case (D).

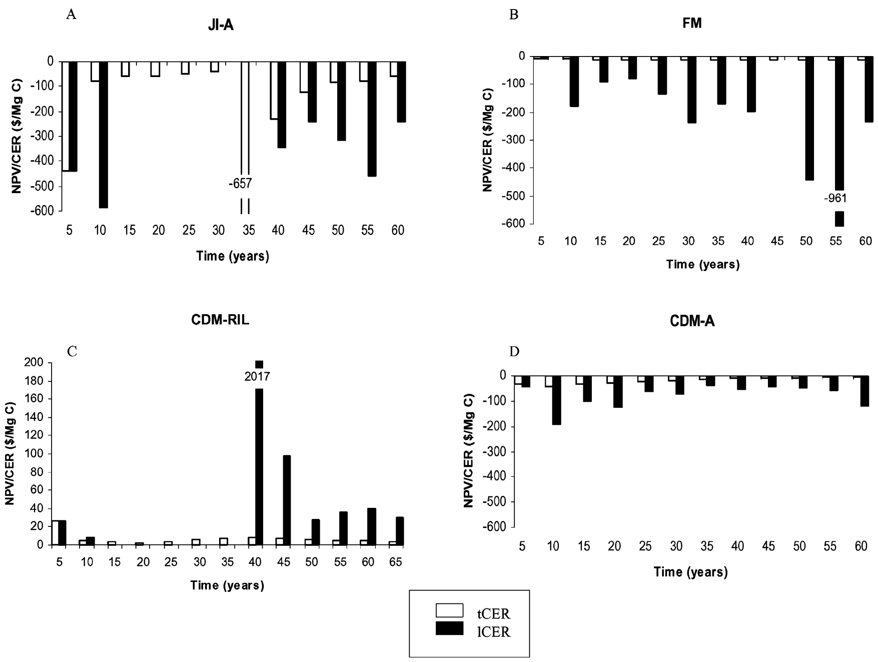

Figure 5. Development of NPV per tCER and lCER for the JI case in Romania (A), the FM case in Central Europe (B), the CDM-RIL case (C) and the CDM-A case (D). Negative NPV means that net costs must be made in order to sequester carbon.

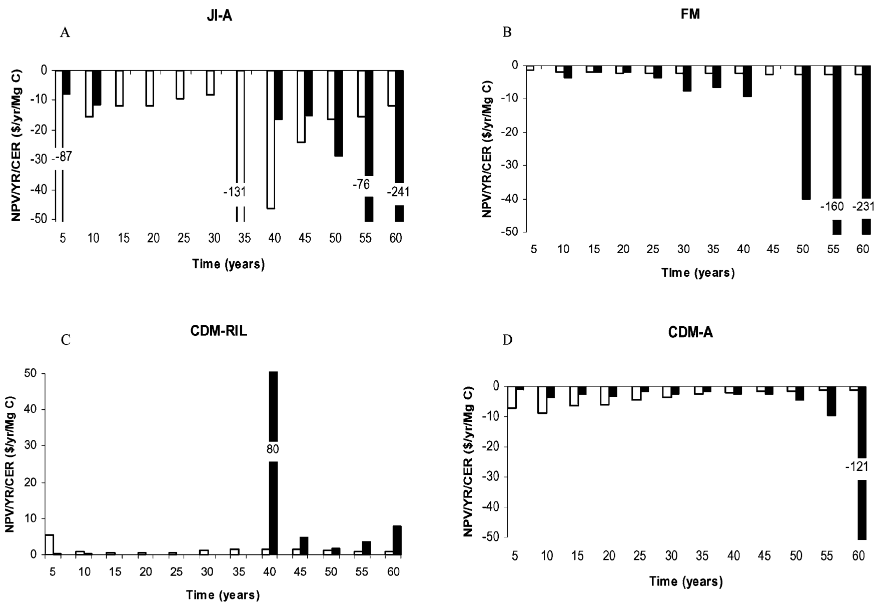

Figure 6. NPV per year that a CER is valid for the JI case in Romania (A), the FM case in Central Europe (B), the CDM-RIL case (C) and the CDM-A case (D). High values can be a result of either a short validity period of CERs or because high costs are made.

reduction in carbon stock in the soil which is counteracted by the discounting. A drastic change occurs for CDM-RIL, where a net gain of 138 Mg C ha^{-1} is simulated.

The impact of different CER accounting approaches on project feasibilities becomes clear from Figures 4–6. The tCER method obviously generates much more credits, as would be expected (Figure 4). Therefore, also expenses per CER are limited compared to the lCER method (Figure 5). The FM case clearly of all projects generates most tCERs while the CDM-A case yields relatively few tCERs, due to slow regeneration of the forest. The CDM-RIL and JI-A case both generate CER quantities in the same order of magnitude, although the increase in CERs in the CDM-RIL case increases quicker in the earlier years of the project compared to the JI-A case.

Some CER issuing periods, no lCERs are generated, compensating for a forecasted production of negative lCERs (i.e. a CO_2 emission from the ecosystem).

The NPV per CER (Figure 5) is negative in almost every case except for the CDM-RIL case. In other words, the CDM-RIL case is the only project that manages to create a profit already without selling any CERs, these generate only additional income for this projects.

From the perspective of CER buyers, not only the quantity but also the time the credits are valid is of importance, because expired credits have to be replaced in full. It would be useful therefore to have insight in how much money is minimally spend annually on CERs to compensate for one emission reduction unit. Figure 6 shows the NPV per year per CER for the different CER issuing periods for the different cases. As becomes clear from this view, although more tCERs are generated (Figure 4) and the minimal price per tCER is lower than for lCER (Figure 5), due to the longer lifetime of lCERs in the beginning of the project the latter seem cost less than tCERs after all.

6. Discussion and Conclusions

First of all, the results show the wide applicability of CO_2FIX V.3. Here it was applied to sites all over the world and from degrading grasslands to selective logging systems in the tropics. The modelling framework CO_2FIX V.3 allows the application to these sites and management systems. See for a validation of the model Masera et al. (2003), and for a sensitivity analysis Knippers et al. (in preparation).

The cases presented above have shown the wide applicability of the framework tool CO_2FIX V3. For both CER accounting approaches selected, the credits and cost efficiency were assessed excluding any build up of carbon in the wood products pool. It gives comparable results for different types of projects. This gives managers of carbon sequestration projects the tool to assess LULUCF projects in a standard way before they are actually implemented. Largest carbon stock increases (under the assumptions as made here) are gained in the FM system. However, most cost efficient is the CDM-RIL system, generating a positive NPV next to generating CERs. Uncertainty can be quite large in the CO_2FIX model. For the FM case in Central Europe (a case well documented) Knippers et al. (in preparation) calculated that the 95% confidence interval for carbon stock after 90 years amounted to $\pm 20\%$ already. Factors that can cause these uncertainties and that were taken into account in this study were stochasticity in the estimation of the model coefficients and measurement errors in the data or lack of data used for model construction (Knippers et al., in preparation). We are least certain about the soil development in the CDM RIL and CDM afforestation case. In the first case it was assumed that in the baseline (ongoing degradation) only trees continue to form the plant cover. In reality, a grass cover will develop, adding organic matter to the soil compartment. The same applies for the CDM afforestation case that shows a net loss in the project case compared to the base case until year 35 (Figure 4D, negative column in Figure 6). This is to a large extent because we did not parameterise a grass cover until the tree stand comes into closure. The soil compartment is also one of the largest uncertainties in the FM case, where a large extent of the credits is gained in the soil compartment. This is caused by the development of a considerable carbon stock in the dead wood pool (on average 62 Mg C ha^{-1}) in the second half of the simulation time.

Further, the financial cost and income data are quite uncertain, case specific and scale dependent. All costs were parameterised as if these 1-ha cases were part of a larger case. If one single hectare needed to be established, monitored, etc., then costs would be far higher at the hectare scale. Also, we worked with current prices for wood products, which may not be very realistic anymore after 30–50 years. The problems and uncertainties surrounding these projects were also noted by Van Vliet et al. (2003). They found a negative NPV of less than \$0.82/Mg CO_2 (\$3/Mg C) for six different cases in Brazil (15% discounting, and all projects under 30 years), much cheaper than in our case. Their costs (same as in our cases) excluded costs of monitoring, reporting and certification. However, they also noted an order of magnitude uncertainty mainly caused by discount rate and baseline vegetation. Crediting system and product price furthermore caused uncertainty in the range of 200%. They furthermore showed that a price per credit of \$5 would not be enough to make most projects profitable. Boer (2001) for Indonesia found comparable NPV values for projects in Indonesia. Depending on the type of project he found values between \$ −0.22 to 1.77/Mg CO_2 (\$ −0.81 to 6.5/Mg C.)

The tCERs have the lowest price, although due to their limited lifetime they might not be the best deal for a buyer, certainly not in the beginning of a project.

The FM case shows that through forest management a lot of carbon can be stored. However CER generation for a similar FM as shown in this study is not a real life scenario, as projects undertaken within the boundaries of Annex I countries will be included in the carbon balance of that country and will only generate CERs if it is a project under the JI. In that case it has to be proven that additional measurements are taken to increase the carbon sink of the system.

Also the CDM-RIL case was a show case that under the current regulations of the Kyoto protocol will not be possible as only afforrestation and reforestation activities are allowed for CDM projects. The results of this study however show that RIL practices can generate very cost efficient CERs. The main reason for the UNFCCC to not allow other practices than AR is that control of leakage is difficult in case of other projects. Leakage is defined by the UNFCCC as those emissions outside the project area that can be attributed to its implementation. For example, if a forest is protected from logging, this cannot generate CERs because of the risk that a similar area would be logged elsewhere that would not be logged otherwise. This seems not the case though, when a different logging approach is applied in an area that otherwise would be logged as well.

The results also showed that costs for CERs are lower for the CDM-A project compared with the JI-A project. However the build up of CERs under the CDM-A case using indigenous tree species is rather slow. This points out the major weakness of CDM-AR projects. Due to the slow generation of CERs using a mix of indigenous species, it is tempting to use only faster growing commercial or exotic species. This might lead to a positive result for the atmosphere but might not address to the goal of the UNFCCC not to generate negative environmental impacts. The question remains whether this can be effectively monitored or not.

Acknowledgments

This paper has been written as part of the Project Modelling Carbon Sequestration in Forested Landscapes (CASFOR II), funded by the EU INCO-DEV program (Project: ICA4-2001-10100). We thank Lucio Pedroni for his comments to the accounting section. We like to express our appreciation for the PCF Romania Reforestation project team for sharing their information with us. Also we like to thank Paul van Esch for co-operation while programming the CO_2FIX application. The project received co-financing from the Programme 'International Collaboration' of the Ministry of Agriculture, Nature Management and Food Quality in the Netherlands.

Finally two anonymous reviewers gave important remarks that greatly improved the scope of the paper.

Note

[1]According to interpretations all forests that are managed in a country will fall under FM, but the credits are only cut off at the national level CAP.

References

Boer, R.: 2001, 'Economic assessment of mitigation options for enhancing and maintaining carbon sink capacity in Indonesia', *Mit. Adap. Stra. Gl. Ch.* **6**, 257–290.

Boscolo, M., Vincent, J. R. et al.: 1998, 'Discounting costs and benefits in carbon sequestration projects', *Dev. Discuss. Pap.* **638**, 27.

Brown, S., Phillips, H. et al.: 2002, 'Romania Afforestation of Degraded Agricultural Land Project', Baseline Study, Emission Reductions Projection and Monitoring Plans, Prototype Carbon Fund.

Camacho, M. and Finegan, B.: 1997, 'Efectos del aprovechamiento forestal y el tratamiento silvicultural en un bosque húmedo del noreste de Costa Rica', CATIE-Serie Técnica. Informe técnico **295**, 38.

Fearnside, P. M., Lashof, D. A. et al.: 2000, 'Accounting for time in mitigating global warming through land-use change and forestry', *Mitig. Adapt. Strateg. Global Change* **5**, 239–270.

Giurgiu, V., Decei, J. et al. (eds.): 1973, *Biometria Arborilor Si Arboretelor Din Romania-Table Dendrometrice*-Bucuresti.

Hänninen, R.: 2002, *Finnish Forest Sector Economic Outlook 2002–2003*, Finnish Forest Research Institute, Helsinki, METLA, p. 57.

Hoen, H. F. and Solberg, B.: 1995, 'Valuation of global afforestation programs for carbon mitigation' by Sten Nilsson, *Clim. Change* **30**, 259–266 [Editorial Comment].

Knippers, T., van Putten, B., Nabuurs, G. J., and van Esch, P. W.: submitted, 'Quantifying uncertainties in carbon sequestration estimates in a tropical and temperate forest', *Forest Ecol. Manage.*

Masera, O. R., Garza-Caligaris, J. F. et al.: 2003, 'Modelling carbon sequestration in afforestation, agroforestry and forest management projects: The CO_2FIX V.2 approach', *Ecol. Model.* **164**, 177–199.

Moura Costa, P. and Wilson, C.: 2000, 'An equivalence factor between CO_2 avoided emissions and Sequestration – Description and applications in forestry', *Mitig. Adapt. Strateg. Global Change* **5**, 51–60.

Nabuurs, G., Garza-Caligaris, J. F., Kanninen, M., Karjalainen, T., Lapvetelainen, T., Liski, J., Masera, O., Mohren, G. M. J., Olgin, M., Pussinen, A., and Schelhaas, M. J.: 2002, *CO_2FIX V2.0. Manual of a model for quantifying carbon sequestration in forest ecosystems and wood products*, Wageningen, Alterra, Report 445, p. 44.

Nabuurs, G. J. and Mohren, G. M. J.: 1993, 'Carbon in Dutch forest ecosystems', *Netherlands Journal of Agricultural Science* **41**(4), 309–326.

Phillips, H.: 2002, *Afforestation of Degraded Agricultural Land in Romania – Technical, Financial and Environmental Assessment Report*, Prototype Carbon Fund, World Bank, Washington, p. 44.

SBB: 2000, Normenboek staatsbosbeheer 2000–2001, Driebergen, Staatsbosbeheer, Afdeling Personeel en Bedrijf, Sectie Bedrijfsbeleid en Juridische Zaken.

Schelhaas, M. J., van Esch, P. W., Groen, T. A., de Jong, B. H. J., Kanninen, M., Liski, J., Masera, O., Mohren, G. M. J., Nabuurs, G. J., Palosuo, T., Pedroni, L., Vallejo, A., and Vilén, T.: 2004, *CO_2FIX V 3.1 – A Modelling Framework for Quantifying Carbon Sequestration in Forest Ecosystems*, Wageningen, Alterra, Alterra-rapport 1068, p. 122.

UNFCCC: 1997, *The Kyoto Protocol*, UNEP Information Unit for Conventions.

UNFCCC: 2001, *Review of the Implementation of Commitments and of Other Provisions of the Convention*, *Preparations for the First Session of the Conference of the Parties Serving as the Meeting of the Parties to the Kyoto Protocol (Decision 8/CP.4), Decision 5/CP.6, Implementation of the Buenos Aires Plan of Action*, United Nations Office, Geneva, p. 14.

UNFCCC: 2002a, *Views from Parties on Issues Related to Modalities for the Inclusion of Afforestation and Reforestation Project Activities Under the Clean Development Mechanism in the First Commitment Period, Submissions from Parties*, United Nations Office, Geneva, p. 58.

UNFCCC: 2002b, *Report of the Conference of the Parties on its Seventh Session, Held at Marrakech from 29 October to 10 November 2001. Addendum Part Two: Action Taken by the Conference of the Parties*, Conference of the Parties (CoP7), United Nations Office, Marrakech.

UNFCCC: 2003, *Modalities and Procedures for Afforestation and Reforestation Project Activities under the Clean Development Mechanism in the First Commitment Period of the Kyoto Protocol* (Decision 19/CP.9)" (FCCC/CP/2003/6/Add.2).

UNFCCC: 2004, Clean Development Mechanism Guidelines for Completing the Project Design Document for A/R (CDM-AR-NBM), the Proposed New Methodology for A/R: Baseline (CDM-AR-NBM), and the Proposed New Methodology for A/R: Monitoring (CDM_AR_NMM).

Van Vliet, O. P. R., Faaij, A. P. C., and Dieperink, C.: 2003, 'Forestry projects under the clean development mechanism?', *Clim. Change* **61**, 123–156.

(Received 14 January 2004; in revised form 25 June 2004)